Fixation, Partitioning and Export of Carbon in two Species of the Plantaginaceae

by

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ABSTRACT

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University of Guelph, 2013

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During photosynthesis Plantaginaceae species can produce glucose derivatives such as iridoid glycosides and alcohol sugars that in addition to sucrose can be exported from leaves. *Plantago lanceolata* transported sorbitol in addition to sucrose especially at warmer leaf temperatures. However, two iridoids, catalpol and aucubin, found in *P. lanceolata* were not readily labelled from $^{14}$CO$_2$ under any conditions examined. In contrast, in two greenhouse, cut-flower cultivars of *Antirrhinum majus* the iridoids, antirrhinoside and antirrhide, were readily $^{14}$C-labelled along with sucrose but little $^{14}$C was recovered in alcohol sugars (e.g., mannitol). The amount of $^{14}$C-partitioned into antirrhinoside increased at higher temperatures. Exposing leaves of *P. lanceolata* and *A. majus* to reduced-photorespiratory conditions (e.g. short-term CO$_2$ enrichment and/or low O$_2$) increased fixation and export. Under low O$_2$ in *P. lanceolata* sorbitol $^{14}$C-labelling increased relative to sucrose and in *A. majus* $^{14}$C-labelling of sucrose increased relative to antirrhinoside. Also $^{14}$C-labelling of antirrhide increased more than antirrhinoside. During both short-term and long-term acclimation to high CO$_2$, whole plant NCER, leaf photosynthesis and export increased in *A. majus*. Taken together the temperature and CO$_2$ enrichment studies show plasticity in Plantaginaceae species to synthesize and transport sucrose and auxiliary glucose esters and alcohol sugars in a species-specific manner (depending on the rate of carboxylation).
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LIST OF ABBREVIATIONS AND DEFINITIONS

ABA  Abscisic acid; plant hormone
ACN  Acetonitrile
AMF  Arbuscular mycorrhizal fungi; a type of mycorrhizal fungi that penetrate the cortical cells of the root of a vascular plant and help capture nutrients from the soil
ANOVA Analysis of Variance
ATP  Adenosine triphosphate
$^{14}$C Isotope Carbon 14; radiolabeled carbon
CCD Carotenoid cleavage dioxygenase
Ci Internal CO$_2$ concentration (µL L$^{-1}$) in the mesophyll cells of a leaf
$^{14}$CO$_2$ Radiolabeled Carbon Dioxide
CoA Acetyl-coenzyme A
Control 1 (40=>40) Plants were grown under 40 Pa CO$_2$
Control 2 (91=>91) Plants were grown under 91 Pa CO$_2$, long-term CO$_2$ enrichment
CRD Complete Randomized Design
$C_3$ A plant that uses the Calvin cycle to incorporate CO$_2$ into organic material, forming a three-carbon as the first stable intermediate
Diterpenoid A terpenoid made up of a C$_{20}$ skeleton
DMPP Dimethylallyl diphosphate; isomer of IPP, building block for all terpenoid compounds
DOXP 1-deoxy-d-xylulose 5-phosphate pathway; an alternate terpenoid pathway in the chloroplasts of plants, also known as the MEP pathway

DR24 A synthetic analog of strigolactone

Fosmidomycin An antibiotic that inhibits the DOXP pathway, specifically the key enzyme DXP reductoisomerase.

FPP Farnesyl diphosphate

Geraniol A monoterpenoid and an alcohol

GI Group I; Response group of A. majus cultivars recommended for low light and low temperature in winter and early spring harvest. The Group I Cultivar assessed was from the Maryland Series “White/Ivory”.

GII Group II; Response group of A. majus cultivars recommended for late fall and spring harvest

GIII Group III; Response group of A. majus cultivars recommended for late fall and late spring harvest

GIV Group IV; Response group of A. majus cultivars recommended for high light and high temperature in late spring, summer and early fall harvest. The Group IV Cultivar assessed was from the Protomac Series “White/Ivory”.

GGPP Geranylgeranyl diphosphate

HMG-CoA 3-hydroxy-3 methylglutaryl CoA

HPLC High Performance Liquid Chromatography

IDI Isoprenyl diphosphate isomerase; interconverts IPP and its isomer DMAPP
IG  Iridoid glycoside; A type of monoterpane (glucose ester) derived from geraniol that has a general form of cyclopentopyran but in some cases one of the rings is broken as in secologanin.

IPP  Isopentenyl pyrophosphate; An intermediate of the two existing terpenoid pathways that is the building block for all terpenoid compounds.

ISPS  Isoprene synthase; a type of terpene synthase from the TPS gene family that catalyzes the reaction to form isoprene and diphosphate from the terpenoid precursor DMAPP.

LSC  Liquid Scintillation Counting, a standard laboratory instrument to measure radiation from beta-emitting nucleides.

MEV  Mevalonic acid.

MEVP  Mevalonic acid pathway; a terpenoid pathway in the cytosol of plants.

Monoterpenoid  A terpenoid made up of a C$_{10}$ skeleton.

MVAPP  5-pyrophosphate mevalonate.

NCER  Net Carbon Exchange Rate (µmol CO$_2$ m$^{-2}$s$^{-1}$).

nd  Not determined.

NPQ  Nonphotochemical quenching; A photoprotective mechanism that converts and dissipates excess excitation energy into heat.

pH  Hydrogen potential; measures the hydrogen ion concentration, a measure of acidity (<7) or alkalinity (>7) of a solution.

Pi  Inorganic phosphate.

PROC  Procedure statement in SAS software.
<table>
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<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tr>
<td>P450</td>
<td>Cytochrome P450; a family of enzymes that modify terpenoid backbones</td>
</tr>
<tr>
<td>RH</td>
<td>Relative humidity (expressed as a %)</td>
</tr>
<tr>
<td>RPPP</td>
<td>Reductive Pentose Phosphate Pathway</td>
</tr>
<tr>
<td>RuBP</td>
<td>Ribulose 1,5-biphosphate</td>
</tr>
<tr>
<td>Rubisco</td>
<td>Ribulose 1,5-bisphosphate carboxylase/oxygenase</td>
</tr>
<tr>
<td>SE</td>
<td>Standard error of the mean</td>
</tr>
<tr>
<td>Strigolactone</td>
<td>A suggested class of diterpenoid plant hormones that may inhibit shoot branching</td>
</tr>
<tr>
<td>Terpenoid/terpene</td>
<td>A class of compounds derived structurally from C₅ units</td>
</tr>
<tr>
<td>Tetraterpenoid</td>
<td>A terpenoid made up of a C₄₀ skeleton</td>
</tr>
<tr>
<td>TLC</td>
<td>Thin Liquid Chromatography</td>
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<td>Terpene synthases/cyclases</td>
</tr>
<tr>
<td>Triterpenoid</td>
<td>A terpenoid made up of a C₃₀ skeleton</td>
</tr>
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<td>TS 1 (40=&gt;91)</td>
<td>Transient switch 1, Plants were grown under 40 Pa CO₂ and exposed to short-term 91 Pa CO₂</td>
</tr>
<tr>
<td>TS 2 (40=&gt;91)</td>
<td>Transient switch 2, Plants were grown under 91 Pa CO₂ and exposed to short-term 40 Pa CO₂</td>
</tr>
<tr>
<td>WUE</td>
<td>Water Use Efficiency, the rate of NCER to transpiration (µmol CO₂/mmol H₂O)</td>
</tr>
<tr>
<td>3-PGA</td>
<td>3-phosphoglycerate</td>
</tr>
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CHAPTER 1

General Introduction

1.1 Plant Terpenoids, Biomass and Photosynthesis

Over 96% of the dry mass of plants is made up of three elements, carbon, hydrogen, and oxygen (CHO). One of the most diverse groups of carbohydrates in plants are the terpenoids with over 40,000 forms identified that can account for a large proportion of the plant biomass (Bohlmann et al., 2008). As introduced very briefly below, terpenoids can accumulate in many specialised structures and some are integrally involved in the photosynthetic processes (Mahmoud and Croteau, 2002; Bohlmann et al., 2008). Photosynthesis is the process responsible for acquisition of carbon; however, it is not clear that terpenoids may be readily synthesized from newly fixed CO$_2$ during photosynthesis.

It is certainly well recognized that one group of terpenoids known as the carotenoids accumulate in chloroplasts and are essential in photoreactions (Bartley et al., 1995). Carotenoids have an important role in providing structural support for light harvesting complex II. They also act as accessory light harvesting pigments and transfer the energy absorbance to chlorophyll (Buchanan et al., 2000). However, carotenoids also accumulate in chromoplasts that are not photosynthetically active. Similarly, menthol accumulates in trichomes and taxol accumulates in phloem ducts but it is not known if their precursor building blocks are derived from photoassimilates (Bartley et al., 1995; Russin et al., 1995; Croteau et al., 2005). In the case of isoprene emissions, some 2 to 50% of photosynthetic C can be emitted as this end product (Sharkey and Yeh, 2001). The synthesis and production of different terpenoids in photosynthetic (source) and non-photosynthetic (sink) tissues is diverse.

A terpenoid that is a key growth regulator, abscisic acid (ABA) moves in the xylem and has also been isolated from phloem sap (Marschner, 1995). Strigolactones, a newly recognized class of growth regulators that is also mobile in the xylem, seems to
control canopy branching structures that can alter light trapping capacity of the plant (Xie et al., 2010). Interestingly, there is one class of terpenoids, iridoid glucosides (IGs), that accumulate in high concentrations in certain tissues but also are translocated within the phloem during photosynthesis (Gowan et al., 1995; Voitsekhovskaja et al., 2006; Cloutier, 2008).

From ancient times, man has recognized the existence of terpenoids (terpenes) in plants even though there was no knowledge of their chemistry or their role in plant regulation and growth. We come across terpenoid compounds every-day. Terpenoids, such as the carotenoids, contribute to the color of many fruits and flowers (Bartley et al., 1995). Carotenoids make up the most important group of pigments next to chlorophyll in photosynthetic cells and tissues (Bartley et al., 1995; Bohlmann et al., 2008). In addition, apocarotenoids such as vitamin A are essential in our diet (Bartley et al., 1995). Terpenoids also contribute to many of the flavors in our foods, the scents in perfumes, and important components of many medicinal recipes (Bartley et al., 2005; Crozier et al., 2006). Perhaps less understood is the important ecological role of terpenoids in regulating the interaction of plants with other organisms in nature (Crozier et al., 2006; Beninger et al., 2007). The pathways for the synthesis of terpenoids are complex and have been difficult to probe. Identification of enzymes and genomes of many plants has aided in determining the natural chemistry of the terpenoids and the roles these compounds play in plants. Recent studies show that many naturally occurring terpenoid compounds are very important in plant development and regulation throughout the plant life cycle (Marschner, 1995; Umehara et al., 2008; Modolo et al., 2009).

1.2 The Pathways

The complex nature of plant terpenoid biosynthetic pathways accounts for their chemical diversity (Bohlmann et al., 2008). Large arrays of enzymes are responsible for their synthesis and can be placed into three groups (Modolo et al., 2009). The first group of enzymes catalyze the boundary steps between primary and secondary metabolism that direct further modification of these compounds (Modolo et al., 2009).
The second group classified by these authors are those that form secondary metabolite scaffolds that control flux into different major terpenoid branch pathways (Modolo et al., 2009). The last group modify secondary metabolite scaffolds, resulting in the immense number of naturally occurring terpenoids (Modolo et al., 2009).

The boundary between primary and secondary metabolites is not as apparent for terpenoids as it is for alkaloids or phenylpropanoids. For alkaloids the de-carboxylation of amino acids marks the interface between primary and secondary compounds, whereas for phenylpropanoids this interface is marked by the enzyme L-phenylalanine ammonia-lyase (Modolo et al., 2009). Terpenoids include both primary and secondary products as final compounds that encompass primary constituents, such as the light-trapping carotenoids and hormones (Modolo et al., 2009). All terpenoid compounds are synthesized from the same precursors: isopentenyl diphosphate (IPP) and its isomer dimethylallyl diphosphate (DMAPP) (Lichtenthaler et al., 1999; Crozier et al., 2006; Bohlmann et al., 2008; Modolo et al., 2009). In higher plants these precursors are synthesized by two independent pathways: the cytosolic mevalonic acid pathway (MEVP) and the chloroplastic 1-deoxy-d-xylulose-5-phosphate pathway (DOXP) (Lichtenthaler et al., 1999; Eisenreich et al., 2004) (Fig. 1.1).

The MEVP is derived from three major processes: (1) three molecules of acetyl-coenzyme A (CoA) fuse and form 3-hydroxy-3-methylglutaryl-Coenzyme A (HMG-CoA); (2) HMG-CoA is reduced by HMG-CoA reductase to mevalonic acid (MAV) which is phosphorylated by two kinases; and (3) the resulting mevalonic acid 5-diphosphate (MVAPP) is converted into the precursor, IPP, by mevalonate-5-pyrophosphate decarboxylase (Lichtenthaler et al., 1999; Eisenreich et al., 2004; Crozier et al., 2006). The enzyme isoprenyl diphosphate isomerase (IDI) interconverts IPP and its isomer, DMAPP (Lichtenthaler et al., 1999) (Fig. 1.1). Part of step (2) of the MEVP that involves the reduction of HMG-CoA to MAV is localized in the endoplasmic reticulum (Sapir-Mir et al., 2008). Recent localization of MEVP enzymes suggests that a part of the pathway may also be localized in the peroxisomes (Sapir-Mir et al., 2008).
**Figure 1.1.** Cytosolic MEV Pathway of the terpenoid precursors, IPP and DMAPP.

Acetyl-CoA, acetyl-Coenzyme A; acetylaceetyl-CoA, acetylaceetyl-Coenzyme A; DMAPP; dimethylallyl diphosphate; HMG-CoA synthase, 3-hydroxy-3-methylglutaryl-coenzyme A; HMG-CoA, 3-hydroxy-3-methylglutaryl-Coenzyme A; HMG-CoA reductase; 3-hydroxy-3-methylglutaryl-Coenzyme A reductase; IDI, isopentenyl diphosphate isomerase; IPP, isopentenyl diphosphate; MVA, mevalonic acid; MVA kinase, mevalonic acid kinase; MVAP, mevalonic acid 5-phosphate; MVAP kinase; phosphomevalonate kinase; MVAPP; mevalonic acid 5-diphosphate; MVAPP decarboxylase, mevalonate-5-pyrophosphate decarboxylase. Modified from Eisenreich et al. (2004).
Twenty years after the discovery of the MEVP, it was recognized that this pathway could not account for the biosynthesis of all terpenoids under all conditions (Eisenreich et al., 2004; Crozier et al., 2006). An alternate pathway, the DOXP (1-deoxy-D-xylulose-5-phosphosphate pathway) was proposed based on carbon-labelling studies. The DOXP steps include: the condensation of the substrates pyruvate and glyceraldehyde-3-phosphate (GA3P) to DOXP; carbon skeleton rearrangement of DOXP resulting in 2C-methyl-D-erythritol 4-phosphate, which is converted into 2C-methyl-D-erythritol 2,4-cyclodiphosphate; and lastly the formation of IPP and DMAPP (6:1 ratio) from 1-hydroxy-2-methyl-2-(E)-butenyl 4-diphosphate (Litchenthaler et al., 1999; Eisenreich et al., 2004; Crozier et al., 2006) (Fig. 1.2).

The MEVP and DOXP are precursors for different terpenoid classes. For example, the MEVP supplies precursors for sterols and ubiquinone side chains, while the DOXP provides precursors for monoterpenoids, diterpenoids, carotenoids, and chlorophyll plastoquinone side chains (Modolo et al., 2009). Interchange between the two pathways in the form of IPP has also been demonstrated by isotope-labelling studies (Litchenthaler et al., 1999). Much progress has been made in determining intermediates, genes, and enzymes of the DOXP. 1-Deoxy-D-xylulose and other intermediates can be synthetically made and used in labeling studies to investigate downstream terpenoid pathways (Eisenreich et al., 2004). Moreover, this is a novel route in plants, most eukaryotic bacteria, and apicomplexan parasites, but it is absent in archaea and animals, and this makes it a prominent focus for the development of antibiotics, antimalarials, and herbicides (Eisenreich et al., 2004; Bohlmann et al., 2008). The MEVP is responsible for producing all terpenoids in archaea and animals (Eisenreich et al., 2004).

IPP and DMAPP are precursors for short-chain prenyltransferases (Bohlmann et al., 2008; Modolo et al., 2009). The assembly of the C₅ units to form the prenyl phosphates by head-to-tail addition of IPP and DMAPP are catalyzed by geranyl diphosphate synthase, farnesyl diphosphate synthase, and geranylgeranyl diphosphate synthase, resulting in the structural backbone for mono-, sesqui-, and di-terpenoids
Figure 1.2. Chloroplastic DOXP biosynthesis for the terpenoid precursors, IPP (isopentenyl diphosphate) and DMAPP (dimethylallyl diphosphate). (1) 1-deoxy-D-xylulose 5-phosphate synthase (2) 2C-methyl-D-erythritol 4-phosphate synthase (3) 4-diphosphocytidyl 2C-methyl-D-erythritol synthase (4) 4-diphosphocytidyl 2C-methyl-D-erythritol kinase (5) 2C-methyl-D-erythritol 2,4-cyclodiphosphate synthase (6) 1-hydroxy-2-methyl-2-(E)-butenyl 4-diphosphate synthase (7) 1-hydroxy-2-methyl-2-(E)-butenyl 4-diphosphate reductase. IPP, isopentenyl diphosphate; IDI, isopentenyl diphosphate isomerase; DMAPP; dimethylallyl diphosphate. Modified from Eisenreich et al. (2004).
1 - deoxy-D-xylulose 5-phosphate

2C - methyl-D-erythritol 4-phosphate

4 - diposphocytidyl 2C - methyl-D-erythritol

2C - methyl-D-erythritol 2,4-cyclophosphate

1 - hydroxy-2-methyl-2-(E)-butenyl 4-diphosphate
respectively (Fig. 1.3). On the other hand, tri- and tetraterpenoids are synthesized by the condensation of two farnesyl diphosphate and two geranylgeranyl diphosphates, respectively (Fig.1.3) (Bohlmann et al., 2008; Modolo et al., 2009). The resulting terpenoid polymers are used as precursors by terpene synthases/cyclases (TPS) and direct flux into major classes of terpenoids (Modolo et al., 2009). The complete genome sequence of *Arabidopsis thaliana* includes 32 possible TPS genes, while 47 are possible in the genome sequence of poplar (*Populus trichocarpa*) (Bohlmann et al., 2008). Such an array of genes suggests a wide range of chemical diversity and distribution of terpenoids as a single TPS can form multiple products and can undergo further modifications.

Secondary metabolite scaffolds are further modified by a large number of enzymes that include the cytochrome P450 family producing an assortment of terpenoid products with biological activity in plants (Modolo et al., 2009). These enzymes can catalyze hydroxylation, epoxidation, aryl migration, glycosylation, methylation, sulfation, acylation, prenylation, oxidation, and reduction reactions to modify terpenoid backbones (Modolo et al., 2009). Biotechnology has and is providing tools to understand the complex biochemical function and regulation of genes involved in terpenoid pathways.

1.3 Carotenoids

The yellow color of many fruits and vegetables and flower petals, and the display of yellows of leaves in the fall are some of the most visible examples of carotenoid pigments in nature. Carotenoids are tetraterpenoids (C\(_{40}\)) derived from the condensation of two GGPP compounds, resulting in a symmetrical compound with conjugated double bonds (Bartley et al., 1995; Howitt and Pogson, 2006) (Fig.1.4). Over 700 naturally occurring carotenoids have been identified and are found ubiquitously among plants (Howitt and Pogson, 2006). The role of carotenoids is tissue specific (Bartley et al., 1995; Howitt and Pogson, 2006).
Figure 1.3. Biosynthesis of different classes of plant terpenoids, showing the biosynthetic source of isoprene, menthol, iridoid glycoside, Taxol, carotenoid, abscisic acid, and strigolactone. IPP, isopentenyl diphosphate; IDI, isopentenyl diphosphate isomerase; DMAPP, dimethylallyl diphosphate. Modified from Bohlmann et al. (2008).
In photosynthetic tissues, carotenoids are central in assembly of photosystems since they have a structural role in organizing light-harvesting complexes (Buchanan et al., 2000). Carotenoids also act as accessory pigments by gathering light outside of the chlorophyll absorbance spectrum (Bartley et al., 1995; Buchanan et al., 2000). Another vital function of carotenoids is the protection of the photosynthetic apparatus from photooxidative damage resulting from excess excitation creating triplet state chlorophyll (Bartley et al., 1995; Buchanan et al., 2000). Carotenoids accept excitation energy from triplet chlorophyll, preventing the formation of singlet oxygen and avoiding photooxidation of triglycerols, unsaturated lipids, and phenol quinones (Bartley et al., 1995; Bohlmann et al., 2008). The xanthophylls are a group of carotenoids that also play an important role in the dissipation of excess excitation energy, especially plants exposed to high light (Bartley et al., 1995; Buchanan et al., 2000). This dissipation of excess excitation energy in high light is through the conversion of violaxanthin into zeaxanthin by de-epoxidation resulting in the stimulation of non-photochemical quenching in light harvesting complexes (Buchanan et al., 2000). Major depletion of these vital compounds in plants, especially under high light, can be fatal. On the other hand, carotenoids in chromoplasts accumulate in high concentrations and provide the colors of flower petals, fruits, and some roots of plants. The pigmentation contributed by the carotenoids helps as an attractant for pollinators, such as bees during reproduction that can be an important factor in fruit production and seed dispersal (Howitt and Pogson, 2006).

1.4 Apocarotenoid Products and Plant Hormones

The importance of carotenoids in the regulation of plant function is further demonstrated by the fact that they are also precursors of other primary constituents, including the well-recognized growth regulator, the plant hormone, ABA. ABA regulates seed production and the induction of reserve proteins lipids (Buchanan et al., 2000). ABA is an essential messenger in modulating water stress in response to drought and salinity through its involvement in stomatal function in leaves (Marschner, 1995; Buchanan et al., 2000). ABA plays an important role in vascular plants because it acts as a regulatory signal that is mobile in both the xylem and phloem tissues (Marschner,
ABA regulates stomatal function and the availability of CO₂ for carbon fixation and subsequent processes, such as C-partitioning, C-gain and phloem transport (loading/unloading) (Fromm, 1991; Marschner, 1995).

Whereas ABA has been linked to many growth and stress responses in plants, a new class of plant hormones that are also terpenoids has been discovered recently. Strigolactones are a group of compounds that are derived from the cleavage of β-carotene by carotenoid cleavage dioxygenases (CCDs), and have been identified either to be precursors to hormones or to be plant hormones that inhibit shoot branching (Gomez-Roland et al., 2008; Umehara et al., 2008; Tsuchiya et al., 2009). Their common structure consists of a four-ring backbone and structural differences are apparent in the degree of saturation of rings A and B (Lopez-Raez et al., 2008) (Fig. 1.4). Numerous strigolactones have been identified to date, but modifications to the A and B rings suggest that over a hundred may exist in higher plants (Lopez-Raez et al., 2008). Three roles of endogenous strigolactones have been proposed: (1) germination stimulants of parasitic weeds; (2) regulators of arbuscular mycorrhizal fungi (AMF) formation to increase the effective contact of the plant with the soil; and (3) regulators of the shoot branching.

Strigolactones were first discovered to stimulate seed germination of obligate parasitic weeds Striga spp. (witchweed) and Orobanche spp. (Broomrape) (Tsuchiya et al., 2009). The second role suggested for strigolactones is regulation of branching of
AMF (Gomez-Roland et al., 2008; Umehara et al., 2008; Chen et al., 2009). AMF are thought to have evolved 400 million years ago and to have aided in the process of land colonization of plants, but their role in controlling nutrient uptake is only beginning to be appreciated (Chen et al., 2009). These obligate biotrophic organisms are both ecologically and economically vital forming mutualistic symbiosis with over 80% of terrestrial plants (Chen et al., 2009). Roots of plants release branching factors, strigolactones, which increase hyphal branching of AMF and may also enhance chances of hyphae associating with the plant roots (Chen et al., 2009).

A third important role of strigolactones appears to be as regulators of plant shoot development. Recent biotechnological advances involving grafting studies have shown that strigolactones or closely related compounds act as signaling hormones that control plant canopy architecture (Gomez-Roland et al., 2008; Umehara et al., 2008). Pea, Arabidopsis, petunia, and rice mutants were used to show that mutant genes involved in strigolactone biosynthesis increase shoot branching (Gomez-Roland et al., 2008; Umehara et al., 2008). These studies showed not only that strigolactones inhibit branching, but also suggest that they act from a distance and travel acropetally (Gomez-Roland et al., 2008). Strigolactone-inhibiting mutants show that these terpenoids can act at low concentrations (0.1 nM) to return branching mutants to their normal phenotype, similar to other hormones. Many plants contain strigolactones and all higher plants contain the CCD gene (Gomez-Roland et al., 2008; Umehara et al., 2008).

Giberellins (GAs) are another group of plant hormones that are terpenoids. GAs are involved in plant development and growth in stem elongation, reproductive processes, arresting leaf and fruit senescence, and promotion of seed germination (Buchanan et al., 2000). GAs are the main intermediates between the perception of environmental cues and the subsequent growth responses. GAs are diterpenoids synthesized from geranylgeranyl diphosphate through the chloroplastic DOXP pathway (Yamaguchi et al., 2008). Over 100 GAs have been identified in plants and more than 10 may be found in a single plant; however, many non-bioactive GAs are present in plants as precursors to bioactive or deactivated GA forms (Yamaguchi et al., 2008). GA
conjugates, such as GA-O-β-glycosides or GA-O-β-glucosyl esters may also be found in some plants (Buhcanan et al., 2000; Yamaguchi et al., 2008). It is not known whether conjugation is involved in the deactivation of GAs or in regulation of bioactive GA levels. The highest amounts of GAs are found in rapidly growing tissues and are also active in vascular tissues of expanded leaves, signifying that the site of GA synthesis may be in the leaves and then transported to other organs (Bucanan et al., 2000). Even though GAs act as mobile signals the mechanism of movement of GAs is unknown.

1.5 Isoprene Emission

Isoprene is an interesting terpenoid since isoprene is the most common hydrocarbon released into the atmosphere from plants but its source is largely from woody plants (Sharkey and Yeh, 2001; Sharkey, 2008). The annual global emission rate of isoprene is about 440–660 Tg C (Cinege et al., 2009). Isoprene is a highly reactive compound that can be oxidized by hydroxyl radicals to produce ozone (Sharkey, 2008). Moreover, isoprene in the atmosphere can form aerosols that can lead to detrimental health effects in humans. These aerosols are the cause of the blue haze over densely forested areas, such as the Australian Blue Mountains and the Blue Ridge Mountains of the Eastern United States (Sharkey, 2008).

The hemiterpenoid, isoprene (2-methylbuta-1,3-diene), is synthesized in the chloroplast by the DOXP pathway and is dependent on the Calvin cycle (Sharkey and Yeh, 2001; Savitch et al., 2002) (Fig. 1.2). The enzyme isoprene synthase (ISPS), a type of TPS, catalyzes the reaction to form isoprene and diphosphate from the terpenoid precursor DMAPP (Sharkey and Yeh, 2001; Sharkey, 2008). Calculations based on the DOXP synthesis of isoprene indicate that the energy costs of emitting an isoprene are 6 carbon atoms, 20 ATP, and 14 NADPH (Sharkey, 2008). Isoprene emission can amount from 2 to 50% of photosynthetically assimilated carbon depending on different species and environmental condition, but the role of isoprene emission in leaves is not understood (Sharkey and Yeh, 2001).

One plausible theory is that isoprene release provides thermotolerance (Sharkey et al., 2008; Bohlmann et al., 2008; Sharkey, 2008). It is known that isoprene emission
is light dependent and that light can cause an increase in leaf temperature that also results in increased isoprene emission (Sharkey, 2008). Studies that have blocked the DOXP pathway or overexpressing ISPS genes or promoters, support the notion that the benefit derived from emitting large amounts of reduced carbon as isoprene is improved thermoregulation (Bohlmann et al., 2008; Cinege et al., 2009; Sharkey, 2008). The mode of action in thermotolerance is associated with improved thylakoid membrane stability by preventing thylakoid membrane leakiness (Sharkey, 2008). ISPS is evenly located in the stroma and thylakoids; isoprene is hydrophobic and is small and irregular in shape. It appears that this simple compound could fit into the thylakoid membrane structure and stabilize it under thermal stress (Sharkey, 2008). More research on the regulation of isoprene is necessary to understand how elevated CO\textsubscript{2} conditions will affect isoprene emissions in natural populations (Sharkey, 2008).

1.6 Taxol

A classical example of the exploitation of naturally occurring terpenoids for human use is the extraction of Taxol (Paclitaxel) from the bark of some Taxus spp. (Jennewein and Croteau, 2001). The annual market value of Taxol products has been estimated to be several billion dollars. Taxol is a unique drug that affects microtubules within cancer cells and inhibits their growth (Jennewein and Croteau, 2001). It can be used in treatment against many types of cancers that include ovarian, breast, lung, head, neck, bladder, cervix, melanomas, and Kaposi’s sarcoma (Jennewein and Croteau, 2001). However, there are toxicities associated with the use of this drug that restrict its effectiveness (Croteau et al., 2006). Taxol was first derived from the bark of Pacific Yew (Taxus brevifolia Nutt.) (Jennewein and Croteau, 2001). Currently, over 350 different Taxol structures (taxoids) have been identified, but only Taxol and a closely related analog, Taxotere, are used clinically (Jennewein and Croteau, 2001). Due to their unique function and effectiveness, there is a huge demand for these drugs.

Low accumulation of Taxol in Taxus spp., 0.004-0.1% on a dry weight basis, limits effective commercialization (Jennewein and Croteau, 2001). Slow growth of Taxus brevifolia and limited distribution further hinder the production of
Taxol (Jennewein and Croteau, 2001; Bohlmann et al., 2008). It is calculated that 2000-3000 *T. brevifolia* trees are needed to commercially isolate 1 kg of Taxol (Jennewein and Croteau, 2001). Removal of the trees’ bark is a permanently destructive process for sustainable forest cultivation. The search for new methods of Taxol production has led to the discovery of Taxol-producing fungi. Taxol production by the fermentation of fungi shows potential (Ji et al., 2006). Another significant discovery that has potential for increasing Taxol production is the identification of taxanes in hazelnut trees by Hoffman and colleagues (Hoffmann and Shahidi, 2009). Taxanes have been detected in leaves, brown hard shells, and green shells of hazelnuts, but at one-tenth of concentrations of yew trees. Nevertheless, hazelnut trees grow much faster than *Taxus spp.* (Hoffmann and Shahidi, 2009).

The roles of taxanes in plants are unknown. Trees that produce these compounds are poisonous. A number of human and mammalian deaths have been linked to the ingestion of yew leaves (Gillard and Pepini, 1999). Taxanes may protect against herbivory; however, more studies are clearly needed (Egan et al., 1996). Localization studies found that Taxol in *Taxus cuspidate* is found in the cell walls of the phloem, vascular cambium, and xylem (Russin et al., 1995). There are a few studies on the environmental effects of taxanes in *Taxus spp.* (Vance et al., 1994). Knowledge about the ecological role of taxanes is needed to better exploit these terpenoids commercially.

1.7 Menthol

Isoprene is a gaseous terpenoid whose function and commercial importance are unclear. There are at least 1000 naturally occurring monoterpenoids (C$_{10}$) that are generally colorless and volatile (Mahmoud and Croteau, 2002). Most monoterpenes are components of essential oils that have unique flavors and aromas. Their natural roles in plant metabolism are diverse. Monoterpenoids generally accumulate in specialized anatomical structures (Mahmoud and Croteau, 2002). For instance, the monoterpenoid menthol is the main component of the essential oil of peppermint and is synthesized in peltate glandular trichomes (Mahmoud and Croteau, 2002; Croteau, 2005; Bohlmann et
al., 2008). Menthol, synthesized from Mentha and other species of Lamiaceae, is used in industry for pharmaceutical, chemical, food, and flavor and fragrance purposes and valued at $300 million in economic activity (Croteau, 2005; Bohlmann et al., 2008). Essential oils in Mentha spp. can make up 1% of the dry weight, half of that is menthol (Croteau et al., 2005). The fragrance and flavor of menthol extracts can be affected by high temperatures and low light levels; the changes occur because of the production of undesirable metabolites such as menthofuran (Mahmoud and Croteau, 2002). Decreasing expression of genes involved in menthofuran production is a strategy to eliminate unfavorable components in menthol production (Mahmoud and Croteau, 2002). Similar results were also found in plants grown under stressful conditions that would normally promote menthofuran production in wild-type plants (Mahmoud and Croteau, 2002).

1.8 Iridoid Glycosides

To this point a number of terpenoids in plants have been discussed, focusing on these compounds as end products of metabolism. There is a class of terpenoids, the iridoid glycosides that can accumulate in high concentrations in certain tissues having diverse roles such as in plant defense but also appear to be synthesized during photosynthesis and are translocated via the phloem along with other photoassimilates such as sucrose (Voitsekhovskaja et al., 2006, Beninger et al., 2007).

Iridoids are a class of monoterpenoids derived from geraniol that have a general form of cyclopentopyran (Albretch et al., 1999; Timmerman, 2004). However, a recent study has shown instead of geraniol diphosphate, the immediate precursor for all plant iridoids may be 10-oxogeraniol (Geu-Flores et al., 2012). The authors also showed that in Catharanthus roseus iridoid synthase cyclizes the straight monoterpenoid, 10-oxogeraniol to form nepetalactol, a bicyclic compound that may be the general precursor of iridoids. More than 2500 iridoids have been discovered in nature (Sampaino-Santos and Kaplan, 2001). Four main types of iridoids exist: aglycone iridoids, secoiridoids, bisiridoids, and the most common, iridoid glycosides (IGs) (Timmermann, 2004). Secoiridoids can be found as glucosides and they also precursors
to monoterpene indole alkaloids (MIAs) (Sampaino-Santos and Kaplan, 2001). The synthesis of MIAs in *C. roseus* is localized in leaf epidermal cells. However, the expression of genes involved in the DOXP pathway and geraniol-10-hydroxylase, a committed step of secoiridoid synthesis, were localized in the internal phloem-associated parenchyma cells (Murata et al., 2008). In addition, Gue-Flores et al. (2012) also localized iridoid synthase transcripts to the internal phloem-associated parenchyma cells.

IGs are a group of highly oxygenated monoterpenoids that can make up 20% of the dry weight of some plants (Bowers et al., 1992; Beninger et al., 2007). IGs are found in over 50 plant families and more than 800 IG structures have been identified. A range of suggested roles include their involvement in defense against herbivores, control of plant root mycorrhizal interactions, osmoregulation, and translocation of photosynthetically reduced carbon in the phloem (Voitsekhovskaja et al., 2006; Beninger et al., 2007; Bennet and Bever, 2007). They are also known to be anti-inflammatory, cytotoxic, antiviral, and antimicrobial (Timmerman, 2004; Beninger et al., 2007).

**Figure 1.5.** Iridoid glycoside, (A) catalpol and (B) aucubin have analogous chemical structures (C) antirhinoside and (D) antirhride, respectively. Modified from Beninger et al., (2008).
Many researchers have focused on the potential role of IG in defense against herbivores (Beninger et al., 2007). For decades, the common weed ribwort plantain, *Plantago lanceolata*, also known as narrow-leafed plantain, has served as a model species for life history and population studies of host plant-herbivory interactions (Bowers et al., 1992). *P. lanceolata* is known to synthesize the IGs, catalpol and aucubin (Bowers et al., 1992; Marak et al., 2000). Aucubin is a de-crboxylated IG synthesized from 8-epi-loganin and is known to be a precursor of catalpol (Marak et al., 2000). There is substantial variability in the content and distribution of the two main IGs in *P. lanceolata* (Fig. 1.5A and B). Their content varies with ecotype, population variability, tissue (leaf) and plant age, the extent of herbivory, neighboring plants, associations with AMF, and environmental conditions. AMF studies concerning *P. lanceolata* have shown that leaf photosynthesis rate can increase by 20% with the presence of AMF (Staddon et al., 1999; Parádi et al., 2003). Klockars et al. (1993) showed that the older leaves contain mostly aucubin or no IGs, whereas catalpol is the predominant IG in younger leaves. Fluctuations in IG concentrations in field studies due to environmental variation in temperature, water, and light have been observed (Bowers et al., 1992). *P. lanceolata* and its two IGs, catalpol and aucubin, have been extensively studied and thus serve as an important model species in studying IGs within the Plantaginaceae. The family has undergone major reclassification due to molecular systematics (Beninger et al., 2007). Morphology and phytochemistry of Plantaginaceae is variable but IGs are present in a large number of the genera (Beninger et al., 2007). Therefore, the distribution and function of the IGs in other members of this family deserve attention.

*Antirrhinum majus* L. (snapdragon) has been placed in the Plantaginaceae (Albach et al., 2005). This species is a model species for the study of shoot architecture and floral development (Beninger et al., 2007). Thus, *A. majus* seems like a good model species to examine carbon partitioning of major metabolites that would be involved in source to sink interactions. The IGs, antirrhinoside and antirrhide, prevalent in *A. majus* leaves have similar structures to catalpol and aucubin, respectively produced in *P. lanceolata* (Fig. 1.5). Antirrhinoside is present in flowers and roots,
whereas antirrhide is found only in the leaves. This distribution suggests that while antirrhinoside is phloem-mobile, antirrhide is not translocated (Beninger et al., 2007). The IG levels found in A. majus and in P. lanceolata are dependent on leaf age; more antirrhinoside was found in young leaves, whereas more antirrhide was found in older leaves (Beninger et al., 2007). Another member of the family, the invasive species toadflax (Linaria dalmatica) also contains similar IGs in high amounts where antirrhinoside and linarioside concentrations up to 16.5% and 6.7% (respectively) of the dry weight have been measured (Jamieson and Bowers, 2010). A preliminary study examining two generalist herbivores indicates that antirrhinoside extracted from A. majus may be a deterrent of some generalist insect feeders (Beninger et al., 2008). Thus, the IG antirrhinoside may play a role in preventing herbivory when it accumulates in sufficient concentrations in tissues as do the IGs in P. lanceolata (Bowers et al., 1992).

In A. majus antirrhinoside is readily labeled from $^{14}$CO$_2$ in significant amounts in leaf and petiole tissues (Cloutier, 2008). Two species of Asarina, A. scandens and A. barclaiana, both members of Plantaginaceae, partition newly assimilated $^{14}$C into antirrhinoside that is recovered in phloem sap (Gowan et al., 1995; Voitsekhovskaja et al., 2006).

1.9. Photosynthesis, Photoassimilate Partitioning and Translocation

The capacity to export carbon from leaves in several forms may be part of a regulator strategy to maintain homeostasis in species under stressful conditions (Jiao and Grodzinski, 1996; Grodzinski et al., 1998). Grodzinski et al. (1998) showed that salvia, catnip, coleus, and cucumber, which transport raffinose series sugars in addition to sucrose, have high relative carbon export rates of 75%. In addition, celery, a mannitol transporter also has high relative export rates. Furthermore, two A. majus cultivars that synthesize and transport antirrhinoside in addition to sucrose have been shown to have relative export rates over 70% (Gutierrez, 2003; Cloutier, 2008).

Environmental factors, such as light, temperature, CO$_2$, and O$_2$ alter carboxylation by Rubisco and carbon partitioning to photoassimilates and transport to
sink tissues (Jiao and Grodzinski, 1996). Feedback regulation of carbon fixation can occur if sink capacity is not maintained when carboxylation efficiency of Rubisco is increased (Jiao and Grodzinski, 1996; Moore et al., 1999). Increasing temperatures above growth conditions in C₃ plants can result in diminished photosynthetic and export rates (Jiao and Grodzinski, 1996). Under high temperatures the oxygenase activity of Rubisco increases, resulting in photorespiration and loss of carbon through the glycolate cycle (Brooks and Faraquar, 1985; Jiao and Grodzinski, 1996). In addition, stomatal closure due to increased water loss and reduced CO₂ diffusion can result during high temperatures. Elevated CO₂ and low O₂ can reduce photorespiratory effects. Plant response to enriched CO₂ is species-specific and while some species immediately respond to short-term CO₂ with increased photosynthetic rates, this response can be down-regulated during acclimation to elevated CO₂ (Sage at al., 1989; Arp, 1991; Makino and Mae, 1999; Moore et al., 1999; Long et al., 2004). This occurs when the utilization of carbon in sinks is exceeded by the carbon fixation resulting in carbon accumulation that leads to the feedback inhibition of photosynthesis (Stitt, 1991; Makino and Mae, 1999; Moore et al., 1999).

Terpenoids are the most chemically diverse natural products in plants. There are multiple pathways that explain how such diversity exists. The accumulation of specific terpenoids in plant tissues may alter plant interactions with animals, insects, fungi (AMF), and bacteria being attractants or deterrents of neighbor/visitor interactions. Some terpenoids, such as Taxol and monoterpenoids, are found in the phloem. In the newly classified family, the Plantaginaceae, the IG, antirrhinoside, is heavily labelled relative to sucrose when plants were exposed to ¹⁴CO₂. Thus, the synthesis and transport of photoassimilates, including monoterpenes (glucose esters) in the Plantaginaceae may be altered by environmental conditions, such as temperature and atmospheric gas concentrations.

1.10 Thesis Overview and Hypothesis Statement

It is not known to what extent IGs that are derivatives of glucose metabolism are sensitive to environmental perturbations and signals. My hypothesis is that within the
Plantaginaceae monoterpenes, such as IGs, are made during photosynthesis from newly fixed CO$_2$ and furthermore that compounds, such as antirrhinoside and catalpol, are transported along with sucrose as major phloem constituents. The main objective of this thesis was to examine $^{14}$C-partitioning among IGs and primary photoassimilates in two species of the Plantaginaceae, *P. lanceolata* and *A. majus*. Photosynthetic and export rates were investigated to determine which major photoassimilates were synthesized and translocated under different environmental conditions.

To test this hypothesis, $^{14}$C-gas exchange and labelling studies were conducted to determine the photosynthetic rate, the $^{14}$C-export rate and $^{14}$C-partitioning of major photoassimilates and IGs in source leaves of *P. lanceolata* and *A. majus* during light saturated levels and different environmental conditions. The $^{14}$C-recovered in the subtending petiole tissues was examined to determine the photoassimilates that were transported. Whole plant gas exchange studies were also conducted to determine if the export rate was able to meet sink demands during different environmental conditions.

In Chapter 2 the focus was on *P. lanceolata* that is known to synthesize two well-known IGs, catalpol and aucubin (Fig. 1.5A and B). In terms of terpenoid metabolism the objective of Chapter 2 was to determine if catalpol and aucubin are readily $^{14}$C-labelled. Leaf photosynthetic and $^{14}$C-export rates were determined, as well as the $^{14}$C-partitioning of major photoassimilates in source leaves and petiole tissues. Metabolites were separated and quantified by high pressure liquid chromatography (HPLC) methods and a liquid scintillation counter (LSC). Leaf photosynthesis, export rates and partitioning profiles were compared during four short-term temperature challenges (15°C, 25°C, 35°C and 45°C) and various short-term combinations of CO$_2$ (40 and 91 Pa) and O$_2$ (21 and 2 kPa) that altered the photorespiratory conditions. Whole plant gas exchange studies during three short-term temperature treatments (15°C, 25°C and 35°C) were conducted to relate to leaf photosynthetic and export rates to gain further insight into how these plants are able to maintain homeostasis during varying environmental conditions.
In Chapter 3, a parallel study using two cultivars of *A. majus* that produce the IGs, antirrhinoside and antirrhide, (Fig. 1.5C and D) is described. Previous studies have shown that these IGs are directly synthesized from photosynthesis. Two commercially available greenhouse cultivars, GI (Protomac Ivory White) and GIV (Maryland Ivory White), were compared during three short-term temperature (15°C, 25°C and 35°C) challenges experienced during production. In addition, the labelling and export of primary photoassimilates at the same CO₂ and O₂ levels as in Chapter 2 were determined. Whole plant gas exchange studies were also done to examine if the export rate was able to meet the sink demand during the three short-term temperature treatments.

In Chapter 4 the two *A. majus* cultivars were acclimated to CO₂ enrichment (91 Pa) for several weeks. Photosynthesis, export rate and ¹⁴C-partitioning into major photoassimilates and IGs was compared for four treatments; *A. majus* plants were grown and assayed under 40 Pa CO₂ (Control-1 (40=>40)) and 91 Pa CO₂ (Control-2 (91=>91)) and plants were transferred for a short-term analysis at the reciprocal CO₂ level (i.e., (TS1 (40=>91)) and at 40 Pa CO₂ (TS2 (91=>40))). Whole plant and leaf photosynthetic rates as well as ¹⁴C-export rates were compared to better understand how these plants were able to maintain source-sink balance during acclimation to high CO₂ conditions.

In Chapter 5, the overall thesis discussion, the two species of the Plantaginaceae were compared as pointed out above. In *P. lanceolata* the iridoids, catalpol and aucubin, were not labelled from ¹⁴CO₂, but sorbitol was labelled and translocated in addition to sucrose. In contrast, in the two *A. majus* cultivars very little label was recovered in the dominant alcohol sugar, mannitol, but the two IGs, antirrhinoside and antirrhide, were labelled during photosynthesis and antirrhinoside moved. In addition, short and long-term environmental changes altered the ratios of primary metabolites and IGs. Taken together, these studies indicate that within the Plantaginaceae sucrose is the major translocate but alternative glucose derivatives, such as, antirrhinoside, can be phloem mobile.
CHAPTER 2

The effect of temperature and photorespiratory conditions on photosynthesis, C-partitioning and growth in *Plantago lanceolata* L.

2.1 Abstract

Photosynthesis and water use efficiency (WUE) of the whole plant and a recently expanded source leaf of *P. lanceolata* were measured after exposure to three different daytime temperatures: 15°C, 25°C and 35°C. The primary $^{14}$C-labelled photoassimilates were determined and rates of $^{14}$C-export estimated. Leaf and plant WUE significantly decreased at 35°C but photosynthesis and leaf export increased concomitantly with enhanced $^{14}$C-partitioning into sucrose and sorbitol. Two glucose ester, catalpol and aucubin, found in *P. lanceolata* were not $^{14}$C-labelled. During CO$_2$ enrichment (91 Pa) and exposure to a low O$_2$ (2 kPa) condition that favoured increased carboxylation and reduced photorespiration at the warmer temperatures, the rate of export increased as did the partitioning of $^{14}$C- in sorbitol and sucrose. The results showed that the IGs examined in this study are not readily labelled or transported in *P. lanceolata*. However, sorbitol was readily synthesized and was transported along with sucrose in the phloem. In addition, $^{14}$C-partitioning of sorbitol and sucrose, as well as $^{14}$C-export rates were altered with environmental conditions.

2.2 Introduction

The defence against herbivory in relation to the well-known IGs, catalpol and aucubin, has been extensively studied in *P. lanceolata* (Bowers et al., 1992). Bowers et al. (1992) found that variation in temperature, drought conditions, light intensity, and nutrient content may affect the production and breakdown of IG content in *P. lanceolata*. In source leaves of *A. majus* plants, a relative of *P. lanceolata*, the IGs, antirrhinoside and antirrhide, which are similar to catalpol and aucubin, respectively, are readily labeled from $^{14}$CO$_2$ during photosynthesis (Beninger et al., 1997). However, to our knowledge there are no data demonstrating whether catalpol and aucubin are synthesized and labelled during photosynthesis from newly fixed $^{14}$CO$_2$ in *P. lanceolata*. 
As mentioned in Chapter 1, in other members of the newly classified Plantaginaceae, the IG, antirrhinoside, can account for a significant amount of newly fixed CO$_2$. Although it appears that this IG is also translocated from source leaves along with sucrose, the effect of varying environmental conditions on partitioning of newly fixed C into antirrhinoside versus sucrose is not known (Gowan et al., 1995; Voitsekhovskaja et al., 2006; Beninger et al., 2007). Preliminary studies from our group showed that in snapdragon the amount of $^{14}$C-partitioned to antirrhinoside and antirrhide versus sugars, such as sucrose and mannitol, does vary with light and temperature (Cloutier, 2008).

Acclimation to stress conditions, such as temperature and drought, are often related to the accumulation of particular photoassimilates such as alcohol sugars (Wahid et al., 2007). Alcohol sugars, such as sorbitol and mannitol, can account for over 30% of primary production and metabolism of these photoassimilates has been linked to energy storage, enzyme regulation, translocation, osmoregulation, and homeostasis notably under different temperatures (Loescher, 1987; Moing et al., 1994; Reidel et al., 2009). In addition to IGs, both sorbitol and mannitol are synthesized in herbaceous perennials including members of the Plantaginaceae. *Asarina scandens*, *Asarina barclaiana* and *A. majus*, all members of the family, synthesize mannitol but mannitol is not recovered in minor veins during $^{14}$C-labelling studies (Moore et al., 1997; Voitsekhovskaja et al., 2006; Beninger et al., 2007; Reidel et al., 2009). Sorbitol is uniformly found in the genera *Plantago* and is often found in concentrations higher than sucrose (Rønstead et al., 2000; Rønstead et al., 2003, Taskova et al., 2005; Voitsekhovskaja et al., 2006, Reidel et al., 2009). Phloem loading of sorbitol in *P. major* and *P. maritima*, close cousins of *P. lanceolata* has been studied (Nadwodnik & Lohaus, 2008; Reidel et al., 2009). To our knowledge, no rates of photoassimilate translocation have been published. Although *P. lanceolata* is a well-known C$_3$ weed introduced to North America from Europe (Cavers et al. 1980) there is very little information available on the primary processes of photosynthesis, respiration, and photoassimilate production and translocation of source leaves. The prominence of *P. lanceolata* in our changing urban/rural environment has identified it as one the top 12 most successfully invasive “non-cultivated colonizing species” (Sagar and Harper, 1964; Cavers et al. 1980). It is a perennial weed that is commonly found in lawns and along dry roadsides and endures a
range of temperatures experienced from early spring to hot summer days. In well watered, arable field without competition individual plants that form a leaf rosette can support 30 flowering spikes that produce as many as 10,000 seeds (Cavers et al., 1980). In addition to its reproductive potential, it has a well-developed root system that contributes to survival under drought conditions, non-fertilized soils, and soils contaminated with heavy metals (Cavers et al., 1980; Wu and Antonovics, 1987).

Photosynthetic capacity of many C₃ species is limited by the present atmospheric CO₂/O₂ concentration (Buchanan et al., 2000). C₃ species lose as much as 40 to 50% of the carbon assimilated under ambient CO₂ conditions due to photorespiration (Buchanan et al., 2000). Photorespiratory processes are regulated by CO₂ and O₂ levels as well as temperature (Buchanan et al., 2000). The carboxylase to oxygenase reaction occurs at a rate of three to one under the present atmospheric CO₂ conditions (Buchanan, et al., 2000). C₃ species have the greatest potential to respond to enriched CO₂ and can have several direct and immediate effects, such as an increase in the primary substrate, CO₂ for carboxylation and reduction of the oxygenase activity of Rubisco (Bowes, 1993; Jiao and Grodzinski, 1996; Drake and González-Meler 1997; Long et al., 2004; Ainsworth and Rogers, 2007).

Previous studies suggest that some C₃ plants export a larger proportion of the newly fixed carbon in the light because they have the ability to manufacture and export other carbohydrates and sugars in addition to sucrose (Jiao and Grodzinski, 1996; Grodzinski et al., 1998). The relationship between export from source leaves during photosynthesis, and the growth and maintenance of developing sinks is complex and remains one of the most poorly understood traits in vascular plants (Grodzinski et al., 1998; Wilson et al., 2006; Murchie et al., 2009). Three levels of organization, the whole plant, the leaf tissue and the partitioning into primary metabolites were examined in this study to provide a better understanding of how *P. lanceolata* responded to variations in canopy temperature and thus maintain source leaf function. *P. lanceolata* is a common weed species with a wide temperature tolerance. At elevated temperatures photorespiration decreases carboxylation. Our original hypothesis was that *P. lanceolata* that produces starch, sucrose, and sorbitol was also able to synthesize and
transport the iridoids, catalpol and aucubin, glucose esters that are structurally analogous to antirrhinoside and antirrhide in other members of the Plantaginaceae that were readily labelled from $^{14}$CO$_2$ in source leaves. Our objective was to use temperature stress to elicit changes in leaf photosynthesis and photorespiration by altering CO$_2$ and O$_2$ levels that would reveal the extent of plasticity in $^{14}$C-partitioning between primary assimilates, such as starch, sugars, and other glucose derivatives.

2.3 Materials and Methods

2.3.1 Plant materials and growth conditions

*P. lanceolata* seeds were collected from plants in the lawns near the Bovey building located on the University of Guelph campus, Guelph, ON, Canada (43° and 15’ L.N.) in July and August of 2008. Seeds were sown in “128 cavity-plug trays” (Landmark Co. Plastic, Akron, OH, USA) and placed on a misting bench in a glass greenhouse on site. Germination took place at 22°C /15°C day/night temperatures, under natural light conditions. After three weeks seedlings were transplanted into pots (1 L, 10 cm diameter x 15 cm) containing a soil-less growth medium (Pro-mix GXP®; Les tourbières Premier Ltée, Rivière de Loup, QC, Canada) and grown in June of 2009 and 2010 for eight to ten weeks (reproductive stage). Day/night growth temperatures in the greenhouse were approximately 25°C /18°C; the relative humidity was maintained between 40% and 60% under natural lighting conditions.

2.3.2 Whole plant gas exchange

A whole plant gas exchange system, based on an earlier design (Dutton et al., 1988, Leonardos et al., 2003), utilized a LabView 2009 program run on a Dell, Precision 490 computer that controlled the environment inside the plant chambers. Our new system employed six clear polycarbonate (lexan) plant chambers measuring 81.3 cm in height, 45.7 cm in length, and 45.7 cm in width. Six high pressure sodium vapour (HPS) 1000 W lamps (XT 1000W HPS Bulb, Philips Lighting Canada, Markham, ON) provided photosynthetic photon flux density (PPFD) that was monitored using Li-Cor quantum sensors (LI-190SA, Li-Cor Inc., Nebraska, USA) placed at plant rosette level.
Tempered glass and water baths were placed at the top of chambers between the light sources to avoid heat load.

A single, flowering, *P. lanceolata* plant grown at a 25°C/18°C day/night temperature was placed into each of the six chambers (Fig. 2.1A). For each temperature treatment all six chambers were maintained at the same temperature. A total of six plants were measured for NCER during each temperature treatment; however, only five plants were measured for transpiration due to the malfunction of a balance. Air temperature was maintained at 18°C, 25°C or 35°C for the 12 h light period but at 18°C during the 12 h dark period during which net CO₂ exchanges were measured constantly. CO₂ was maintained at ambient, 40 Pa whereas the humidity of the air inside the chamber was maintained at 50/55 (± 5% R.H.) day/night. The PPFD was maintained at 1000 ± 50 μmol m⁻²·s⁻¹ for the 12 h photoperiod. Plants were acclimated to the plant analysis chambers overnight.

When whole plant net carbon exchange rate (NCER) was being measured inlet and exhaust solenoid valves were closed and the chamber was sealed. During the NCER sampling cycle, air was drawn from each chamber for 90 seconds through an outlet sampling valve to a second IRGA (LI-820, Li-Cor Inc., Nebraska, USA) and returned back to the chamber via a return sampling valve. NCER was calculated from both IRGA initial and final CO₂ concentrations. NCER measurements were taken continuously throughout the day and night cycles (12 h light and 12 h dark). Each chamber was sampled for 1.5 min; thus, for each chamber one NCER measurement was taken every 9 min. Daytime C-gain was estimated from NCER during the light, whereas nighttime C-loss is the integrated negative NCER during the dark. The difference between the daytime C-gain and the nighttime C-loss was used to calculate the daily plant growth (Dutton et al., 1988; Leonardos et al., 2003; Leonardos and Grodzinski, 2005). The leaf area measurements were obtained using a leaf area meter (LI-3000; LI-COR).
2.3.3 Leaf gas exchange, export, and $^{14}$CO$_2$ labelling

An open-flow leaf gas exchange system, based on an earlier design, utilised a LabView 2009 program run on a Dell PC and was used to conduct $^{14}$CO$_2$ steady-state labelling experiments (Jiao and Grodzinski, 1996, Leonardos and Grodzinski, 2000). The new system employed four leaf cuvettes. Source leaf transpiration, photosynthesis, and $^{14}$C-export measurements were made on a portion of one fully expanded, intact, and attached leaf from the inner or mid-rosette of six to eight different plants (Fig. 2A.1B). Plants grown at 25°C/18°C day/night temperatures were acclimated to growth chamber conditions overnight. Light levels were set at 1000 ± 50 µmol m$^{-2}$·s$^{-1}$ PPFD. The plant chamber air and leaf cuvette temperatures were maintained at 15°C, 25°C, 35°C, or 45°C. The relative humidity was maintained at 50 (± 5% R.H.). The same CO$_2$ level (either 40 Pa or 91 Pa) was maintained in both the plant chamber and the leaf

**Figure 2.1.** A whole plant cuvette containing a *P. lanceolata* plant (A). A source leaf of *P. lanceolata* (B) mounted in a leaf cuvette used for $^{14}$CO$_2$ feeding and export measurements.
cuvette. However, during the 2 kPa O₂ challenges only the leaf cuvette was kept at 2 kPa O₂, not the entire plant. The ¹⁴CO₂ specific activity was kept constant during an experiment by a precision syringe pump (PHD 2000 Infusion, Harvard Apparatus, Holliston, MA, USA).

2.3.4 ¹⁴C-Partitioning

Frozen leaf and petiole samples were rapidly extracted in 80% boiling ethanol (ethanol: water, 5:1 v/v), vacuum dried (Model SC210A, SpeedVac® Plus, Savant). A liquid scintillation counter (LSC) (Winspectral 1414 LSC, Wallace, Turuk, Finland) was used to determine total radioactivity. Vacuum dried samples were resuspended in water and partitioned in chloroform (chloroform (CHCl₃): water, 1:1 v/v) as described by Jiao and Grodzinski (1996). A 0.2 µm filter (Whatman International Ltd., Maidstone, UK) was used to filter that water fraction that was again vacuum dried and then resuspended in HPLC grade solvents. Individual sugars and the iridoid glycosides were separated using two HPLC columns linked to a (Beckman Instrument Inc. Altex division) 118 solvent module with a refractive index detector and a fraction collector (LKB Broma 2111). The Alltech cation exchange 700 CH carbohydrate column (4.6 X 300 mm; 10 µm particle size; Alltech Associates, Mandel Scientific, Guelph, ON, Canada) was used to separate sucrose (retention time=11.3 min), glucose (retention time=14.8 min), fructose (retention time=18.2 min) and sorbitol (retention time=23.9 min) fractions (Fig. 2.2). The iridoid glycosides co-eluted on this column and therefore the Ascentis® RP Amide column (4.6 X 250 mm; 5 µm particle size; Sigma-Aldrich, Canada Inc.) was used to separate the iridoid glycosides, catalpol (retention time=11.3 min) and aucubin (retention time=16.5min) from the sugar fractions including sorbitol (retention time=6.9) that co-eluded as a single peak (Fig. 2.3). Effluent was collected in a set of 60 scintillation vials (4-mL Omni vials; Wheaton Ltd., Millville, NJ, USA) and dissolved in 2.3 mL ES CytoSynt cocktail (MP Biomedicals Inc., Irving, CA, USA) and radioactivity was determined by LSC (Fig. 2.2; Fig. 2.3). The Alltech column was equilibrated at 85°C with a Waters column heating unit. The solvent system was 100% HPLC water with a flow rate of 0.3 mL·min⁻¹. The PR Amide column was equilibrated at room temperature. The solvent system was 100% HPLC water with a flow rate of 1 mL·min⁻¹.
Figure 2.2. A representative chromatogram showing the peaks and retention times for standards separated with the Alltech cation exchange 700 CH carbohydrate column. Peaks are numbered in sequence: for sucrose (1=11.3 min), glucose (2=14.8 min), fructose (3=18.2 min) and sorbitol (4=23.9 min) (NB: peaks may shift with column age). Standard concentrations were as described in the Materials and Methods (A). B) A representative chromatogram of the water soluble extract from a $^{14}$CO$_2$ labeled source leaf of *P. lanceolata* showing the retention times of: 1=sucrose, 2=glucose, 3=fructose and 4=sorbitol (B). A representative profile of the $^{14}$C-recovered from the different sugars and sugar alcohol separated Alltech column. Peaks are numbered in sequence: 1=sucrose, 2=glucose, 3=fructose and 4=sorbitol (C). The arrows indicate the collection time.
Figure 2.3. A representative chromatogram showing the peaks and retention times for standards separated with the PR Amide column. Peaks are numbered in sequence: the total sugars (sucrose, glucose, and fructose) including sorbitol (1=6.9 min), catalpol (2=11.3 min), aucubin (3=16.5min) (A). A representative chromatogram of the water soluble extract from a $^{14}$CO$_2$ labeled source leaf of ribwort showing the amounts: 1=total sugars including sorbitol and 2=catalpol (B). A representative profile of the $^{14}$C-recovered from the PR Amide column. Peaks are numbered: 1=total sugars including sorbitol (C). The arrows indicate the collection time.
Calibration curves were obtained with $r^2$ values that were greater than 0.9935 using concentrations from 0 to 4.38 mM for sucrose, 0 to 8.33 mM for glucose and fructose, 0 to 8.23 mM for sorbitol, 0 to 2.21 mM for catalpol and 0 to 2.9 mM for aucubin.

CHCl$_3$ (pigments and lipids) and ethanol-soluble fractions were counted by LSC to quantify $^{14}$C in each fraction. The radioactivity remaining in the ethanol-insoluble (95% starch) was counted by LSC after samples were combusted in a biological oxidizer (Model OX300, R.J. Harvey Instrument Corp. Hillside, NJ, USA).

2.3.5 Statistical analyses

The experimental design of these studies was completely randomized. Statistical analysis was carried out using Statistical Analysis Software, version 9.3 (SAS Institute Inc., NC, USA). Parameters for *P. lanceolata* plants were performed by analysis of variance (ANOVA) using a general linear model (PROC GLM). To ensure assumptions for the one-way ANOVA were met, a test of residuals was performed using PROC UNIVARIATE. The Shapiro Wilkes test of residuals was computed to determine if the distributions were normal. To verify if outliers were present, standardized residuals were calculated and assessed against Lund’s critical value. Data expressed as percentage were transformed using arcsine square root or log transformations prior to analysis. Data transformations, arcsine square root and log, were selected for the specific data sets as per recommendations from Bowley (1999). Values for percent data were back-transformed to the original scale. The standard errors of these means were not back-transformed and are not represented in tables or graphs since these statistics are not relevant on the original scale (Bowley, 1999). Mean ± se of five to six different plants for whole plant measurements were calculated. Means ± se of six to eight independent leaves on different plants were calculated. Multiple comparisons (LSmeans, SAS) were used to determine differences between treatments.
2.4 Results

2.4.1 Whole plant NCER, WUE and daily C-gain

Whole plant water loss (Fig. 2.4A and B), NCER (Fig. 2.4C and D) and the resulting diel pattern of net C-gain (Fig. 2.4E) and C-loss (Fig. 2.4F) of healthy, flowering *P. lanceolata* plants (Fig. 2.1) were determined during exposure to three different day/night temperature regimes (18°C/18°C; 25°C/18°C and 35°C/18°C) that reflect environmental conditions that might be experienced by this invasive, weed species when it is growing naturally in the field at saturating light levels.

Figure 2.2A shows the time course of water loss from these mature plants due to transpiration at the growth regime of 25°C/18°C compared to a reduced daytime temperature of 18°C and a much warmer daytime temperature of 35°C. Canopy transpiration during the photoperiod was greatest at 35°C and because the average whole plant photosynthesis (Table 2.1) was not significantly different between 18°C, 25°C, and 35°C plant WUE was significantly lower at 35°C (Fig. 2.4A, Table 2.1). Water loss during dark periods was always lower than that in the light but statistically similar regardless of the daytime temperature (Fig. 2.4B; Table 2.1). At 18°C, 25°C and 35°C these flowering plants did not show signs of wilting but plants subjected to 40°C wilted within a few hours (data not shown). Whole plant dark respiration rate at 18°C (Fig. 2.4D) was similar between 25°C and 35°C treatments and decreased for the 18°C treatment (Fig. 2.4C; Table 2.1).

At the growth temperature of 25°C/18°C the total biomass gain during the photoperiod (Fig. 2.4E) and the total biomass lost during the dark period (Fig. 2.4F) were 4.28 and 0.62 g C·m$^{-2}$ respectively, resulting in a daily net C-gain of 3.66 g C·m$^{-2}$·day$^{-1}$ (Table 2.1). *P. lanceolata* at the growth temperatures, 25°C/18°C day/night, had a slightly higher whole plant photosynthesis and net C-gain, but was not significantly different from 18°C or 35°C.
Figure 2.4. Effect of three daytime temperatures on whole plant transpiration (A and B), NCER, photosynthesis (C) dark respiration (D), and C-budget, C-gain during a 12 h photoperiod (E) and C-loss during the 12 h dark period (F). Plants were grown at 25/18°C day/night temperatures and were exposed to 18°C (●,—; closed, solid line), 25°C (○,—--;open, dashed line), and 35°C (●,—;; shaded, dotted line) daytime temperatures, the nighttime temperature was maintained at 18°C. Each NCER (C and D) and C-budget (E and F) values represent the mean ± se of 6 replicates. Transpiration (A and B) values represent mean ± se of 5 replicates.
Table 2.1. The effect of varying daytime temperature on whole plant photosynthesis, dark respiration, transpiration, WUE and daily C-budget of *P. lanceolata* plants grown at 25°C/18°C day/night temperatures. Each value represents the mean of 6 replicates. For transpiration each value represents the mean of 5 replicates. The values in parentheses represent ± se for each mean. Letters (a, b, c) indicate statistical differences (α=0.05) among temperature treatments within a row.

<table>
<thead>
<tr>
<th>Whole Plant Parameters</th>
<th>Temperature Light/Dark</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>18°C/18°C</td>
</tr>
<tr>
<td>CO₂ and H₂O exchange</td>
<td></td>
</tr>
<tr>
<td>Photosynthesis (μmol C·m⁻²·s⁻¹)</td>
<td>7.38 (0.41)</td>
</tr>
<tr>
<td>Dark Respiration (μmol C·m⁻²·s⁻¹)</td>
<td>-0.79 (0.08)</td>
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<tr>
<td>Transpiration (mmol H₂O·m⁻²·s⁻¹)</td>
<td>1.07 (0.04)</td>
</tr>
<tr>
<td>WUE(μmol C/ mmol H₂O)</td>
<td>7.13 (0.64)</td>
</tr>
<tr>
<td>C-budget</td>
<td></td>
</tr>
<tr>
<td>C-gain (g C·m⁻²)</td>
<td>3.83 (0.21)</td>
</tr>
<tr>
<td>C-loss (g C·m⁻²)</td>
<td>0.41 (0.04)</td>
</tr>
<tr>
<td>Daily C-gain (g C·m⁻²·day⁻¹)</td>
<td>3.36 (0.21)</td>
</tr>
</tbody>
</table>

Statistical analyses appended in Tables A.1.1 to A.1.7.

2.4.2 Leaf photosynthesis, WUE and ¹⁴C-export rate

Leaf transpiration values were higher than whole plant transpiration rate measurements (Fig. 2.4A; Data not shown for leaf transpiration). These differences can be explained by mutual shading at the canopy level resulting in lower transpiration rates as well as the differences in the air flow through the whole plant and leaf cuvette (Fig. 2.4A and B). Between 15°C and 45°C leaf-transpiration rates significantly increased (data not shown) while WUE significantly decreased (Fig. 2.5A). However, both leaf photosynthesis (B) and export rates (C and D) were significantly higher at 35°C than at 15°C, 25°C, and 45°C (Fig. 2.5B).
Figure 2.5. The effect of temperature on leaf WUE (A), photosynthesis (B), export (C), and relative export (i.e., as a % of photosynthesis) (D) of *P. lanceolata* source leaves. Each value represents the mean ± se of 6 replicates. Letters (a, b, c) indicate significant differences (α=0.05) for each parameter between temperatures. Data expressed as percentage were arcsine square root transformed prior to analysis. Values for percent data were back-transformed to the original scale. Statistical analyses appended in Tables A.2.1 to A.2.4.
2.4.3 14Carbon partitioning in source leaves

An increase in leaf temperature between 25°C and 45°C resulted in an increase in 14C-labelling of sugars and a corresponding decrease in the labelling of the leaf ethanol-insoluble (primarily starch) (Table 2.2). A small amount of 14C (1-2%) was partitioned into the CHCl₃ soluble fraction at all temperatures (data not shown). Changes in 14C-partitioning to sorbitol and sucrose appeared to be related to the effect of temperature on photosynthesis and export rates (Figure 2.3; Table 2.3). At 35°C photosynthesis and export rates were the highest (Fig. 2.5) and labelling of sorbitol was greater than that of sucrose, glucose, or fructose (Table 2.2). With a further increase of 10°C in aerial temperature to 45°C there was a reduction in leaf photosynthesis and export and similar amounts of labelled sucrose and sorbitol were detected.

<table>
<thead>
<tr>
<th>14C-Partitioning</th>
<th>15°C</th>
<th>25°C</th>
<th>35°C</th>
<th>45°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insoluble (Starch)</td>
<td>15.78 (2.14)ᵇ</td>
<td>17.54 (2.67)ᵇ</td>
<td>14.38 (1.89)ᵃᵇ</td>
<td>8.35 (2.33)ᵃ</td>
</tr>
<tr>
<td>Soluble</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sucrose</td>
<td>12.69 (1.43)ᵇ</td>
<td>6.18 (0.61)ᵃ</td>
<td>7.27 (1.01)ᵃ</td>
<td>11.98 (1.04)ᵇ</td>
</tr>
<tr>
<td>Glucose</td>
<td>4.63 (0.46)ᵇ</td>
<td>5.49 (0.53)ᵇᶜ</td>
<td>6.47 (0.38)ᶜ</td>
<td>2.60 (0.35)ᵃ</td>
</tr>
<tr>
<td>Fructose</td>
<td>2.85 (0.35)ᵃ</td>
<td>4.65 (0.43)ᵇ</td>
<td>5.02 (0.40)ᵇ</td>
<td>2.29 (0.20)ᵃ</td>
</tr>
<tr>
<td>Sorbitol</td>
<td>5.13 (0.55)ᵃ</td>
<td>5.21 (0.48)ᵃ</td>
<td>9.21 (0.49)ᵇ</td>
<td>9.58 (0.39)ᵇ</td>
</tr>
<tr>
<td>Aucubin</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Catalpol</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sucrose:Sorbitol Ratio</td>
<td>2.12 (0.25)ᶜ</td>
<td>1.18 (0.18)ᵃᵇ</td>
<td>0.79 (0.10)ᵃ</td>
<td>1.27 (0.13)ᵇ</td>
</tr>
</tbody>
</table>

Statistical analyses appended in Tables A.3.1 to A.3.6.
Tables 2.3 and 2.4 show an experiment in which the leaf photosynthetic rate was altered in favour of the carboxylation reaction of Rubisco. A short-term CO\(_2\) level of 91 Pa was chosen since this level of CO\(_2\) should be sufficient to increase the carboxylation efficiency of Rubisco. From a commercial standpoint, CO\(_2\) enrichment is a commonly used greenhouse commercial practice and CO\(_2\) levels are often enriched up to 100 Pa (Kramer, 1981; Porter and Grodzinski, 1985; Leonodos and Grodzinski, 2011; Blom et al., 2012). In addition, 70 to 100 Pa CO\(_2\) is the range predicted for the next 50 to 100 years due to global warming. The O\(_2\) level was reduced to 2 kPa, which is a level known to inhibit photorespiration without affecting mitochondrial respiration. Leaf WUE was markedly higher at enriched CO\(_2\) conditions and significantly increased with reduced photorespiratory conditions since transpiration rates were lower at 91 Pa CO\(_2\) (Table 2.3). Leaf photosynthesis and export rates significantly increased with exposure to 2 kPa O\(_2\) treatments and were the highest when the leaf was exposed to 2 kPa O\(_2\) under 91 Pa CO\(_2\) (Table 2.3). Compared to 40 Pa CO\(_2\), at 91 Pa CO\(_2\) more \(^{14}\)C was partitioned into ethanol-insoluble fraction (primarily starch) and solubles (sugars) (Table 2.3).

### Table 2.3. The effect of short-term CO\(_2\) enrichment and reduced O\(_2\) on leaf photosynthesis, transpiration, WUE, and export rates. Data are shown as a % control from the ambient 40 Pa; 21 kPa CO\(_2\); O\(_2\) condition, which is shown as 100%. Attached source leaves of *P. lanceolata* were assayed under 40 Pa and 91 Pa CO\(_2\) and 21 and 2 kPa O\(_2\) treatments and were fed \(^{14}\)CO\(_2\) for 3 h after which they were analysed. Each value represents the mean of 6 replicates. Letters (a, b, c) denote statistical differences (\(\alpha=0.05\)) for leaf parameters between treatments. Data were log transformed prior to analysis, and the mean values were back-transformed to the original scale.

<table>
<thead>
<tr>
<th>Leaf Parameter</th>
<th>CO(_2) (Pa) ; O(_2) (kPa) conditions</th>
<th>40 ; 21</th>
<th>40 ; 2</th>
<th>91 ; 21</th>
<th>91 ; 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photosynthesis</td>
<td>(100^a)</td>
<td>(127^{ab})</td>
<td>(143^{bc})</td>
<td>(184^c)</td>
<td></td>
</tr>
<tr>
<td>Transpiration</td>
<td>(100^b)</td>
<td>(105^b)</td>
<td>(74^a)</td>
<td>(94^{ab})</td>
<td></td>
</tr>
<tr>
<td>WUE</td>
<td>(100^a)</td>
<td>(121^b)</td>
<td>(182^c)</td>
<td>(196^c)</td>
<td></td>
</tr>
<tr>
<td>Export</td>
<td>(100^b)</td>
<td>(127^{bc})</td>
<td>(64^a)</td>
<td>(153^c)</td>
<td></td>
</tr>
</tbody>
</table>

Statistical analyses appended in Tables A.4.1 to A.4.4.
Table 2.4. The effect of varying CO\textsubscript{2} and O\textsubscript{2} levels on \textsuperscript{14}C-partitioned among selected metabolites in source leaves and petioles. Attached source leaves of \textit{P. lanceolata} were assayed under 40 Pa and 91 Pa CO\textsubscript{2} and 21 and 2 kPa O\textsubscript{2} treatments and were fed \textsuperscript{14}CO\textsubscript{2} for 3 h after which they were analysed. Each value represents the mean of a minimum 6 replicates. The values in parentheses represent ± se for each mean. Letters denote statistical differences (α=0.05) for leaf parameters between treatments. Data expressed as percentage were arcsine square root transformed prior to analysis. Values for percent data were back-transformed to the original scale.

<table>
<thead>
<tr>
<th>\textsuperscript{14}C-Partitioning</th>
<th>CO\textsubscript{2} (Pa) ; O\textsubscript{2} (kPa) conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40 ; 21</td>
</tr>
<tr>
<td>\textsuperscript{14}C-Leaf Tissues (mmol C·m\textsuperscript{-2})</td>
<td></td>
</tr>
<tr>
<td>Insoluble (Starch)</td>
<td>60.29 (8.64)\textsuperscript{ab}</td>
</tr>
<tr>
<td>Solubles</td>
<td></td>
</tr>
<tr>
<td>Sucrose</td>
<td>16.02 (1.89)\textsuperscript{a}</td>
</tr>
<tr>
<td>Sorbitol</td>
<td>21.29 (2.47)\textsuperscript{a}</td>
</tr>
<tr>
<td>Sucrose:Sorbitol Ratio</td>
<td>0.75 (0.06)\textsuperscript{a}</td>
</tr>
<tr>
<td>\textsuperscript{14}C-Petiole (%-label)</td>
<td></td>
</tr>
<tr>
<td>Sucrose</td>
<td>88.54\textsuperscript{ab}</td>
</tr>
<tr>
<td>Sorbitol</td>
<td>12.01\textsuperscript{a}</td>
</tr>
<tr>
<td>Sucrose:Sorbitol Ratio</td>
<td>7.41 (0.32)\textsuperscript{ab}</td>
</tr>
</tbody>
</table>

2.4). CO\textsubscript{2} enrichment during exposure to both 21 and 2 kPa O\textsubscript{2} increased \textsuperscript{14}C-partitioning into the ethanol-insoluble fraction (starch). Whereas partitioning into \textsuperscript{14}C-sucrose significantly increased in each condition that reduced photorespiration, incorporation of label in sorbitol remained statistically similar. During exposure to low O\textsubscript{2} the photosynthetic and export rates dramatically increased and the \textsuperscript{14}C-sucrose to \textsuperscript{14}C-sorbitol ratio in the petiole and venial tissue outside the feed area decreased indicating that a greater amount of \textsuperscript{14}C-sorbitol was transported at these conditions compared to exposure to 21 kPa O\textsubscript{2} under 40 Pa and 91 Pa CO\textsubscript{2}. However, \textsuperscript{14}C-sucrose always greatly exceeded that of \textsuperscript{14}C-sorbitol in tissues outside of the feed area of the cuvette (Table 2.4).
2.4.4 Iridoid glycosides

In addition to testing for sucrose and sorbitol in *P. lanceolata* leaf and petiole extracts, at each temperature as well as at each CO$_2$ and O$_2$ challenge we assayed for $^{14}$C-labelling of the two IGs, catalpol and aucubin. Using the PR Amide column well defined peaks were visible with standards. However, although unlabelled catalpol was detected in trace amounts the level of $^{14}$C-catalpol was never above the level of background amounts of $^{14}$C, even during an 11.5 h $^{14}$CO$_2$ feed (data not shown).

2.5 Discussion

Cavers et al. (1980) and others (Sagar and Harper, 1964) have noted that *P. lanceolata* is a successful, invasive weed found in a wide range of niches where there might be fluctuations in the daytime temperatures. The balance between photosynthetic and respiratory processes and the transport of photoassimilates to developing sinks is vital to plant growth and survival (Grodzinski et al., 1998; Murchie et al., 2009).

Generally the leaf photosynthetic rates exceed the photosynthetic potential of the whole plant (when both are expressed on a leaf area basis) because of two factors. First, gas exchange of the organism as a whole includes reproductive structures, stems, and roots, all of which will be releasing CO$_2$ during respiration. Second, mutual shading of lower leaves in a canopy can easily account for less than maximal rates of C-fixation during photosynthesis predicted solely on a leaf area basis. Leaf photosynthetic rates found in this study are in the range of leaf photosynthetic rates of *P. lanceolata* reported by others (Staddon et al., 1999; Paràdi et al., 2003). The similarity of our leaf and whole plant photosynthesis rate at the lower temperatures (Fig. 2.4C; Fig. 2.5B) indicate that excessive respiration of non-laminar structures and mutual shading did not alter the net photosynthetic activity determined at the whole plant level. However, when the temperature was raised to 35°C leaf photosynthesis was much higher than at 15°C or 25°C (Fig. 2.5B). Also, the leaf photosynthesis rate at 35°C was considerably above that of the whole plant (Fig. 2.4C and 2.3B). At 35°C concurrent $^{14}$C-export rates were also significantly higher than at other temperatures (Fig. 2.5C). The effect of 35°C on leaf photosynthesis versus whole plant photosynthesis is consistent with higher
respiration rates of all organs that would depress whole plant NCER proportionally more than at the lower temperatures. Plants studied had many well developed reproductive sinks. At 35°C, the respiratory demands of these sinks might have been sufficient to diminish whole plant NCER and also enhance export rates from the source leaves.

Whole plant photosynthesis expressed on a leaf area basis at 35°C on their own tend to underestimate the actual total amount of C-fixed and exported by source leaves to respiring sinks (Fig. 2.4C; Fig. 2.5A; Table 2.1). These flowering sinks represent a large potential for seed production and dispersal (Cavers et al. 1980). It follows that on warm days the demand for photoassimilates by reproductive sinks in *P. lanceolata* can be met by the increased export of assimilates from the leaves. At high temperature WUE decreased in *P. lanceolata* but source leaf photosynthesis and export rates were both maintained.

In most C₃ plants higher leaf temperatures generally increase the $^{14}$C-sugar to$^{14}$C-starch ratio (Stitt and Grosse, 1988, Jiao and Grodzinski, 1996). Starch synthesis usually decreases at elevated temperatures and this decrease is attributed to the reduced activity of soluble starch synthases at high temperatures (Jenner, 1994). Elevated canopy and leaf temperatures are known to inhibit C-export and this reduction in assimilate supply between the source leaves and respiring sink tissues can result in abortion of floral organs (Jiao and Grodzinski, 1996, Jiao and Grodzinski, 1998). In *P. lanceolata*, at the higher leaf temperatures less $^{14}$C-insoluble (starch) accumulated and more label appeared in sugars, particularly sorbitol and sucrose (Table 2.2). At 35°C when the export rate was maximal the amount of $^{14}$C-sorbitol labelled in *P. lanceolata* exceeded that at 15°C and 25°C (Fig. 2.5C; Table 2.2). Jiao and Grodzinski (1996) and Grodzinski et al., (1998) noted that the production of auxiliary sugars in addition to sucrose by some C₃ species may contribute to higher export rates during photosynthesis. They found increased export of raffinose, stachyose and sucrose, as well as storage of sucrose and raffinose with a temperature increase of 15°C to 40°C in *Salvia* (Jiao and Grodzinski, 1996).

Very little is known about the relationship between sucrose and the alcohol sugar sorbitol in herbaceous plants, such as *P. lanceolata*. In many tree species, such as
apple, apricot, and peach classified in the Rosaceae (Loescher, 1987) from 60-90% of the newly fixed carbon exported can be sorbitol. In *P. lanceolata* the amount of label in sucrose being translocated exceeded that of sorbitol (Table 2.2). At the higher temperatures more of the $^{14}$C-sorbitol (Fig. 2.5C) appeared to be retained, which is consistent with a possible role for this metabolite as an osmoregulator. In response to abiotic and biotic stresses, such as drought, cold hardiness, and resistance of disease, plants can accumulate sorbitol that acts to osmotically adjust water balance (Loescher, 1987; Cheng et al., 2005). Homeostasis appears to be maintained in part through the inter-conversion of starch and sorbitol (Lambers et al., 1981; Cheng et al., 2005).

In peach, a sorbitol translocator, as photosynthetic rates increase more $^{14}$CO$_2$ is partitioned into sucrose and starch rather than sorbitol (Escobar-Gutiérres and Gaudillère, 1997). In apple, elevated CO$_2$ levels increase labelling into sorbitol and starch in source leaves; however, above 70 Pa CO$_2$ enrichment starch synthesis is favoured over sorbitol (Wang et al., 1999). Changes are more dramatic in the source leaves than in sink, or in sink to source transition leaves (Wang et al., 1999). In both studies, tree species, that make sorbitol are examined, leaf export rates are not measured. When mature source leaves of *P. lanceolata* were exposed to 91 Pa CO$_2$ to enhance carboxylation there was an increase in the amount of label accumulating in starch and sucrose (Table 2.4). Interestingly, the amount of $^{14}$C-sorbitol was not significantly changed and the rate of export was not increased during CO$_2$ enrichment at ambient O$_2$ levels (Table 2.4). However, depression of photorespiration by decreasing the O$_2$ level to 2 kPa at 40 Pa and 91 Pa CO$_2$, both conditions in which the oxygenase reaction of Rubisco would be diminished resulted in higher photosynthesis rates and increased synthesis of sugars that is consistent with higher $^{14}$C-export rates (Table 2.3; Table 2.4). There was a concomitant $^{14}$C-partitioning into sucrose production in leaves and a decrease in the sucrose to sorbitol ratio found in the petiole tissue (Table 2.4). Thus, an increase in export rate was consistent with increased sorbitol transport.

Although *P. lanceolata* is known to synthesize the IGs, catalpol and aucubin, these glucose esters were not recovered as $^{14}$C-labelled intermediates from either the leaf tissue or the subtending petiole tissue in the time frame of our feed experiments.
Even in labelling periods that extended for nearly a full photoperiod (e.g., 11.5 h) catalpol and aucubin were not labelled. Taken together, studies with the ecotypes and conditions tested provided no evidence that these iridoid glucosides were synthesized from the chloroplastic terpenoid pathway (Figure 1.2) and were directly labelled from photosynthesis. Thus, my hypothesis that species within the Plantaginaceae synthesize IGs from newly fixed $^{14}$CO$_2$ and is transported along with sucrose in phloem tissues is rejected. Differences of IG selection lines of *P. lanceolata* have also been reported (Bowers et al., 1992; Marak et al., 2000). In our studies a low IG selection line of a pasture ecotype may have been chosen. Future work on herbaceous species, such as *P. lanceolata* and tolerance of different ecotypes to a wide range of environments may be associated with primary photosynthesis and C-translocation in the form of alcohol sugars or IGs (Voitsekhovskaja et al., 2006; Reidel et al., 2009).

The extent that auxiliary sugars, such as sorbitol and mannitol, contribute to translocation in higher plants is not well known (Loescher, 1987; Grodzinski et al., 1998; Noiraud et al., 2001; Reidel et al., 2009). Weeds, such as *P. lanceolata*, that can manufacture, partition and allocate auxiliary sugars in addition to sucrose may have an advantage in adverse environments. When *P. lanceolata* is exposed to warmer temperatures the WUE significantly decreases; however, because of increased partitioning and export of sorbitol, *P. lanceolata* is able to maintain photosynthesis and transport photoassimilates to developing sinks. An observation that supports the concept that sorbitol production facilitates source strength in *P. lanceolata* comes from experiments at low O$_2$. When photorespiration was diminished at 2% O$_2$ there was an increase in export rate and labelling of sorbitol in petioles.

Why *P. lanceolata* can thrive in many environments remains unanswered; however, as illustrated from the whole plant and leaf studies, environmental factors, such as temperature and CO$_2$ affect leaf metabolism and export that are important leaf traits defining source strength.
CHAPTER 3

The effect of temperature on daily C-budget, $^{14}$C-partitioning and export of assimilates in two cultivars of Antirrhinum majus L. recommended for different seasonal production cycles

3.1 Abstract

The effects of short-term temperature challenges on whole plant photosynthesis and daily C-gain, as well as leaf photosynthesis, $^{14}$C-export rates and $^{14}$C-partitioning among primary metabolites, including iridoid glycosides, in two cultivars of A. majus were determined. Whole plant NCER measurements showed that the GIV cultivar recommended for warm sunny greenhouse production cycles had higher photosynthesis and daily C-gain compared to the GI cultivar under three day/night temperature regimes. High rates of leaf photosynthesis and export resulted in more $^{14}$C-labelling of antirrhinoside. Petiole analysis indicated that the GI cultivar transported more $^{14}$C-antirrhinoside at the lower temperature of 15°C. In contrast, the GIV cultivar seemed to transport more $^{14}$C-antirrhinoside at the higher temperatures. In both cultivars leaf photosynthesis and export rates increased under short-term CO$_2$ and/or low O$_2$ treatments. Partitioning of $^{14}$C into sucrose and IGs increased during short-term CO$_2$ enrichment in both cultivars. $^{14}$C-labelling of antirrhinoside relative to sucrose generally increased at 25°C and 35°C compared to 15°C under short-term CO$_2$ and/or low O$_2$ treatments. At 25°C and 35°C and 21% O$_2$ but not at 15°C more antirrhinoside was labelled than antirrhide in both cultivars indicating that the metabolism of the IGs may itself be sensitive to photorespiratory conditions. The results confirm that the IGs synthesized by A. majus are directly labelled from photosynthesis and that partitioning into these compounds and major photoassimilates were altered with environmental conditions.

3.2 Introduction

Previous studies have shown clearly that the IGs, antirrhinoside and antirrhide, which are chemical analogues of aucubin and catalpol, are directly $^{14}$CO$_2$ labelled in A.
The focus of this chapter was to use two climatic cultivars of *A. majus* as model plants to examine $^{14}$C-export and partitioning into IGs during different temperature and CO$_2$ conditions. As noted in Chapter 2 above, temperature alters carboxylation efficiency and greatly affects gas exchanges and carbon allocation among primary photoassimilates such as, sucrose and the alcohol sugar, sorbitol that might relate to the ability of the plant to maintain sink demand and plant growth under high temperature conditions. *A. majus* is a species that has been used to develop several cut flower climatic cultivars (GI, GII, GIII, and GIV) suited for production in different seasons such as, summer and winter production cycles that create different greenhouse environments (Rogers, 1992; Hamrick, 2003). *A. majus* is a well domesticated ornamental species and has been of interest as a model organism for plant genetics and development over the past century (Hundson et al., 2008; Swarz-Sommer et al., 2003). Year-round production of snapdragon is available due to the development of F$_1$ hybrid cultivars that have been categorized into four climatic response groups corresponding to flowering response dependent on day length, light intensity and temperature (Rogers, 1992). The GI cultivar group is recommended for short days, low light levels, and night temperatures between 7-10°C. The GII cultivar group is recommended for short days (longer than GI), moderate light levels, and night temperatures between 10-13°C. The GIII cultivar group is recommended for medium to long days, moderate to high light levels, and night temperatures between 13-16°C. The GIV cultivar group is recommended for long days, high light levels, and night temperatures higher than 16°C (Rogers, 2003; Cloutier, 2008). Cultivar selection should be based on local climate or season for quality and timely production as well as the reduction on greenhouse costs by the conservation of energy (Rogers, 1992). In our studies we used a GI cultivar group, Protomac Ivory White, and a GIV cultivar group, Maryland Ivory White, as models since these cultivars are recommended for two extreme seasonal production times (winter and summer) and are more likely to show differences.

Both Campos Núñez (1994) and Moore et al. (1997) found an 'unknown' in their carbohydrate extracts from leaves of *A. majus*. Moore et al. (1997) found that the 'unknown' compound(s) has a close retention time to glucose and Campos Núñez
(1994) determined that the unknown compounds account for 15 to 24% of the total carbohydrate in the phloem sap. Beninger et al. (2007) extracted, isolated, purified and identified the ‘unknown’ labelled photoassimilates as iridoid glycosides (IGs), primarily antirrhinoside and antirrhide. Høgedal and Mølgarrd (2000) determined that antirrhinoside and antirrhide accounts for 90-98% of the IGs in *A. majus*. They showed that leaves of field grown snapdragon cultivars have 2.3 to 9.8% of the total carbon in the form of antirrhinoside. In addition, they found that antirrhide increases in leaf extracts and antirrhinoside decreases after flowering. Beninger et al. (2007) showed that antirrhinoside is present in all tissues of *A. majus* whereas antirrhide is present only in the leaf lamina. They also found that antirrhinoside concentrations decrease with leaf age while antirrhide increases. The concentration of antirrhinoside ranges from 9.2% to 23.7% of dry weight in certain tissues and $^{14}$C-antirrhinoside is recovered in the petiole tissue and accounts for 45% of the $^{14}$C-label relative to sucrose (Beninger et al., 2007).

As stated in Chapters 1 and 2, other species within the Plantaginaceae family synthesise and transport antirrhinoside in significant amounts (Gowan et al., 1995; Voitsekhovskaja et al., 2006). Gowan et al. (1995) found that in *Asarina scandens*, antirrhinoside is rapidly $^{14}$CO$_2$ labelled and is recovered in the phloem sap. But rates of export were not measured. The alcohol sugars, sorbitol and mannitol, are also synthesized in many members of the Plantaginaceae (Moore et al., 1997; Beninger et al., 2007; Reidel et al., 2009).

Høgedal and Mølgarrd (2000) were the first to examine if seasonal variation (light, temperature and humidity) alters IG content in *A. majus*; however, in their field studies they were unable to relate seasonal variation to IG content. Cloutier (2008) and Gutierrez (2003) showed that light levels and temperature alter photosynthetic responses, $^{14}$C-export rates, and $^{14}$C-partitioning in laminar and petiole tissues of a GI and a GIV climatic group cultivars. Differences in growth and development between the cultivars were observed; however, $^{14}$C-distribution of IGs between the two cultivars was similar.

As in the previous chapter, the whole plant, and leaf tissue and the partitioning into primary metabolites were examined. Taken together, these studies provide a better
understanding of how the two *A. majus* climatic group cultivars responded to alterations in canopy temperatures with respect to leaf and canopy net photosynthetic ability. Our primary objective was to use varying short-term temperature challenges during which leaves were also exposed to varying CO$_2$ and O$_2$ conditions to alter source leaf photosynthesis and photorespiration to determine the changes in $^{14}$C-partitioning among primary photoassimilates, especially in the IGs, antirrhinoside and antirrhide. The results consist of three sub-sections: section 3.4.1 describes the short-term temperature effects on whole plant NCER and C-budgets, leaf photosynthesis, partitioning and export in the two cultivars; section 3.4.2 describes the effects of short-term enriched CO$_2$ and exposure to low O$_2$ at 35°C a high temperature on leaf photosynthesis, partitioning and export in the two cultivars; and section 3.4.3 describes the effect of short-term enriched CO$_2$ and low O$_2$ exposure at three temperatures conditions on photosynthesis, export, and partitioning for the two cultivars.

3.3 Materials and Methods

3.3.1 Plant materials and growth conditions

Protomac Ivory White (GIV) and Maryland Ivory White (GI) cultivars of *A. majus* L. F1 hybrid seeds provided by PanAmerican Seed™ (Chicago, IL, USA) were sown in 128 cavity plug trays (Landmark Co. Plastic, Akron, OH, USA) in a soil-less growth medium (Pro-mix GXP®, Premier Horticulture Ltée/LTD Rivière du Loup, QC, Canada). Germination took place in a glass greenhouse in Guelph, ON, Canada (43.3° 15’ L.N) on a misting bench at 25/18°C day/night temperatures, under natural light conditions. After a four to six week period, the seedlings were transplanted to 1.8 L plastic containers filled with aerated nutrient solution (Johnston et al. 2005). The containers were placed in a larger black plastic container and its lid was covered with a black-on-white plastic sheeting to exclude light to prevent algal growth. Hydroponic plants were placed in growth chambers (GC-20 Bigfoot series, BioChambers, Winnipeg, MB, Canada) and set at a 25/18°C day/night temperature regime with a 12 h photoperiod and provided 350 ± 50 µmol m$^{-2}$ s$^{-1}$ PPFD at the canopy height. CO$_2$ was maintained at 40 Pa and the relative humidity was maintained at 60±5% R.H. Commercial hydroponic
formulation (1.15 g of 6-11-35 nitrogen: phosphorus: potassium supplemented with 0.85 g of calcium nitrate (CaNO$_3$) per liter, Plant Products Ltd., Brampton, ON) was used to fertilize the plants. pH and electroconductivity were kept constant at 6.0 and 1.9 mS/cm, respectively, and were measured using an Oakton pH/Conductivity meter (Model WD-34631-60, Cole-Parmer Canada Inc., Montreal, QC, Canada). For the first week seedling received half-strength nutrient solution and after received full strength nutrient solution and its level was maintained during the experiment. Plants were grown for three to four weeks till they developed fully expanded axillary leaves on the 4$^{th}$ node (vegetative stage).

3.3.2 Whole plant gas exchange

Whole plant gas exchange measurements were conducted in a manner similar to that described in Chapter 2. Two *A. majus* (GI or GIV) plants were placed into each of the six chambers to increase the sensitivity of the system since plants were in their vegetative state and had a small leaf area (Fig. 3.1A). Gas exchange measurements were repeated over a one week period for each temperature treatment. A sample size of 12 (24 plants; 2 per chamber) were measured for NCER for each temperature treatment; however, only a samples size of 10 was measured for transpiration due to a malfunctioning balance. Air temperature was maintained at 18°C, 25°C or 35°C for the 12 h light period but at 18°C during the 12 h dark period during which net CO$_2$ exchanges were measured constantly. CO$_2$ was maintained at ambient, 40 Pa and the humidity of the air inside the chamber was maintained at 50/55 (± 5% R.H.) day/night. Plants were acclimated to the whole plant analysis chambers overnight. The same method described Chapter 2; Section 3.2 was used to calculate whole plant NCER and daily carbon budgets (Dutton et al. 1988; Leonardos et al. 2003; Leonardos and Grodzinski, 2005). The leaf area measurements were obtained using a leaf area meter (LI-3000; LI-COR).

3.3.3 Leaf gas exchange and $^{14}$CO$_2$ labelling

The same open-flow leaf gas exchange system as in Chapter 2 was used to conduct $^{14}$CO$_2$ steady-state labelling experiments (Jiao and Grodzinski, 1996;
Leonardos and Grodzinski, 2000). A description of our new system can be found in Chapter, 2, Section 3.3. Source leaf transpiration, photosynthesis, and \(^{14}\)C-export measurements were made on a portion of one fully expanded, intact, and attached leaf from the fourth node of four to eight different A. majus plants (Fig. 1B). Plants grown at 25°C/18°C day/night temperatures were acclimated to growth chamber conditions. Light levels were set at 1000 ± 50 µmol·m\(^{-2}\)·s\(^{-1}\) PPFD. The plant chamber air and leaf cuvette temperatures were maintained at 15°C, 25°C, or 35°C. The relative humidity was maintained at 50 (± 5% R.H.). The same CO\(_2\) level (40 Pa, 91 Pa or 182 Pa) were maintained in both the plant chamber and the leaf cuvette. However, during the 2 kPa O\(_2\) challenges only the leaf cuvette was kept at 2 kPa O\(_2\), not the entire plant. The \(^{14}\)CO\(_2\) specific activity varied from 0.21-0.37 kBq·µmol\(^{-1}\)C for the temperature treatments and from 0.37-0.63 kBq·µmol\(^{-1}\)C for the high CO\(_2\) and low O\(_2\) treatments. The leaf inside the cuvette was traced and the leaf area was determined using Adobe\textsuperscript{®} Photoshop\textsuperscript{®} CS3 Extended. The leaf tissue seen by the GM detector in the cuvette and
the petiole tissue outside the feed area were immediately frozen in liquid nitrogen and stored in a -80°C freezer prior to extraction.

**3.3.4 ¹⁴C-Partitioning**

Frozen leaf and petiole samples were extracted and prepared for HPLC separation in the same manner as in Chapter 2, Section 3.4. Individual sugars and the IGs were separated by the Supelcosil™ LC-NH₂ amino column (4.6 X 250 mm, 5 µm particle size; Sigma-Aldrich, Canada Inc.) linked to a (Beckman Instrument Inc. Altex division) 118 solvent module with a refractive index detector and a fraction collector (LKB Broma 2111). The Supelcosil™ column separated the IGs, antirrhide (retention time=4.8 min) and antirrhinoside (retention time=6.1 min) from fructose (retention time=7.8 min), glucose/mannitol (co-eluded) (retention time=8.5 min), and sucrose (retention time=12.1 min) (Fig. 2.2). The column was equilibrated at room temperature. The solvent system was 75 to 80% ACN (depending on column age) in water with a flow rate of 1 mL·min⁻¹. Since, mannitol and glucose co-eluded with the Supelcosil™ column the Alltech cation exchange 700 CH carbohydrate column (4.6 X 300 mm; 10 µm particle size; Alltech Associates, Mandel Scientific, Guelph, ON, Canada) were used to separate sucrose (retention time=11.3 min), glucose (retention time=14.8 min), fructose (retention time=18.2 min) and mannitol (retention time=23.9 min) fractions (Fig. 2.3). However the IGs, antirrhinoside and antirrhide co-eluded with the Alltech column. The Alltech column was used primarily to determine that only a small amount of ¹⁴CO₂ was partitioned into the mannitol fraction at the growth condition for the two *A. majus* leaf extracts. The Alltech column was equilibrated at 85°C with a Waters column heating unit. The solvent system was 100% HPLC water with a flow rate of 0.3 mL·min⁻¹. The same method was used to collect effluent and to determine radioactivity in all fractions as in Chapter 2, Section 3.4. Calibration curves were obtained with r² values that were greater than 0.9935 using concentrations from 0 to 4.10 mM sucrose 0 to 4.11 mM glucose and fructose, 0 to 8.23 mM for mannitol, 0 to 9.1 mM for antirrhinoside and 0 to 7.6 mM antirrhide.
Figure 3.2. A representative chromatogram showing the peaks and retention times for standards separated with the Supelcosil™ LC-NH₂ amino column. Peaks are numbered in sequence: antirrhide (1=4.8 min), antirrhinoside (2=6.1 min), fructose (3=7.8) glucose (4=8.5 min) and sucrose (5=12.1 min) (NB: peaks may shift with column age). Standard concentrations were as described in the Materials and Methods (A). A representative chromatogram of the water soluble extract from a ¹⁴CO₂ labeled source leaf of A. majus showing the amounts of sugars and IGs: 1=antirrhide, 2=antirrhinoside, 3=fructose, 4=glucose/mannitol and 5=sucrose (B). A representative profile of the ¹⁴C-recovered from the different sugars and sugar alcohol separated by HPLC using the Supelcosil™ LC-NH₂ amino column. Peaks are numbered in sequence: 1=antirrhide, 2=antirrhinoside, 3=fructose, 4=glucose and 5=sucrose (C). The arrows indicate the collection time.
Figure 3.3. A representative chromatogram showing the peaks and retention times for standards separated with the Alltech cation exchange 700 CH carbohydrate column. Peaks are numbered in sequence: sucrose (1=13.3 min), glucose (2=16.9 min), IGs (3=18.4 min) fructose (4=20.2 min) and mannitol (5=23.9 min) (NB: peaks may shift with column age). Standard concentrations were as described in the Materials and Methods (A). A representative chromatogram of the water soluble extract from a 14CO₂ labeled source leaf of A. majus showing the amounts of sugars and a sugar alcohol: 1=sucrose, 2=glucose, 3=IGs, 4=fructose and 5=mannitol (B). A representative profile of the 14C-recovered from the different sugars and sugar alcohol separated by HPLC using the Alltech column. Peaks are numbered in sequence: 1=sucrose, 2=glucose, 3=IGs, 4=fructose and 5=mannitol (C). The arrows indicate the collection time.
The diagram shows three different graphs labeled A, B, and C.

- **Graph A**
  - Graph A is a series of peaks labeled 1, 2, 3, 4, and 5 over time ranging from 0 to 30 minutes.
  - The y-axis represents radioactivity (Bq).
  - The x-axis represents time (min).

- **Graph B**
  - Graph B is a similar series of peaks labeled 1, 2, 3, 4, and 5.
  - The units on the y-axis are not specified.
  - The x-axis is labeled as Minutes and ranges from 0 to 30.

- **Graph C**
  - Graph C is labeled with a y-axis representing $^{14}C$-Radioactivity (Bq) ranging from 0 to 5.00.
  - The x-axis shows time (min) from 10 to 28.

The graphs illustrate the variation of radioactivity over time with distinct peaks at various time points.
3.3.5 Statistical analyses

The experimental design for these studies was set up as a completely randomized design. Statistical analysis was carried out using Statistical Analysis Software, version 9.3 (SAS Institute Inc., NC, USA). Parameters for *A. majus* and *P. lanceolata* plants were performed by analysis of variance (ANOVA) using a general linear model (PROC GLM). To ensure assumptions for the one-way and two-way ANOVA were met, a test of residuals was performed using PROC UNIVARIATE. The Shapiro Wilkes test of residuals was computed to determine if the distributions were normal. To verify if outliers were present, standardized residuals were calculated and assessed against Lund’s critical value. Data expressed as percentage were arcsine square root transformed prior to analysis. Data transformation, arcsine square root, was selected for the specific data sets as per recommendations from Bowley (1999). Values for percent data were back-transformed to the original scale. The standard errors of these means were not back-transformed and are not represented in tables or graphs since these statistics are not relevant on the original scale (Bowley, 1999). Two repetitions of six to five whole plant measurements were pooled according to Tukey’s t-test. Means ± se of 12 to 10 different plants for whole plant measurements were calculated. Means ± se of four to eight independent leaves on different plants were calculated. Multiple comparisons (LSmeans, SAS) were used obtain differences between treatments. Contrast and estimate statements were used to examine differences between the cultivars within the GLM procedure.

3.4 Results

3.4.1 The effects of temperature on whole plant and leaf metabolism in *A. majus*

3.4.1.1 The effects of temperature on whole plant NCER, WUE, and daily C-gain

The panels in Figure 3.4 illustrate the whole plant H₂O (Fig. 3.4A-D) and CO₂ exchanges (Fig. 3.4E-H) of a GI and a GIV cultivar of *A. majus* during light saturated conditions. Panels I-L show the net accumulation and net loss of biomass (g of C) due to plant photosynthesis and respiration. Panels A-D show the daily pattern of water loss
from the whole plant due to transpiration at the growth temperature of 25°C during the light period compared to exposures at 18°C and 35°C in the GI and the GIV cultivar. The three temperature regimes (18°C/18°C, 25°C/18°C and 35°C/18°C) that A. majus plants were exposed to in this study are temperatures that cut flowers experience during greenhouse growth conditions. Whole plant transpiration during the 12 h photoperiod was significantly higher with each increase in the daytime temperature (Figs. 3.4A and C; Table 3.1). During the nighttime, the transpiration rates were much lower (Figs. 3.4B and D). WUE significantly decreased with each increase in daytime temperature. There were no significant differences in transpiration between cultivars at 25°C and 18°C; however, transpiration was higher in the GIV cultivar at 35°C (Table 3.1). Whole plant photosynthesis was fairly steady in the GI cultivar, but slightly deceased in the GIV cultivar towards the end of the photoperiod (Fig. 3.4E and G). Whole plant photosynthesis increased with each temperature and was significantly higher in the GIV cultivar (Table 3.1) ranging from 15.19 ± 0.20 to 18.10 ± 0.37 µmol C·m⁻²·s⁻¹ and 17.05 ±0.32 to 20.05 ± 0.53 µmol C·m⁻²·s⁻¹ in the GI and the GIV cultivar, respectively. Figure 3.4F and H show dark respiration at 18°C. Dark respiration was higher in the GIV cultivar (Fig. 3.4; Table 3.1). Panels: I-J, in Figure 3.4, show the C-gain and loss at 18°C/18°C, 25°C /18°C, and 35°C/18°C day/night temperature regimes in the two A. majus cultivars. Daily C-gain significantly increased with each daytime temperature interval for both cultivars and was also significantly different between cultivars, where C-gain was higher in the GIV cultivar when compared to the GI cultivar (Fig. 3.4I and K). C-loss was also significantly higher in the GIV cultivar when compared to the GI cultivar (Table 3.1). Overall, whole plant daily C-gain for the 24 h period significantly increased with each temperature interval for both cultivars, ranging from 6.71 ± 0.14 to 7.97 ±0.17 and 7.56 ±0.16 to 8.76 ± 0.25 (g C·m⁻²·day⁻¹) in the GI and the GIV cultivar, respectively (Table 3.1).
Figure 3.4. Effect of three daytime temperatures on whole plant transpiration rate (A-D), NCER (E-H), and C-budget during a 12-hour photoperiod (I and K) and C-loss during a 12-hour dark period (J and L). Two greenhouse cultivars of *A. majus* were grown at 25/18°C day/night temperatures and were exposed to 18°C (●,——; closed, solid line), 25°C (○,----; open, dashed line) and 35°C (◆,······; shaded, dotted line) daytime temperatures; the nighttime temperature was maintained at 18°C. Each NCER (E-H) and C-budget (I-L) value represents the mean ± se of 12 replicates. Transpiration (A-D) values represent mean ± se of 10 replicates.
Table 3.1. The effect of several daytime temperature regimes on whole plant photosynthesis, dark respiration, transpiration, WUE and daily C-budgets of two greenhouse cultivars of *A. majus* (GI, GIV). Each value represents the mean of 12 replicates. For transpiration each value represents the mean of 10 replicates. The values in parentheses represent ± se for each mean. Letters (a, b, c) and (A, B, C) indicate statistical differences (α=0.05) for whole plant parameters within a row for temperature treatments for the GI and the GIV cultivar, respectively. Symbols (* ) indicate statistical differences (α=0.05) between cultivars.

<table>
<thead>
<tr>
<th>Whole Plant Parameters</th>
<th>GI Temperature Light/Dark</th>
<th>GIV Temperature Light/Dark</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>18/18°C 25/18°C 35/18°C</td>
<td>18/18°C 25/18°C 35/18°C</td>
</tr>
<tr>
<td><strong>CO₂ and H₂O exchange</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Photosynthesis (µmol C·m⁻²·s⁻¹)</td>
<td>15.19 (0.20)ₐ* 16.81 (0.32)ₜₐ* 18.10 (0.37)ₜₐ*</td>
<td>17.05 (0.32)ₐ* 19.03 (0.44)ₜₐ* 20.05 (0.53)ₜₐ*</td>
</tr>
<tr>
<td>Dark Respiration (µmol C·m⁻²·s⁻¹)</td>
<td>-2.23 (0.07)ₐ* -2.90 (0.13)ₜₐ* -2.70 (0.08)ₜₐ*</td>
<td>-2.93 (0.14)ₐ* -3.01 (0.12)ₐ* -3.15 (0.13)ₐ*</td>
</tr>
<tr>
<td>Transpiration (mmol H₂O·m⁻²·s⁻¹)</td>
<td>1.04 (0.06)ₐ* 1.70 (0.04)ₜₐ* 2.35 (0.11)ₜₐ*</td>
<td>1.04 (0.06)ₐ* 1.72 (0.06)ₐ* 2.65 (0.16)ₐ*</td>
</tr>
<tr>
<td>WUE (µmol C/ mmol H₂O)</td>
<td>14.85 (1.02)ₐ 9.96 (0.42)ₜ 7.68 (0.28)ₜ</td>
<td>14.31 (1.14)ₐ 11.21 (0.50)ₐ 7.55 (0.46)ₐ</td>
</tr>
<tr>
<td><strong>C-Budgets</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-Gain (g C·m⁻²)</td>
<td>7.88 (0.11)ₐ* 8.72 (0.17)ₜₐ* 9.39 (0.15)ₜₐ*</td>
<td>8.84 (0.16)ₐ* 9.74 (0.21)ₜₐ* 10.40 (0.27)ₜₐ*</td>
</tr>
<tr>
<td>C-Loss (g C·m⁻²)</td>
<td>1.17 (0.07)ₐ* 1.44 (0.06)ₜₐ* 1.40 (0.04)ₜₐ*</td>
<td>1.51 (0.04)ₐ* 1.62 (0.06)ₐ* 1.63 (0.07)ₐ*</td>
</tr>
<tr>
<td>Daily C-gain (g C·m⁻²·day⁻¹)</td>
<td>6.71 (0.14)ₐ* 7.28 (0.15)ₜₐ* 7.97 (0.17)ₜₐ*</td>
<td>7.56 (0.16)ₐ* 8.12 (0.19)ₜₐ* 8.76 (0.25)ₜₐ*</td>
</tr>
</tbody>
</table>

Statistical analyses appended in Tables A.6.1 to A.6.7.
3.4.1.2 The effects of temperature on leaf photosynthesis, WUE and $^{14}$C-export rate

Panels in Fig. 3.5 show source leaf water exchanges (Fig. 3.5A), photosynthesis (Fig. 3.5B), and export rates (Fig.3.5C) and relative export rates (Fig. 3.5D) of the GI and the GIV cultivars exposed to 15°C, 25°C and 35°C during ambient CO$_2$ and O$_2$ conditions at light saturated levels. The three daytime temperatures are within the range that can be observed in commercial greenhouses. Leaf WUE significantly decreased with each temperature interval in both A. majus cultivars (Fig. 3.5A). Leaf photosynthetic values at 15°C were 11.50 ± 0.3 µmol C·m$^{-2}$·s$^{-1}$ in the GI cultivar and 13.20 ± 0.89 µmol C·m$^{-2}$·s$^{-1}$ in the GIV cultivar and were significantly lower at 15°C compared to 25°C and 35°C in both cultivars. Leaf photosynthetic rates were similar at 25°C and 35°C; however, photosynthesis was the highest at the growth temperature at 21.40 ± 0.13 and 20.80 ± 0.93 µmol C·m$^{-2}$·s$^{-1}$ in both the GI and the GIV cultivars, respectively and was significant in the GI cultivar (Fig. 3.5B). A similar pattern to leaf photosynthesis was seen in $^{14}$C-export rates that were significantly higher at 25°C and 35°C compared to 15°C in both cultivars (Fig. 3.5C). Relative export (% relative to photosynthesis) was similar, ranging from 62 to 78% for both cultivars during the three temperature treatments (15°C, 25°C and 35°C) (Fig. 3.5D).
Figure 3.5. The effect of leaf temperature on WUE (A), photosynthesis (B), export rate (C), and relative export (i.e. as % of photosynthesis) (D) of two greenhouse cultivars of A. majus. Each value represents the mean ± se of a minimum 6 replicates. Letters (a, b, c) and (A, B, C) indicate significant differences (α=0.05) for each parameter between temperatures for the GI and the GIV cultivar, respectively. Symbol (*) indicates significant differences (α=0.05) between cultivars. Data expressed as percentage were arcsine transformed prior to analysis. Values for percent data were back-transformed to the original scale. Statistical analyses appended in Tables A.7.1 to A.7.4.
3.4.1.3 The effects of temperature on leaf $^{14}$C-partitioning

Table 3.2 shows the partitioning of $^{14}$C into major carbohydrate fractions in leaf and petiole extracts. The amount of $^{14}$C-recovered in the ethanol insoluble (primarily starch) fraction was significantly higher at 25°C in both cultivars compared to 15°C and 35°C. $^{14}$C-partitioned in the soluble fraction was the most heavily labelled in sucrose; the second heaviest labelling being in antirrhinoside during the temperature treatments. Significantly more $^{14}$C-sucrose was retained at 25°C than at 15°C and 35°C in the GI cultivar. Similar amounts $^{14}$C-sucrose were partitioned at the higher temperatures in the GIV cultivar (Table 3.2). $^{14}$C-partitioning in glucose and fructose were similar and similar patterns to sucrose were observed between cultivars and between the temperatures (Table 3.2). Minor labelling of the alcohol sugar mannitol was detected at the growth temperature in the leaf tissues but not in the petiole.

For both the GI and GIV cultivars significantly more $^{14}$C-antirrhinoside was retained at the two higher temperatures compared to 15°C paralleling the increases in leaf photosynthesis and export rates (Fig. 3.5C; Table 3.2). At all three temperatures a second IG, antirrhide, was $^{14}$C-labelled in the leaves but none was ever found in the petiole tissues of either cultivar (Table 3.2). At 15°C the labeling of antirrhide was similar to that of antirrhinoside. However, in both cultivars as photosynthesis and export increased at 25°C and 35°C the amount of labelled antirrhide relative to that in antirrhinoside was significantly less. In both cultivars there was heavier labelling of antirrhide at the growth temperature of 25°C (Table 3.2).

Table 3.2 also shows the % of $^{14}$C-partitioned into sugars, sucrose and antirrhinoside in petiole tissues (Table 3.2). The % $^{14}$C-sugars in petiole tissues increased at the two higher temperatures in the GI cultivar and decreased in the GIV cultivar (Table 3.2). In petiole tissues 10 to 17% of the $^{14}$C in the soluble fraction was in antirrhinoside. The % of $^{14}$C-antirrhinoside in petiole tissues was higher at the low temperature in the GI cultivar and was higher at the two highest temperatures in the GIV cultivar (Table 3.2).
Table 3.2. The effect of temperature on $^{14}$C-partitioning among selected metabolites in leaves and subtending petiole tissue of two greenhouse cultivars of *A. majus* (GI, GIV). Each value represents the mean of a minimum value of 6 replicates. nd = not determined. The values in parentheses represent ± se for each mean. Letters (a, b, c) and (A, B, C) indicate statistical differences ($\alpha=0.05$) for leaf parameters within a row for temperature treatments for the GI and the GIV cultivar, respectively. Symbols (*) indicate statistical differences ($\alpha=0.05$) between cultivars. Data expressed as percentage were arcsine transformed prior to analysis. Values for percent data were back-transformed to the original scale.

<table>
<thead>
<tr>
<th>$^{14}$C-Partitioning</th>
<th>GI $^{15}$C</th>
<th>25°C</th>
<th>35°C</th>
<th>GI $^{15}$C</th>
<th>25°C</th>
<th>35°C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>$^{14}$C-Leaf Tissues (mmol C·m$^{-2}$)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insoluble (Starch)</td>
<td>16.91 (1.55)$^b$</td>
<td>28.91 (1.71)$^c$</td>
<td>10.90 (1.68)$^a$</td>
<td>13.14 (1.52)$^A$</td>
<td>24.86 (2.35)$^B$</td>
<td>13.56 (1.10)$^A$</td>
</tr>
<tr>
<td>Soluble</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sucrose</td>
<td>9.99 (1.21)$^a$</td>
<td>16.78 (1.67)$^b$</td>
<td>15.83 (2.34)$^{ab}$</td>
<td>13.02 (2.56)$^A$</td>
<td>27.00 (2.91)$^{B}$</td>
<td>19.08 (2.12)$^A$</td>
</tr>
<tr>
<td>Glucose</td>
<td>4.67 (0.42)$^a$</td>
<td>14.04 (3.49)$^b$</td>
<td>6.92 (1.54)$^a$</td>
<td>7.21 (0.84)$^A$</td>
<td>17.95 (1.83)$^{B}$</td>
<td>7.79 (1.52)$^A$</td>
</tr>
<tr>
<td>Fructose</td>
<td>3.26 (0.33)$^a$</td>
<td>11.64 (2.79)$^b$</td>
<td>5.67 (1.65)$^a$</td>
<td>6.07 (0.60)$^A$</td>
<td>15.58 (2.51)$^{B}$</td>
<td>6.51 (1.63)$^A$</td>
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<tr>
<td>Antirrhinoside</td>
<td>1.97 (0.16)$^a$</td>
<td>10.17 (1.87)$^b$</td>
<td>8.46 (1.46)$^b$</td>
<td>3.05 (0.67)$^A$</td>
<td>13.66 (0.91)$^{B}$</td>
<td>9.07 (1.89)$^B$</td>
</tr>
<tr>
<td>Antirrhide</td>
<td>1.30 (0.16)$^a$</td>
<td>4.61 (0.97)$^b$</td>
<td>2.30 (0.33)$^a$</td>
<td>1.93 (0.38)$^A$</td>
<td>5.01 (0.48)$^{B}$</td>
<td>3.56 (0.49)$^{AB}$</td>
</tr>
<tr>
<td>Mannitol</td>
<td>Nd (Nd)</td>
<td>0.31 (0.08)</td>
<td>Nd (Nd)</td>
<td>Nd (Nd)</td>
<td>0.51 (0.05)</td>
<td>Nd (Nd)</td>
</tr>
<tr>
<td><strong>$^{14}$C-Petiole (%-label)</strong></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Sugars</td>
<td>84.79$^{a^*}$</td>
<td>87.67$^{ab^*}$</td>
<td>90.24$^{b^*}$</td>
<td>90.07$^{B^*}$</td>
<td>83.20$^{A^*}$</td>
<td>85.86$^{AB^*}$</td>
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<tr>
<td>Sucrose</td>
<td>52.97$^b$</td>
<td>30.41$^{a^*}$</td>
<td>53.46$^b$</td>
<td>51.14$^B$</td>
<td>21.76$^{A^*}$</td>
<td>52.36$^B$</td>
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<tr>
<td>Antirrhinoside</td>
<td>15.21$^{b^*}$</td>
<td>12.39$^{ab^*}$</td>
<td>9.76$^{a^*}$</td>
<td>9.92$^{A^*}$</td>
<td>16.80$^{B^*}$</td>
<td>14.13$^{AB^*}$</td>
</tr>
</tbody>
</table>

Statistical analyses appended in Tables A.8.1 to A.8.9.
The $^{14}$C-sucrose to $^{14}$C-insoluble (starch) ratio increased at the highest temperature (Table 3.3). The activity of soluble starch synthases are reduced at elevated temperatures and often results in decreased starch synthesis (Jenner, 1994). The $^{14}$C-sucrose to $^{14}$C-antirrhinoside retained in leaves decreased at the two higher temperatures in both cultivars compared to $15^\circ$C (Table 3.3). The ratio of $^{14}$C-antirrhinoside to $^{14}$C-antirrhide was significantly higher at $35^\circ$C when compared to the lower temperatures in the GI cultivar. However, in the GIV cultivar the $^{14}$C-antirrhinoside to $^{14}$C-antirrhide ratio was the highest at the growth temperature (Table 3.3). The ratio of $^{14}$C-sucrose to $^{14}$C-antirrhinoside was the lowest at the growth temperature in both cultivars. The $^{14}$C-ratio was the highest at $35^\circ$C in the GI cultivar and were the highest at $15^\circ$C in the GIV cultivar (Table 3.3).

Table 3.3. The effect of temperature on the ratio of $^{14}$C-partitioning among selected metabolite fractions in source leaves and the subtending petiole tissues of two greenhouse cultivars of A. majus (GI, GIV). Each value represents the mean of a minimum 6 replicates. The values in parentheses represent ± se for each mean. Letters (a, b, c) and (A, B, C) indicate statistical differences ($\alpha=0.05$) for leaf parameters within a row for temperature treatments for the GI and the GIV cultivar, respectively. Symbols (*) indicate statistical differences ($\alpha=0.05$) between cultivars.

<table>
<thead>
<tr>
<th>Ratios</th>
<th>GI</th>
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<tr>
<td></td>
<td>15°C</td>
<td>25°C</td>
<td>35°C</td>
<td>15°C</td>
</tr>
<tr>
<td>$^{14}$C-Leaf Tissues</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sucreose:Insoluble</td>
<td>0.64 (0.13)$^a$</td>
<td>0.60 (0.08)$^a$</td>
<td>1.87 (0.27)$^b$</td>
<td>0.99 (0.13)$^A$</td>
</tr>
<tr>
<td>Sucreose:Antirrhinoside</td>
<td>5.09 (0.38)$^b$</td>
<td>2.25 (0.60)$^a$</td>
<td>2.18 (0.18)$^a$</td>
<td>4.50 (0.43)$^B$</td>
</tr>
<tr>
<td>Antirrhinoside:Antirrhide</td>
<td>1.57 (0.14)$^a$</td>
<td>2.40 (0.40)$^a$</td>
<td>3.64 (0.53)$^b$</td>
<td>1.61 (0.12)$^A$</td>
</tr>
<tr>
<td>$^{14}$C-Petiole</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Sucreose:Antirrhinoside</td>
<td>3.70 (0.56)$^a$</td>
<td>2.58 (0.30)$^a$</td>
<td>6.94 (2.02)$^b$</td>
<td>5.34 (0.57)$^B$</td>
</tr>
</tbody>
</table>

Statistical analyses appended in Tables A.9.1 to A.9.4.
3.4.2 The effects of varying short-term CO\(_2\) and O\(_2\) levels on *A. majus* at 35°C

3.4.2.1 The effects of CO\(_2\) and O\(_2\) on leaf photosynthesis, WUE and \(^{14}\)C-export rate at 35°C

Tables 3.4, shows how altering the levels of atmospheric CO\(_2\) and O\(_2\) in favour of the carboxylation reaction of Rubisco affects primary water and CO\(_2\) gas exchange and export of the two snapdragon cultivars, GI and GIV, when exposed to 35°C. A short-term CO\(_2\) level of 91 Pa was chosen since this level of CO\(_2\) should be sufficient to increase the carboxylation efficiency of Rubisco. From a commercial standpoint, CO\(_2\) enrichment is a commonly used greenhouse commercial practice and CO\(_2\) levels are often enriched up to 100 Pa (Kramer, 1981; Porter and Grodzinski, 1985; Leonardos and Grodzinski, 2011; Blom et al., 2012). In addition, 70 to 100 Pa CO\(_2\) is the range predicted for the next 50 to 100 years due to global warming. The O\(_2\) level was reduced to 2 kPa, which is a level known to inhibit photorespiration without affecting mitochondrial respiration. Leaf photosynthesis significantly increased with short-term CO\(_2\) enrichment (Table 3.4). Lowering the O\(_2\) level from 21 kPa to 2 kPa O\(_2\) further increased photosynthesis (Table 3.4). Leaf WUE was significantly higher under enriched CO\(_2\) conditions in part due to reduced transpiration rates for both cultivars. Exposure to 2 kPa O\(_2\) at 40 Pa CO\(_2\) did not alter the transpiration rate (Table 3.4). No significant differences were apparent for the export rate between short-term conditions in the GI cultivar; however the export rate was significantly higher during enriched CO\(_2\) and low O\(_2\) exposure in the GIV cultivar (Table 3.4). A higher WUE was seen in the GI cultivar due to a lower transpiration rate under ambient conditions when compared to the GIV cultivar. The GI cultivar had a higher photosynthetic and export rate under short-term CO\(_2\) enrichment than the GIV cultivar (Table 3.4).

3.4.2.2 The effects of CO\(_2\) and O\(_2\) on leaf \(^{14}\)C-partitioning at 35°C

Table 3.5 shows \(^{14}\)C-partitioning in source leaves of the GI and GIV cultivars at 35°C when CO\(_2\) and O\(_2\) were altered. \(^{14}\)C-Partitioning into sucrose and the ethanol-soluble fraction (starch) both increased under short-term enriched CO\(_2\) conditions and
with low O$_2$ exposure (Table 3.5). $^{14}$C-Partitioning into antirrhinoside in source leaves increased under short-term and low O$_2$ exposure in both cultivars. $^{14}$C-partitioning into antirrhinoside in the GI V cultivar was the highest during the most non-photorespiratory condition when export was significantly increased (Table 3.4; Table 3.5). More $^{14}$C was retained as antirrhide in both the GI and the GI V cultivars under low O$_2$ conditions at either CO$_2$ treatment (Table 3.5). The % $^{14}$C-partitioned into sugars, sucrose, and antirrhinoside in the subtending petiole tissues are shown in Table 3.5. The % $^{14}$C in antirrhinoside decreased relative to sucrose when leaves were exposed to 2 kPa O$_2$ in petiole tissues (Table 3.5).

Table 3.6 shows the ratios between $^{14}$C-partitioning into metabolites and fraction in leaf and petiole tissues. The $^{14}$C-sucrose to $^{14}$C-insoluble (starch) ratios decreased when leaves were exposed to enriched CO$_2$ and low O$_2$ treatments when compared to the ambient condition (Table 3.6). The $^{14}$C-sucrose to $^{14}$C-antirrhinoside ratio retained in leaves was higher during exposure to low O$_2$. The $^{14}$C-antirrhinoside to $^{14}$C-antirrhide ratio was lower when leaves were exposed to low O$_2$ (Table 3.6). The % $^{14}$C-sucrose to $^{14}$C-antirrhinoside ratios in petioles increased during exposure to low O$_2$ treatments (Table 3.6).
**Table 3.4.** The effect of short-term CO$_2$ enrichment and low O$_2$ exposure on leaf WUE, transpiration, leaf NCER, and export of two greenhouse cultivars of *A. majus*. Source leaves were assayed under 40 Pa and 91 Pa CO$_2$ and 21 and 2 kPa O$_2$ treatments at 35°C. Each value represents the mean of 4 to 6 replicates. The values in parentheses represent ± se for each mean. Letters (a, b, c, d) and (A, B, C, D) indicate statistical differences (α=0.05) for leaf parameters within a row for temperature treatments for the GI and the GIV cultivar, respectively. Symbols (*) indicate statistical differences (α=0.05) between cultivars.

<table>
<thead>
<tr>
<th>Plant Parameters</th>
<th>GI CO$_2$ (Pa) ; O$_2$ (kPa)</th>
<th>GIV CO$_2$ (Pa) ; O$_2$ (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photosynthesis (μmol C·m$^{-2}·$s$^{-1}$)</td>
<td>19.12 (0.79)$^a$ 24.17 (0.75)$^b$ 30.08 (1.19)$^c$ 37.83 (1.51)$^d$</td>
<td>20.18 (0.64)$^A$ 23.81 (1.28)$^B$ 26.45 (0.86)$^B$ 39.23 (1.87)$^C$</td>
</tr>
<tr>
<td>WUE (μmol C/ mmol H$_2$O)</td>
<td>5.12 (0.14)$^a$ 6.55 (0.06)$^b$ 10.30 (0.52)$^c$ 11.82 (0.15)$^d$</td>
<td>4.95 (0.04)$^A$ 6.36 (0.11)$^B$ 10.09 (0.23)$^C$ 12.88 (0.14)$^D$</td>
</tr>
<tr>
<td>Transpiration (mmol H$_2$O·m$^{-2}·$s$^{-1}$)</td>
<td>3.58 (0.24)$^b$ 3.69 (0.10)$^b$ 2.77 (0.06)$^a$ 3.20 (0.10)$^{ab}$</td>
<td>4.07 (0.11)$^B$ 3.74 (0.21)$^B$ 2.52 (0.05)$^A$ 3.05 (0.18)$^A$</td>
</tr>
<tr>
<td>Export (μmol C·m$^{-2}·$s$^{-1}$)</td>
<td>15.70 (1.20)$^a$ 14.43 (1.53)$^a$ 18.71 (1.22)$^A$ 18.04 (3.02)$^A$</td>
<td>13.01 (1.28)$^A$ 13.89 (1.12)$^A$ 14.44 (1.15)$^A$ 21.39 (0.98)$^B$</td>
</tr>
</tbody>
</table>

Statistical analyses appended in Tables A.10.1 to A.10.5.
Table 3.5. The effect of short-term CO$_2$ enrichment and reduced O$_2$ levels on $^{14}$C-partitioning among major assimilate pools in two greenhouse cultivars of *A. majus* (GI, GIV). Source leaves were assayed under 40 Pa and 91 Pa CO$_2$ and 21 and 2 kPa O$_2$ treatments at 35°C. Each value represents the mean of 4 to 6 replicates. The values in parentheses represent ± se for each mean. Letters (a, b, c, d) and (A, B, C, D) indicate statistical differences (α=0.05) for leaf parameters within a row for temperature treatments for the GI and the GIV cultivar, respectively. Symbols (*) indicate statistical differences (α=0.05) between cultivars. Data expressed as percentage were arcsine transformed prior to analysis. Values for percent data were back-transformed to the original scale.

<table>
<thead>
<tr>
<th>$^{14}$C-Partitioning</th>
<th>GI (CO$_2$ (Pa) ; O$_2$ (kPa))</th>
<th>GIV (CO$_2$ (Pa) ; O$_2$ (kPa))</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO$_2$ (Pa) ; O$_2$ (kPa)</td>
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<td>40 ; 2</td>
</tr>
<tr>
<td><strong>$^{14}$C-Leaf Tissues (mmol C·m$^{-2}$)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Insoluble (Starch)</strong></td>
<td>10.59 (1.90)$^a$</td>
<td>44.80 (6.09)$^b$</td>
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<tr>
<td><strong>Soluble</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sucrose</strong></td>
<td>15.84 (2.34)$^a$</td>
<td>40.19 (3.21)$^b$</td>
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<tr>
<td><strong>Antirrhinoside</strong></td>
<td>8.46 (1.46)$^a$</td>
<td>18.65 (1.56)$^b$</td>
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<tr>
<td><strong>Antirrhide</strong></td>
<td>2.30 (0.33)$^a$</td>
<td>13.02 (1.93)$^c$</td>
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<tr>
<td><strong>$^{14}$C-Petiole (%-label)</strong></td>
<td></td>
<td></td>
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<tr>
<td><strong>Sugars</strong></td>
<td>90.24 (0.33)$^{ab}$</td>
<td>92.81 (1.93)$^b$</td>
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<tr>
<td><strong>Sucrose</strong></td>
<td>53.46 (0.33)$^{ab}$</td>
<td>50.24 (1.93)$^a$</td>
</tr>
<tr>
<td><strong>Antirrhinoside</strong></td>
<td>9.76 (0.33)$^{ab}$</td>
<td>7.20 (1.93)$^a$</td>
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</table>

Statistical analyses appended in Tables A.11.1 to A.11.7.
Table 3.6. The effect of short-term CO₂ enrichment and reduced O₂ levels on ¹⁴C-partitioning ratios of selected metabolites of two greenhouse cultivars of A. majus (GI, GIV). Source leaves were assayed under 40 Pa and 91 PaCO₂ and 21 and 2 kPa O₂ treatments at 35°C. Each value represents the mean of 4 to 6 replicates. The values in parentheses represent ± se for each mean. Letters (a, b, c, d) and (A, B, C, D) indicate statistical differences (α=0.05) for leaf parameters within a row for temperature treatments for the GI and the GIV cultivar, respectively. Symbols (*) indicate statistical differences (α=0.05) between cultivars.

<table>
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<tr>
<th>Ratios</th>
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<td></td>
<td>CO₂ (Pa)</td>
<td>O₂ (kPa)</td>
<td>CO₂ (Pa)</td>
<td>O₂ (kPa)</td>
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<td>40 ; 21</td>
<td>40 ; 2</td>
<td>91 ; 21</td>
<td>91 ; 2</td>
</tr>
<tr>
<td>¹⁴C-Leaf Tissues</td>
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<td></td>
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<tr>
<td>Sucrose: Insoluble</td>
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<td>1.94</td>
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<td>(0.27)ₐ</td>
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<td>(0.11)ₐ</td>
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<tr>
<td></td>
<td>0.84</td>
<td>1.04</td>
<td>0.97</td>
<td>0.88</td>
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<td>(0.29)ₐ</td>
<td>(0.02)ₐ</td>
<td>(0.10)ₐ</td>
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<tr>
<td>Sucrose: Antirrhinoside</td>
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<td>1.96</td>
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<td>(0.18)ₐ</td>
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<td>2.81</td>
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<td>(0.21)ₐ</td>
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<td>(0.34)ₐ</td>
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<tr>
<td></td>
<td>3.64</td>
<td>1.34</td>
<td>2.34</td>
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</tr>
<tr>
<td></td>
<td>(0.53)ₜ</td>
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<td>(0.17)ₜ</td>
<td>(0.18)ₜ</td>
</tr>
<tr>
<td></td>
<td>2.13</td>
<td>0.95</td>
<td>2.09</td>
<td>1.08</td>
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<td>(0.15)ₜ</td>
<td>(0.06)ₜ</td>
<td>(0.13)ₜ</td>
<td>(0.02)ₜ</td>
</tr>
<tr>
<td>Antirrhinoside: Antirrhide</td>
<td>6.94</td>
<td>6.97</td>
<td>3.83</td>
<td>6.09</td>
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<tr>
<td></td>
<td>(2.02)ₜ</td>
<td>(2.02)ₜ</td>
<td>(0.52)ₜ</td>
<td>(1.35)ₜ</td>
</tr>
<tr>
<td></td>
<td>5.26</td>
<td>7.44</td>
<td>4.44</td>
<td>5.67</td>
</tr>
<tr>
<td></td>
<td>(0.67)ₜ</td>
<td>(0.91)ₜ</td>
<td>(0.30)ₕ</td>
<td>(0.44)ₕ</td>
</tr>
</tbody>
</table>

Statistical analyses appended in Tables A.12.1 to A.12.4.
3.4.3 The effects of three temperatures, two elevated CO₂ levels and a reduced O₂ level on leaf metabolism of *A. majus*

3.4.3.1 Temperature effects on leaf photosynthesis, WUE and ¹⁴C-export rates in during varying CO₂ and O₂ levels

A second series of ¹⁴C-labelling studies at light saturated levels were conducted to further examine how altering three temperatures (15°C, 25°C, and 35°C) and increasing carboxylation efficiency by manipulating the CO₂ and O₂ levels altered the ¹⁴C-fixation, export and partitioning particularly into sucrose versus the two IGs antirrhinoside and antirrhide. Figure 3.6 shows the leaf photosynthesis (A,B, and C), export (D, E, and F) and relative export rates (G, H, and I) in the GI cultivar exposed to 15°C, 25°C, and 35°C and assayed during three short-term CO₂ conditions, 40 Pa, 91 Pa, and 182 Pa, and exposed to 21 and 2 kPa O₂. Two short-term CO₂ enrichment treatments of 91 Pa and 182 Pa were chosen to maximize carboxylation efficiency of Rubisco and a low O₂ treatment of 2 kPa was selected to reduce photorespiration without affecting mitochondrial respiration. The plants were grown at 25°C. The photosynthetic rate was significantly higher at 25°C and 35°C compared to 15°C under all three CO₂ conditions. Under 91 and 182 Pa CO₂ the photosynthetic rate increased at the two higher temperatures compared to ambient CO₂ (Fig. 3.6A, B, and C). The photosynthetic rate increased under all three temperature conditions when leaves were exposed to low O₂ under ambient and 91 Pa CO₂ but not under 182 Pa CO₂.

The stomatal conductance (G) and the internal CO₂ concentration (Ci) at 25°C and 35°C were lower at 182 Pa CO₂; 2 KPa O₂ compared to 182 Pa CO₂; 21 kPa O₂ (data not shown). The export rate exposed to the three temperatures had a similar pattern to photosynthesis, as well as when plants were assayed under the three CO₂ conditions (Fig. 3.6D, E, and F). The export rate increased with short-term CO₂ enrichment from 40 to 91 Pa CO₂ by 15% and further increased when plants were assayed at 182 Pa CO₂ at 35°C; however, there were no further increases when photorespiration was further reduced with leaf exposure to low O₂ (Fig. 3.6D,E, and F). The relative export flux was maintained above 40% for all three temperatures when
assayed under the three CO₂ conditions and were exposed to low O₂ (Fig. 3.6G, H, and I). The relative export flux was lower when plants were assayed under enriched CO₂ conditions, but under 182 Pa CO₂ when leaves were exposed to 2 kPa O₂ the relative export rate increased at the two higher temperatures (Fig. 3.6G, H, and I). Panels in Figure 3.7 show parallel panels to Figure 3.6 for the GIV cultivar. Similar patterns were observed for the GIV cultivar for leaf photosynthetic rates as in the GI cultivar (Fig. 3.6A, B, and C), with the exception that under 182 Pa CO₂ and leaf exposure to 2 kPa O₂ the photosynthetic rate was higher than at exposure to 21 kPa O₂ (Fig. 3.7.A, B, and C). The GCO₂ and Ci were higher under low O₂ exposure compared to ambient O₂ at 182 Pa CO₂ for source leaves of the GIV cultivar (data not shown). The export rate and relative export flux also showed similar patterns between the two cultivars with the exception that when GIV leaves were assayed at 91 Pa CO₂ and exposed to low O₂ at 35°C export rate significantly increased compared to ambient O₂ exposure (Fig. 3.7.D-I).

Panels in Figure 3.8 show the leaf transpiration rate (A, B, and C) and WUE (D, E, and F) of the GI cultivars exposed to 15°C, 25°C, and 35°C and assayed under 40, 91, and 182 Pa CO₂ conditions and exposed to 21 and 2 kPa O₂. Transpiration significantly increased with each temperature treatment and decreased with increased CO₂ conditions (Fig. 3.8.A, B, and C). WUE decreased with each temperature interval, and increased with increased CO₂ conditions and was further increased during exposure to 2 kPa O₂ (Fig. 3.8.D, E, and F). Panels in Figure 3.9 show parallel panels for leaf transpiration rates and WUE for the GIV cultivar to Figure 3.8. Similar trends were observed for the GIV cultivar to the GI cultivar (Fig. 3.8D, E, and F).

3.4.3.2 Temperature effects on ¹⁴C-partitioning during varying CO₂ and O₂ levels

Panels in Figure 3.10 show that the amount of ¹⁴C-sucrose (A, B, and C), ¹⁴C-insoluble (starch) (D, E, and F) and the ¹⁴C-sucrose to ¹⁴C-insoluble (starch) ratio (G, H, and I) retained in source leaves of the GI cultivar exposed to 15°C, 25°C, and 35°C assayed under 40, 91, and 182 Pa CO₂ conditions exposed to 21 and 2 kPa O₂. When plants were assayed under the ambient CO₂ condition the amount of sucrose retained
was the highest at the growth temperature; however, when leaves were exposed to low O$_2$ there was a significant increase in the amount of $^{14}$C-sucrose retained during all temperature treatments (Fig. 3.10A). Under 91 and 182 Pa CO$_2$ enrichment, the amount of sucrose retained increased at the two higher temperatures (Fig. 3.10B and C). When leaves were exposed to 2 kPa O$_2$ the amount $^{14}$C-sucrose increased for all temperature treatments during 91 Pa CO$_2$ (Fig. 3.10A, B, and C). During 182 Pa and low O$_2$ exposure at 35°C, the amount $^{14}$C-sucrose did not increase when compared to 21 kPa O$_2$ exposure (Fig. 3.10C). The amount of $^{14}$C-insoluble (starch) retained increased with increased CO$_2$ treatments and at the higher temperate treatments (Fig. 3.10D, E, and F). $^{14}$C-insoluble (starch) further increased during low O$_2$ exposure during 40 and 91 Pa CO$_2$; however it decreased during 35°C at 182 Pa CO$_2$. The $^{14}$C-sucrose to $^{14}$C-insoluble (starch) ratio increased with temperature under ambient conditions (Fig. 3.10G). When plants were assayed during 91 and 182 Pa CO$_2$ the $^{14}$C-sucrose to $^{14}$C-insoluble (starch) ratio was lower than during 40 Pa CO$_2$ at 35°C (Fig. 3.10G, H, and I). When leaves were exposed to 2 kPa under 40 Pa CO$_2$ the $^{14}$C-sucrose to $^{14}$C-insoluble (starch) ratio was similar to 21 kPa O$_2$ but was significantly lower at 35°C (Fig. 3.10G). When leaves were exposed to low O$_2$ under 91 and 182 Pa CO$_2$ the $^{14}$C-sucrose to $^{14}$C-insoluble (starch) ratio decreased with increased temperature (Fig. 3.10H and I). Panels in Figure 3.11 show parallel panels to Figure 3.10 for the GIV cultivar. Similar pattern were observed for the two cultivars for $^{14}$C-retained in sucrose and insoluble (starch) (Fig. 3.11A-F), with the exception that during 91 Pa CO$_2$ and exposure to low O$_2$ at 25°C the amount of $^{14}$C-retained in sucrose decreased compared to exposure at 21 kPa O$_2$ (Fig. 3.11C).

Panels in Figure 3.12 show the amount of $^{14}$C-antirrhinoside (A, B, and C), $^{14}$C-antirrhine (D, E, and F) and the $^{14}$C-antirrhinoside and $^{14}$C-antirrhine ratio (G, H, and I) retained in source leaves of the GI cultivar exposed to 15°C, 25°C, and 35°C assayed under 40, 91 and 182 Pa CO$_2$ and exposed to 21 and 2 kPa O$_2$. The amount of $^{14}$C-antirrhinoside retained increased at the two higher temperatures when plants were assayed at 40, 91 and 182 Pa CO$_2$ (Fig. 3.12A, B, and C). When leaves were exposed to low O$_2$ under 40 Pa CO$_2$ the amount of $^{14}$C-antirrhinoside significantly increased with each temperature interval, and was significantly higher under 2 kPa than under 21 kPa
O2 (Fig. 3.12A). 14C-partitioning into antirrhinoside increased during 91 Pa CO2 and was further increased under 182 Pa CO2, especially at 25°C and 35°C (Fig. 3.12B and C). During 91 Pa and 182 Pa CO2 when leaves were exposed to 2 Pa O2 the amount of 14C-antirrhinoside decreased at the two higher temperatures compared to exposure at 21 Pa O2, especially during 182 Pa CO2 (Fig. 3.12C). 14C-antirrhide retained in leaves was the highest at the growth temperature during ambient conditions between temperatures; however when leaves were exposed to 2 kPa O2, 14C-antirrhide increased at 25 and 35°C (Fig. 3.12D). 14C-antirrhide retained in leaves increased with CO2 enrichment and was further increased with low O2 during 91 Pa CO2 (Fig. 3.12D and E). This increase was not seen during 182 Pa CO2 at low O2 exposure (Fig. 3.12F). At ambient O2 exposure the 14C-antirrhinoside to 4C-antirrhide ratio increased at the higher temperatures (Fig. 3.12G, H, and I). Exposure to 2 kPa O2 resulted in a lower 14C-antirrhinoside to 4C-antirrhide ratio compared to 21 kPa O2 exposure under all CO2 conditions at 25°C and 35°C (Fig. 3.12G, H, and I). Panels in Figure 3.13 are parallel to the panels shown in Figure 3.12 to the GIV cultivar. Similar patterns were observed between the two cultivars for 14C-retained in antirrhinoside and antirhhide during ambient O2 conditions; however during low O2 exposure the amount of antirrhinoside and antirhhide did not increase under short-term CO2 enrichment (Fig. 3.12; Fig. 3.13). The antirrhinoside and antirhhide ratios were similar to the ratios observed in the GI cultivar (Fig. 3.12; Fig. 3.13).

Panels in Figure 3.14 show the 14C-sucrose to 14C-antirrhinoside ratio in leaves (A, B, and C), and the %14C-sucrose to 14C-antirrhinoside ratio in petiole tissues (D, E, and F) in the GI cultivar at 15°C, 25°C, and 35°C assayed under 40, 91, and 182 Pa CO2 exposed to 21 and 2 kPa O2. The 14C-sucrose to 14C-antirrhinoside ratio in leaves was higher at the lowest temperature under all conditions (Fig. 3.14 A, B, and C) with the exception of under 182 Pa CO2 where a similar ratio was observed between temperatures (Fig. 3.14C). The % 14C-sucrose to 14C-antirrhinoside ratio in petiole tissues was significantly higher at 35°C under ambient CO2 and O2 conditions. Under 91 and 182 Pa CO2 as well as 21 and 2 kPa O2 the ratio recovered in the petiole was significantly lower at 25°C compared to 15°C and 35°C (Fig. 3.14E and F). Panels in Figure 3.15 show parallel panels to Figure 3.14 for the GIV cultivar. The 14C-sucrose to
\(^{14}\)C-antirrhinoside in leaves showed similar patterns for both cultivars for all temperatures and assayed conditions, with the exception that in 182 Pa CO\(_2\) the ratio of sucrose to antirrhinoside was similar between 15 and 35°C (Fig. 3.15A, B, and C). The \(^{14}\)C-sucrose to \(^{14}\)C-antirrhinoside in petioles was the highest at 15°C in the GIV cultivar. However, in all CO\(_2\) conditions the \(^{14}\)C-sucrose to \(^{14}\)C-antirrhinoside ratio was the lowest at 25°C (Fig. 3.15.E and F). Differences were observed for \(^{14}\)C-sucrose to \(^{14}\)C-antirrhinoside ratios in petioles between cultivars in that when leaves were exposed to low O\(_2\) under 91 Pa CO\(_2\) the ratio significantly increased at the two higher temperatures in the GIV cultivar compared to the GI cultivars but was higher in the GI cultivar at 15°C and 35°C (Fig. 3.14E and H; Fig. 3.15.E and H). In addition, under 182 Pa CO\(_2\) and low O\(_2\) the ratio in the petioles was significantly higher at 15°C in the GIV cultivar and was the highest at 15°C and 35°C in the GI cultivar (Fig. 3.14F and I; Fig. 3.15F and I).
Figure 3.6. The effect of temperature on leaf photosynthesis (A, B, and C), export rate (D, E, and F), and relative export rate (% of photosynthesis) (G, H, and I) of GI A. majus source leaves assayed under 40, 91, 182 Pa CO$_2$ and 21 and 2 kPa O$_2$. Each value represents the mean of 4 to 8 replicates. Data expressed as percentage were arcsine transformed prior to analysis. Values for percent data were back-transformed to the original scale. Statistical analyses appended in Tables A.13.1 to A.13.9.
### Relative Export (% of Ps)

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<tr>
<td>25</td>
<td>40</td>
</tr>
<tr>
<td>35</td>
<td>60</td>
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### Temperature (ºC)

- 15
- 25
- 35

### Exports (mmol m⁻² s⁻¹)

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<th>Temperature(ºC)</th>
<th>Exports (mmol m⁻² s⁻¹)</th>
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### Photosynthesis (µmol m⁻² s⁻¹)

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<tr>
<th>Temperature(ºC)</th>
<th>Photosynthesis (µmol m⁻² s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>25</td>
<td>10</td>
</tr>
<tr>
<td>35</td>
<td>15</td>
</tr>
</tbody>
</table>

### CO₂ Concentrations

- 40 Pa CO₂
- 91 Pa CO₂
- 182 Pa CO₂

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**Note:** The data is presented in graphical form with various labels and annotations indicating statistical significances and trends.
Figure 3.7. The effect of temperature on leaf photosynthesis (A, B, and C), export rate (D, E, and F), and relative export flux (% of photosynthesis) (G, H, and I) of GIV A. majus source leaves assayed under 40, 91, 182 Pa CO₂ and 21 and 2 kPa O₂. Each value represents the mean of 4 to 8 replicates. Data expressed as percentage were arcsine transformed prior to analysis. Values for percent data were back-transformed to the original scale. Statistical analyses appended in Tables A.14.1 to A.14.9.
Figure 3.8. The effect of temperature on leaf transpiration (A, B, and C) and WUE (D, E, and F) of Gl A. majus source leaves assayed under 40, 91, 182 Pa CO₂ and 21 and 2 kPa O₂. Each value represents the mean of 4 to 8 replicates. Statistical analyses appended in Tables A.15.1 to A.15.6.
Figure 3.9. The effect of temperature on leaf transpiration (A, B, and C) and WUE (D, E, and F) of GI\textit{V}A. \textit{majus} source leaves assayed under 40, 91, 182 Pa CO\textsubscript{2} and 21 and 2 kPa O\textsubscript{2}. Each value represents the mean of a minimum of 4 to 8 replicates. Statistical analyses appended in Tables A.16.1 to A.16.6.
**Figure 3.10.** The effect of temperature on labelling of $^{14}$C-sucrose (A, B, and C), $^{14}$C-insoluble (starch) (D, E, and F), and the $^{14}$C-sucrose to $^{14}$C-insoluble (starch) ratio (G, H, and I) in G1 *A. majus* source leaves assayed under 40, 91, 182 Pa CO$_2$ and 21 and 2 kPa O$_2$. Each value represents the mean of 4 to 8 replicates. Statistical analyses appended in Tables A.17.1 to A.17.9.
Sucrose: Insoluble (Starch)

Temperature (ºC)
15 25 35

40 Pa CO₂

21 kPa O₂
2 kPa O₂

91 Pa CO₂

182 Pa CO₂
Figure 3.11. The effect of temperature on labelling of $^{14}$C-sucrose (A, B, and C), $^{14}$C-insoluble (starch) (D, E, and F), and the $^{14}$C-sucrose to $^{14}$C-insoluble (starch) ratio (G, H, and I) in GIV A. *majus* source leaves assayed under 40, 91, 182 Pa CO$_2$ and 21 and 2 kPa O$_2$. Each value represents the mean of 4 to 8 replicates. Statistical analyses appended in Tables A.18.1 to A.18.9.
Figure 3.12. The effect of temperature on m$^{14}$C-antirrhinoside (A, B, and C), $^{14}$C-antirrhide (D, E, and F), and the $^{14}$C-antirrhinoside to $^{14}$C-antirrhide ratio (G, H, and I) in Gl A. majus source leaves exposed to 40, 91, 182 Pa CO$_2$ and 21 and 2 kPa O$_2$. Each value represents the mean of 4 to 8 replicates. Statistical analyses appended in Tables A.19.1 to A.19.9.
Figure 3.13. The effect of temperature on $^{14}$C-antirrhinoside (A, B, and C), $^{14}$C-antirrhide (D, E, and F), and the $^{14}$C-antirrhinoside to $^{14}$C-antirrhide ratio (G, H, and I) in GIV A. majus source leaves assayed under 40, 91, 182 Pa CO$_2$ and 21 and 2 kPa O$_2$. Each value represents the mean of 4 to 8 replicates. Statistical analyses appended in Tables A.20.1 to A.20.9.
Figure 3.14. The effect of temperature on the ratio of $^{14}$C-sucrose to $^{14}$C-antirrhinoside in source leaves (A, B, and C), in subtending petiole tissues (D, E, and F) of GI A. majus assayed under 40, 91, 182 Pa CO$_2$ and 21 and 2 kPa O$_2$. Each value represents the mean of 4 to 8 replicates. Statistical analyses appended in Tables A.21.1 to A.21.
Figure 3.15. The effect of temperature on the ratio of $^{14}$C-sucrose to $^{14}$C-antirrhinoside in source leaves (A, B, and C), in subtending petiole tissues (D, E, and F) of GIV A. *majus* assayed under 40, 91, 182 Pa CO$_2$ and 21 and 2 kPa O$_2$. Each value represents the mean of 4 to 8 replicates. Statistical analyses appended in Tables A.22.1 to A.22.6.
3.5 Discussion

3.5.1 The effects of temperature on whole plant and leaf metabolism in *A. majus*

Many F₁ hybrid cultivars of *A. majus* have been developed for year round cut-flower production, (Rogers, 1992). Two climate response cultivars, including the winter (GI) cultivar, Maryland Ivory White, and the summer (GIV) cultivar, Protomac Ivory White, were investigated. Plants were exposed to three different temperature conditions at the whole plant and leaf levels to relate photosynthesis, export rate, and ¹⁴C-partitioning into major metabolites, including the IGs, antirrhinoside and antirrhide.

As noted in Chapter 2, generally the photosynthetic rate of an individual leaf expressed on an area basis exceeds the photosynthetic potential of the whole plant because of two factors. First, gas exchange of the whole organism includes gas exchanges of the reproductive structures, stems, and roots all of which will be respiring CO₂. Second, mutual shading of lower leaves in a canopy can easily account for less than maximal rates of C-fixation during photosynthesis predicted solely on a leaf area basis. However, whole plant and leaf photosynthesis were quite similar in *A. majus* plants, due to a young canopy and the lack of mutual shading, indicating that the leaf was a good representative of the whole plant (Fig. 3.4).

There were significant differences between cultivars during all temperature conditions; the GIV cultivar had higher whole plant photosynthesis (Table 3.1). Previous greenhouse studies found that the GIV cultivar is more vigorous in both the winter and summer seasons, especially during high light conditions (Gutierrez, 2003). Dark respiration was also significantly higher in the GIV cultivar; however C-gain was higher and therefore resulted in significantly higher net C-budgets for the GIV cultivar over a 24 h period compared to the GI cultivar (Table 3.1).

Leaf photosynthesis was significantly higher at 25°C and 35°C compared to 15°C concurrent with an increased export rate at 25°C and 35°C in both cultivars (Fig. 3.5B and C). Earlier studies showed that there is a high linear correlation between leaf photosynthesis and export rate under ambient CO₂ conditions (Grodzinski et al., 1998).
Both cultivars were able to maintain high rates of export and photosynthesis at 35°C when WUE drastically decreased with increased temperature (Fig. 3.5B and C). The relative export flux was also maintained under the three temperature conditions for both cultivars, ranging from 62-76% (Fig. 3.5D). These maximum relative export rates are similar to ones previously reported by Cloutier (2008) and Ortiz Uribe (2007) *A. majus* plants at the vegetative stage. Higher leaf temperatures generally increase the sugars to starch ratio (Stitt and Grosse 1988, Jiao and Grodzinski 1996). At the higher leaf temperatures less $^{14}$C-insoluble (starch) accumulated and more $^{14}$C-label appeared in the soluble fraction (Table 3.3). Partitioning into sucrose, glucose, and fructose decreased at 35°C; however, no reduction in the partitioning of antirrhinoside was observed in the GIV cultivar (Table 3.2). In the GI cultivar both sucrose and antirrhinoside were similar at the two higher temperatures (Table 3.2). Voitsekhovskaja et al. (2006) has proposed the role of antirrhinoside to be an osmoregulator. It may be that the accumulation of antirrhinoside at high temperatures adjusted the water balance and maintained the photosynthetic and export rates during adverse conditions.

Mannitol accumulated in small amounts in *A. majus* source leaves as seen in previous studies (Campos Núñez, 1994; Moore et al, 1997; Cloutier, 2008). Sucrose was the main exported metabolite in both *A. majus* cultivars and exceeded antirrhinoside under all temperature treatments. However, a significant amount of the $^{14}$C-was partitioned into antirrhinoside in petiole tissues. Interestingly, the % of $^{14}$C-labeled antirrhinoside in petioles increased for the GIV cultivar at 25°C and 35°C whereas the highest % in $^{14}$C-antirrhinoside was found at 15°C in the GI cultivar (Table 3.4). These results may indicate that the GI cultivar recommended for short days, low light, and low night temperatures (Rogers, 1992) may favour the transport of sucrose at the higher temperatures and the transport of antirrhinoside at the low temperature. On the other hand the data indicates that the GIV cultivar recommended for long days, high light, and warm night temperatures (Rogers, 1992) may favour the transport of antirrhinoside at the higher temperatures and sucrose at the low temperature. It may be that the two cultivars transport different metabolites under high and low temperatures to maintain homeostasis.
As stated above, previous studies showed that the GIV cultivar is more vigorous than the GI cultivar and thus has higher photosynthetic rates as well as C-gain that was observed in the above whole plant studies (Gutierrez, 2003; Cloutier, 2008). Both cultivars retained similar levels of antirrhinoside in source leaves. Due to the non-reducing nature and high water solubility of antirrhinoside, this IG can be stored and transported with no adverse effects to plant cells (Gowan et al., 1995). As stated in the Introduction (Chapter 1), antirrhinoside is synthesized and transported in other members of the Plantaginaceae: *A. scandens* and *A. barclaiana*. However these studies were not conducted under different temperature conditions (Gowan et al., 1995; Voitsekhovskaja et al., 2006). Voitsekhovskaja et al. (2006) found antirrhinoside to be located mainly in vacuoles, but also to be present in the cytoplasm and chloroplast of *A. barclaiana*. This study also found that the concentration of antirrhinoside was six times higher in the phloem sap than the cytoplasm of mesophyll cells and concluded that the loading of antirrhinoside in *A. barclaiana* is apoplastic.

Voitsekhovskaja et al. (2006) examined aphid stylet exudates of *A. barclaiana* and found high concentration of antirrhinoside. Turgeon and Wolf (2009) stated that the high concentration of antirrhinoside in phloem tissues of *A. barclaiana* may have been induced by aphid feeding on the phloem sap. To avoid plant defense in sealing of the phloem aphids inject saliva and may modify the phloem composition. In addition, aphids stimulate callose formation, induce alterations in gene expression and alter phloem content to increase the quality of the phloem sap (Turgeon and Wolf, 2009). On the other hand, Gowan et al. (1995) used EDTA to confirm that antirrhinoside is present in the phloem sap of *A. scandens*. EDTA is toxic to plants in the light and interferes with the export rate. In addition, it relaxes the tissues and causes the leakage of hexoses from non-phloem cells (Turgeon and Wolf, 2009). The labelling studies in this thesis confirm that antirrhinoside is made and transported in *A. majus* and does not suffer from alterations by aphid feeding or the introduction of artifacts due to EDTA.

According to Gamalei (1991) *A. majus* has a type 2b minor vein configuration, a closed phloem system with transfer cells as companion cells. This indicates that phloem loading in *A. majus* is apoplastic. Currently, very little is known about the role of
antirrhinoside and its mobility; however as illustrated by whole plant and leaf studies newly fixed $^{14}$C was partitioned into antirrhinoside as well as sucrose in both the laminar and petiole tissues. Temperature altered the pattern of partitioning in a cultivar specific manner and thus it may be that this IG may have a role in acclimation responses to varying temperature conditions. The accumulation of antirrhinoside at higher temperatures may maintain homeostatic conditions and the cultivar specific transport of antirrhinoside and sucrose, during different temperature treatments, may contribute to temperature acclimation.

3.5.2 The effects of varying short-term CO$_2$ and O$_2$ levels on _A. majus_ at 35°C

Since $^{14}$C-partitioning into antirrhinoside increased at the two higher temperatures the objective of this section was to examine the effect of altered CO$_2$ and O$_2$ conditions on the two _A. majus_ cultivars at 35°C. During high temperatures photorespiration can decrease the net productivity of photosynthesis by 20-50% (Long et al., 2004; Brooks and Faraquar, 1985; Jiao and Grodzinski, 1996). Photorespiration can be reduced by increasing CO$_2$ or decreasing O$_2$ concentrations which will increase the carboxylation efficiency of Rubisco and decrease the flux of carbon through the glycolate pathway. Photosynthesis increased under all non-photorespiratory conditions from the ambient condition in both _A. majus_ cultivars. Exposing source leaves to low O$_2$ increased photosynthesis by 20-26% whereas increasing the CO$_2$ concentration to 91 Pa increased photosynthesis by 31-57%. Decreasing O$_2$ levels and also increasing CO$_2$ concentrations increased photosynthesis by 94-97% (Table 3.4). The transpiration rate during short-term CO$_2$ enrichment decreased due to stomatal closure, this decrease in transpiration rate was not observed during low O$_2$ exposure. Even though photosynthesis and the WUE efficiency increased with each non-photorespiratory conditions, the export rate did not increase at 35°C (Table 3.4). In the GI cultivar the export rate was higher during enriched CO$_2$ conditions; however this was not significant whereas in the GIV cultivar the export rate was significantly higher at the least non-photorespiratory condition compared to the other treatments. Increase in starch usually occurs during short-term CO$_2$ enrichments and low O$_2$ exposure (Farrar and Williams, 1991). During non-photorespiratory conditions less newly fixed CO$_2$ was partitioned in
sucrose relative to the ethanol-insoluble fraction (starch) thus A. *majus* was not able to export the increased carbon that was fixed. In addition, previous studies have shown that the optimum temperature window is narrower for export than photosynthesis (Jiao and Grodzinski, 1996). It is important to note that during low O\(_2\) exposure at both CO\(_2\) conditions the amount of antirrhinoside in petiole tissues decreased suggesting that the transport of sucrose is favoured over antirrhinoside.

Beninger et al., (2007) found that the IG, antirrhide, is only found within the leaves, in smaller quantities than antirrhinoside. It is known that the IG, aucubin, is the precursor for the IG, catalpol, however; no studies have been conducted concerning the inter-conversion of antirrhinoside and antirrhide (Marak et al., 2000). During 2 kPa O\(_2\) exposure the amount \(^{14}\text{C}\)-retained in antirrhide was higher than during exposure at 21 kPa O\(_2\) in the GI cultivar (Table 3.5). The \(^{14}\text{C}\)-antirrhinoside to \(^{14}\text{C}\)-antirrhide ratio was also lower during low O\(_2\) exposure and the \(^{14}\text{C}\)-sucrose to \(^{14}\text{C}\)-antirrhinoside ratio increased during low O\(_2\) exposure in source leaves of the two cultivars (Table 3.6). It is also important to note that the amount of antirrhinoside did not increase in the petiole during low O\(_2\) exposure indicating that the decrease in antirrhinoside to antirrhide ratio is not due to an increase in export of antirrhinoside from source leaves (Table 3.5; Table 3.6). It may be that during low O\(_2\) exposure at high temperatures the storage of antirrhide was favoured in A. *majus*. The full biochemical synthesis of antirrhinoside and antirrhide are unknown. Antirrhide may be the precursor to or an intermediate in the synthesis of antirrhinoside or they may have a common precursor. It remains to be tested if the conversion of antirrhide to antirrhinoside involves two to three steps that are catalysed by monooxygenases or dioxygenases that require oxygen (Hedden and Kamitya, 1997). It may be that during exposure to 2 kPa O\(_2\) enzymes do not readily convert antirrhide to antirrhinoside because O\(_2\) is limiting enzymatic steps necessary for their conversion. In attempting to modulate the activity of Rubisco by lowering the atmospheric level of molecular oxygen the oxygenation reactions involved in terpenoid synthesis may have been inadvertently altered. In addition, the site of synthesis of iridoid precursors are proposed to be the internal phloem parenchyma cells in *C. roseus*, which are deep in tissues where oxygen may become a limiting metabolite (Gue-Flores et al., 2012). Voitsekhovskaja et al. (2006) has shown that antirrhinoside
accumulates in vacuoles in *A. barclaiana*. Currently, the subcellular site of accumulation of antirrhinoside and antirrhide is unknown as is the pathway for the synthesis and metabolism of these IGs.

### 3.5.3 Temperature effects on *A. majus* during varying CO₂ and O₂ levels

To further investigate the effects of short-term CO₂ and low O₂ at different temperatures on leaf photosynthesis, $^{14}$C-export rate, and $^{14}$C-partitioning into sucrose and IG patterns a series of temperature studies at 15°C, 25°C, and 35°C were conducted where the GI and the GIV cultivars were assayed under 40, 91, and 182 Pa CO₂ and 21 and 2 kPa O₂. The leaf photosynthetic rate of both cultivars increased with non-photorespiratory conditions, however at 182 Pa and ambient and low O₂ leaf photosynthesis in GI leaves was similar and did not increase with reduced O₂ (Fig. 3.6G, D, and A). It is likely that stomatal closure occurred since stomatal conductance decreased by 25% during 21 kPa to 2 kPa O₂ exposure at 182 Pa CO₂. This decrease in stomatal conductance and leaf photosynthesis was not observed in the GIV cultivar during 182 Pa CO₂ and 2% O₂ (Fig. 3.7A). The export rate increased and was maintained during short term CO₂ and low O₂ exposure and the relative export rate was always above 40%.

At ambient CO₂ the amount of antirrhinoside increased at the higher temperatures in both cultivars. More antirrhinoside was generally partitioned in source leaves at the higher temperatures during enriched CO₂ at 21 and 2 kPa O₂ conditions (Fig. 3.14A, B, and C). The accumulation of antirrhinoside in source leaves at higher temperatures indicates that the accumulation and export of antirrhinoside in source leaves may have contributed to maintaining homeostasis in *A. majus* in sustaining photosynthetic and export rates when WUE was decreased. A previous study by Jiao and Grodzinski (1996) suppressed photorespiration in *Salvia splendens* by increasing CO₂ to 180 Pa and lowering O₂ to 2 kPa and found that at 40°C photosynthesis was maintained; however, export was reduced. In Salvia, which is a member of the mint family, transport of auxiliary sugars of the raffinose series occurs. Loading is thought to
be via a symplastic route and high leaf temperatures might affect phloem loading differently in *S. splendens* than in *A. majus*.

In the previous section (Table 3.6) the $^{14}$C-antirrhinoside to $^{14}$C-antirrhide ratio decreased during low O$_2$ exposure at 35°C. This was also observed during 40, 91 and 182 Pa CO$_2$ conditions at 25°C and 35°C (Fig. 3.10 – Fig. 3.13). This further indicates that the accumulation of $^{14}$C-antirrhide was favoured under low O$_2$ exposure at 25°C and 35°C especially in the GI cultivar. Once again this raises questions about the site of antirrhide storage of and the biochemical pathway involved in the regulation of these two IGs.

The extent that auxiliary sugars, such as IGs, contribute to the translocation rate in higher plants is not known (Grodzinski, et al., 1998, Noiraud, et al., 2001, Voitsekhovskaja, et al., 2007; Reidel, et al., 2009). Mannitol in *A. majus* was not heavily $^{14}$C-labelled and does not readily contribute to export (Campos Núñez, 1994; Moore, et al., 1997; Cloutier, 2008). On the other hand the IGs, antirrhinoside and antirrhide, were readily labeled in *A. majus* source leaves. During all conditions the major transport product in the two *A. majus* cultivars was sucrose; however, antirrhinoside was transported along with sucrose in the phloem tissues.
CHAPTER 4

Gas exchange, water use efficiency, export and $^{14}$C-labelling patterns of two iridoid glycosides in CO$_2$ acclimated $A$. $majus$ plants

4.1 Abstract

Two cultivars, GI and GIV, of $A$. $majus$ were grown and assayed under 40 Pa CO$_2$ (Control-1 (40=>$40$)) and 91 Pa CO$_2$ (Control-2 (91=>$91$)). Whole-plant and leaf photosynthesis, $^{14}$C-export rates and $^{14}$C-partitioning patterns among major photo-assimilates were determined. In addition to measuring traits at both growth conditions plants were transferred for a short-term analysis termed a transient switch (TS) at the reciprocal CO$_2$ level (i.e., (TS1 (40=>$91$)) and at 40 Pa CO$_2$ (TS2 (91=>$40$)). In the Control-2 (91=>$91$) treatment leaf and whole-plant gas exchanges were similar indicating minimal mutual shading. Both leaf and whole-plant photosynthetic rates in the Control 2 (91=>$91$) treatment were lower than in the TS1 (40=>$91$) GI cultivar, but not in the GIV cultivar. However, during acclimation to high CO$_2$ (Control 2 (91=>$91$)) export rates of both cultivars were higher than those of all other treatments reflecting the increase in sink demand during long-term high CO$_2$ acclimation. Also, the immediate export rate relative to C-fixation of both cultivars was about 75% for both the Control 2 (91=>$91$) and TS2 (91=>$40$) treatments in both cultivars. The amount of $^{14}$C-partitioned into major IGs was similar under ambient and enriched CO$_2$ growth; however the sucrose to antirrhinoside ratio was lower in both the Control 2 (91=>$91$) and TS2 (91=>$40$) treatments due to decreased $^{14}$C-partitioning into sucrose. An increased percentage of $^{14}$C-sucrose was observed in petiole tissues during long-term CO$_2$ conditions. These results indicate that whole plant sink demand was met by the increased export rate during long-term CO$_2$ enrichment. In addition, $^{14}$C-partitioning and export rate were altered during short and long-term CO$_2$ enrichment.

4.1 Introduction

In Chapter 3 two greenhouse cultivars of $A$. $majus$, cultivars were exposed to short-term temperature, CO$_2$ and low O$_2$ conditions. The amount of labelling of IGs
from newly fixed $^{14}$CO$_2$ and the sucrose to IG ratios, as well as the antirrhinoside to antirrhide ratios were altered by these conditions.

Longer term CO$_2$ enrichment has been understood for decades to improve plant photosynthesis by directly enhancing leaf carboxylation rates and indirectly, during long-term periods due to increased leaf area development in the photosynthetic canopy, supporting more trapping of light energy as well as enhancing C-allocation in support of developing sink tissues (Leonardos and Grodzinski, 2011; Jiao and Grodzinski, 1998). A very important reason for artificially enriching a greenhouse and controlled environments is simply to supply, in these closed environments a source of the primary plant nutrient (carbon in the form of CO$_2$). For this reason CO$_2$ enrichment is a commonly used greenhouse commercial practice (Kramer, 1981; Porter and Grodzinski, 1985; Leonardos and Grodzinski, 2011; Blom et al., 2012).

Studies from both the classical horticulture literature, as well as studies of environmental changes in climate, show that even though some species immediately respond to elevated CO$_2$ this response is species-specific and can be diminished under long-term CO$_2$ enrichment and growth (Sage et al., 1989; Farrar and Williams, 1991; Arp 1991; Makino and Mae, 1999; Long et al., 2004). Decreased rates of photosynthesis are observed when the photosynthetic rate exceeds the sink’s capacity to utilize photosynthetic products for growth (Stitt, 1991; Makino and Mae, 1999; Moore et al., 1999). Alterations in source capacity that allocate carbon to sinks and the ability of sinks to utilize carbon can lead to the accumulation of carbohydrates in source leaves. End product inhibition of photosynthesis occurs when sucrose accumulates in the cytosol, preventing P$_i$ recycling and leading to decreased ATP synthesis, which reduces RuBP regeneration, the activation of Rubisco activase and the conversion of PGA to TP (Sharkey and Vaderveer, 1989; Makino and Mae, 1999). Subsequently, key regulatory enzymes involved in photosynthesis may be down regulated due to long-term feedback inhibition of photosynthesis (Drake and González-Meler, 1997; Moore et al., 1997; Moore et al., 1999). This down regulation might be occurring when the acclimation of sucrose is perceived by sucrose cycling through the hydrolysis of sucrose by invertase to hexoses (Moore et al., 1999; Long et al., 2004). Hexose kinase
phosphorylates these hexoses for the resynthesis of sucrose (Long et al., 2004). A hexose sensing system could signal a source-sink imbalance because of an increased flux through hexokinase. This hexokinase signal might reduce Rubisco content through the down regulation of the small subunit of Rubisco by down regulating rbcL/S gene expression at levels of transcription, post-transcription, translation and post-translation (Long et al., 2004). Reduced transport of TP out of the chloroplasts may lead to accumulation of starch in the chloroplast.

Source-sink relationships are important and determine whether photosynthetic end-products, such as sucrose accumulate in source tissues or are exported to sinks (Arp, 1991). Source tissues can be defined as tissues that are net carbon exporters; fix carbon at a greater rate than they respire it. Sink tissues on the other hand are net carbon importers; fix less carbon than they respire and depend on source tissues for additional carbon. Sinks are generally considered to be the developing leaves, shoots, roots, fruits and seeds. Assimilate export rate has been reported to increase under enriched CO₂ growth in tomatoes; however, this increase was not seen in soybean or Phaseolus plants (Huber et al., 1984; Farrar and Williams, 1991). Grimmer and Komor (1999) found that leaf export of Ricinus communis L. was the same under 35 and 71 Pa CO₂ growth even though photosynthesis was higher in 71 Pa CO₂ grown plants during the light period.

Several studies have shown that export primarily occurs during the light period when photosynthesis is active (Leonardos et al., 2003; Kalt-Torrez, 1987). Leonardos et al. (2003) showed that winter wheat, a C₃ species, under CO₂ enrichment export the majority of the newly fixed C in the light. Kalt-Torrez et al. (1987) also showed that most of the C-fixed is exported during the day in maize, a C₄ species. The diurnal export rates in snapdragon are unknown. The alterations in source to sink balance will ultimately regulate C-partitioning under long-term CO₂ enrichment (Farrar and Williams, 1991).

As discussed in Chapter 2 with P. lanceolata and in Chapter 3 with A. majus numerous plant species transport other photoassimilates in addition to sucrose. In A. majus, which synthesizes the alcohol sugar, mannitol and the IGs, antirrhinoside and
antirrhide, are labelled during $^{14}$CO$_2$ feeding experiments (Beninger et al., 1997; Cloutier, 2008). Almost a decade earlier Moore et al. (1997) using $^{14}$CO$_2$ pulse-chase studies labelled mature leaves of non-flowering A. majus plants and noted slow labeling of mannitol and recovering trace amounts of $^{14}$C-mannitol in stem tissues under both ambient and high CO$_2$ growth conditions. They concluded that mannitol was not a major daytime contributor to export but rather a compatible solute (Moore et al. 1997). Our studies including those outlined above in Chapter 3 of this thesis seem to confirm this finding; namely that a small amount of $^{14}$CO$_2$ is partitioned to $^{14}$C-mannitol in laminar tissues and only trace amounts are recovered in subtending petioles (Cloutier, 2008). Moore et al. (1997) did show that leaves of A. majus grown under high CO$_2$ have significantly more glucose, fructose and starch compared to leaves of the ambient CO$_2$ grown control plants, but sucrose was not altered under enriched CO$_2$ growth conditions. Moore et al. (1997) did not report finding labelled IGs in their studies but did note a significantly labelled unknown constituent in leaf extracts. As shown previously we have noted that two IGs, antirrhinoside and antirrhide, are readily $^{14}$CO$_2$ labelled in leaves of a number of A. majus cultivars (Beninger et al., 2007).

In this chapter, two A. majus cultivars of the GI and GIV response groups that are recommended for greenhouse production cycles were used to compare the effects of short-term CO$_2$ exposure (introduced in Chapter 3) versus long-term CO$_2$ acclimation. In order to compare photosynthetic and export behaviour of source leaves under ambient and CO$_2$ enriched conditions. The A. majus model lines were examined in two ways. First, plants were $^{14}$CO$_2$ labelled at the CO$_2$ levels that they were raised in (controls). Populations were also tested at the reciprocal CO$_2$ level characterizing these as transient switch (TS) treatments of plants grown under ambient or elevated CO$_2$ but exposing plants to short-term high CO$_2$ or ambient CO$_2$ conditions. The treatments for each cultivar included: a Control 1 (40=>40): plants were grown at 40 Pa CO$_2$ and left at 40 Pa CO$_2$; TS 1 (40=>91): plants were grown at 40 Pa CO$_2$ and exposed to short-term enriched CO$_2$ at 91 Pa CO$_2$; Control 2 (91=>91): plants were grown at 91 Pa CO$_2$ and were left at 91 Pa CO$_2$; TS 2 (91=>40): plants were grown at 91 Pa CO$_2$ and exposed to short-term ambient, 40 Pa, CO$_2$. Whole plant and leaf studies of CO$_2$ gas exchanges and carbon gain were conducted and related to $^{14}$CO$_2$ steady-state labelling of source
leaves of vegetative plants. Carbon partitioning to photoassimilates was determined, as well as ¹⁴C-export rates and recovery of primary labelled metabolites in the subtending petiole tissues. The main objective of this chapter was to determine and compare how the synthesis and transport of the sugars and the IGs, antirrhinoside and antirrhide were altered in source leaves of GI and GIV A. majus plants during short and long-term CO₂ enrichment.

4.3 Materials and Methods

4.3.1 Plant material, whole plant gas exchange measurements, and ¹⁴CO₂ labeling

A. majus cultivars were sown and grown in controlled growth conditions to the vegetative stage as described in Chapter 3, section 3.1. Growth chambers (GC-20 Bigfoot series, BioChambers, Winnipeg, MB, Canada) were used to grow plants under ambient (40 Pa) and enriched (91 Pa) CO₂ conditions and were alternated between repetitions to reduce chamber effects. A description of whole plant gas exchange measurements of GIV vegetative plants at ambient CO₂ is given in Chapter 3, Section 3.2. Two vegetative A. majus plant were placed into each of the six chambers and repeated twice (n=12). A sample size of 12 (24 plants; 2 per chamber) were measured for NCER for each temperature treatment; however, only a sample size of 10 was measured for transpiration due to a malfunctioning balance. Whole plant gas exchange measurements were conducted for a 12 h photoperiod and 12 night period at 25°C for plants grown at ambient CO₂ (40 Pa) (Control 1 (40=>40)) and plants grown at 91 Pa CO₂ (Control 2 (91=>91)) in their environmental growth conditions. The same plants were also exposed to short-term conditions (TS) where plants grown at 40 Pa CO₂ were exposed to 91 Pa CO₂ (TS1 (40 =>91)) and plants grown at 91 Pa CO₂ were exposed to 40 Pa CO₂ (TS2 (91=>40)) and were measured for a 3 h period in the light.

Steady-state labelling of fully expanded axially leaves (node 4) of six different vegetative plants was conducted in the same manner as in Chapter 3, Section 3.3. During the 3h ¹⁴C-labeling the chamber air and cuvette temperature was maintained at 25°C. Axillary leaves from plants grown at 40 Pa CO₂ and 91 Pa CO₂ were both labelled under two CO₂ conditions, 40 Pa and 91 Pa CO₂ for treatments: Control 1
(40=>40), TS1 40=>91, Control 2 (91=>91) and TS 2 (91=>40). The \(^{14}\)CO\(_2\) specific activity was kept constant during the feeds. The \(^{14}\)CO\(_2\) specific activity varied from 0.21-0.52 kBq·µmol\(^{-1}\)C for the CO\(_2\) treatments. The leaf tissue seen by the GM detector in the cuvette and the petiole tissue outside the feed area were rapidly frozen in liquid nitrogen and stored in a -80°C freezer prior to extraction.

### 4.3.2 \(^{14}\)C-Partitioning

Frozen leaf and petiole samples were extracted and separated into different fraction as described in Chapter 2, Section 2.4. The radioactivity in the different fractions was counted by LSC. As in Chapter 3 the Supelcosil™ LC-NH\(_2\) amino column (4.6 X 250mm, 5µ particle size, Sigma-Aldrich, Canada Inc.) linked to a (Beckman Instrument Inc. Altex division) 118 solvent module with a refractive index detector and a fraction collector (LKB Broma 2111) was used to analyze \(^{14}\)C-partitioning of the ethanol soluble fraction to separate the two IGs, antirrhinoside and antirrhide from sucrose, glucose/mannitol, and fructose. The same rates and solvents were used as in Chapter 3. Calibration curves were obtained with \(r^2\) values that were greater than 0.9935 using concentrations from 0 to 4.10 mM sucrose 0 to 4.11 mM glucose and fructose, 0 to 8.23 mM for mannitol, 0 to 9.1 mM for antirrhinoside and 0 to 7.6 mM antirrhide. Samples were prepared and diluted or concentrated in the same fashion as in the previous chapter. Effluent was collected in a set of 60 scintillation vials (4-mL Omni vials; Wheaton Ltd., Millville, NJ, USA) and dissolved in 2.3 mL ES CytoSynt cocktail (MP Biomedicals Inc., Irving, CA, USA) and radioactivity was determined by LSC. The radioactivity remaining in the ethanol-insoluble (95% starch) was counted by LSC after samples were combusted in a biological oxidizer (Model OX300, R.J. Harvey Instrument Corp. Hillside, NJ, USA).

### 4.3.3 Statistical analyses

The experimental design for these studies was set up as a completely randomized design. Statistical analysis was carried out using statistical Analysis Software, version 9.3 (SAS Institute Inc., NC, USA). Parameters for A. majus plants
were performed by analysis of variance (ANOVA) using a general linear model (PROC GLM). To ensure assumptions for the two-way ANOVA were met, a test of residuals was performed using PROC UNIVARIATE. The Shapiro Wilkes test of residuals was computed to determine if the distributions were normal. To verify if outliers were present, standardized residuals were calculated and assessed against Lund’s critical value. Data expressed as percentage were transformed using arcsine square root prior to analysis. Data transformation, arcsine square root, was selected for the specific data sets as per recommendations from Bowley (1999). Values for percent data were back-transformed to the original scale. The standard errors of these means were not back-transformed and are not represented in tables or graphs since these statistics are not relevant on the original scale (Bowley, 1999). Two repetitions of six to five whole plant measurements were pooled according to Tukey’s t-test. Means ± se of 12 to 10 different plants for whole plant measurements were calculated. Means ± se of six independent leaves on different plants were calculated. Multiple comparisons (LSmeans, SAS) were used to obtain differences between treatments. Contrast and estimate statements were conducted to determine the magnitude of differences between cultivars.

4.4 Results

4.4.1 Long-term CO₂ and transient switch effects on whole plant and NCER, WUE and ¹⁴C-export rates in A. majus

Table 4.1 shows the canopy area and weight for the two A. majus cultivars grown at 40 and 91 Pa CO₂. No differences were observed in the canopy area between CO₂ conditions; however dry weight of both cultivars was significantly higher when grown at 91 Pa CO₂ compared to 40 Pa CO₂ (Table 4.1). Figure 4.1 shows daily patterns of whole plant transpiration, NCER, and C-budgets for a 24 hour period in GI and GIV A. majus plants that have been grown at 40 Pa and 91 Pa CO₂. Long-term CO₂ enrichment is a common practice in greenhouse cut flower production. Both cultivars during the two CO₂ growth conditions. Photosynthesis of ambient grown plants increased by 30% when plants were grown at 91 CO₂ (Fig. 4.1B and D). Significantly higher whole plant
photosynthetic rates were observed in the GIV cultivars with rates of 19.03 ± 0.44 and 27.53 ± 0.42 μmol C·m²·s⁻¹ for ambient and enriched CO₂ grown plants, respectively, when compared to the GI cultivar (Table 4.2). No significant differences were observed between 40 and 91 Pa CO₂ grown plants for dark respiration (Fig. 4.1F and H; Table 4.2). Whole plant WUE was significantly higher for enriched CO₂ grown plants compared to ambient grown plants in both cultivars (Table 4.2). WUE in the GIV cultivar grown during enriched CO₂ was significantly higher than in the GI cultivar (Table 4.2). Daily C-gain increased by more than 30% in both cultivars grown during enriched CO₂ compared to ambient grown plants (Fig. 4.1A-D; Table 4.2).

Table 4.1. Whole plant area and dry weight of two greenhouse cultivars of *A. majus* (GI, GIV) grown at 40 and 91 Pa CO₂. Each value represents the mean of 12 replicates. The values in parentheses represent ± se for each mean. Symbol (*) and (◊) indicate significant difference between cultivars during 40 Pa CO₂ and 91 Pa CO₂ enriched growth conditions, respectively. Letters (a, b) and (A, B) indicate significant differences between ambient and enriched growth conditions in the GI and the GIV cultivars, respectively.

<table>
<thead>
<tr>
<th>Whole Plant Parameters</th>
<th>GI CO₂</th>
<th>GIV CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40 Pa</td>
<td>91 Pa</td>
</tr>
<tr>
<td>Area (m²)</td>
<td>0.038</td>
<td>0.040</td>
</tr>
<tr>
<td></td>
<td>(0.0012)ᵃ*</td>
<td>(0.0016)ᵃ◊</td>
</tr>
<tr>
<td>Weight (g)</td>
<td>2.42</td>
<td>2.91</td>
</tr>
<tr>
<td></td>
<td>(0.13)ᵇ</td>
<td>(0.11)ᵇ</td>
</tr>
</tbody>
</table>

Statistical analyses appended in Tables A.23.1 to A.23.2.

In Figure 4.2 the values for whole plant transpiration, photosynthesis and WUE for long and short-term CO₂ exposure of the GI and GIV cultivars at light saturated conditions are shown. These include Control 1 (40=>40), TS1 (40=>91), Control 2 (91=>91), and TS2 (91=>40) treatments. Whole plant transpiration decreased in the GI cultivar for the TS1 (40=>91) treatment when compared to the Control 1 (40=>40) treatment. This down-regulation was not observed in the GIV cultivar (Fig. 4.2A-D). Down-regulation of photosynthesis was observed for the Control 2 (91=>91) treatment when compared to the TS1 (40=>91) treatment in the GI cultivar (Fig. 4.2E and F),
Figure 4.1. Whole plant transpiration rate of Gl and GlV A. majus cultivars for a 12 h photoperiod (A and B) and 12 h of darkness (C and D), daily whole plant photosynthesis (E and G) and dark respiration (F and H), and C-gain (I and K) and C-loss (J and L) grown during 40 Pa CO$_2$ (●,----; closed circle, solid line) and 91 Pa CO$_2$ (Δ ,-----; open triangle, dashed line) conditions. Whole plant NCER points represent mean ± se of 12 replicates (A and B), biomass line represent the mean of 12 replicates (E and F), and transpiration points represent mean ± se of 10 replicates (C and D).
Transpiration (mmol H₂O·m⁻²·s⁻¹)

NCER (µmol C·m⁻²·s⁻¹)

C-budget (C-gain/C-loss g C·m⁻²)

Time (hh:mm:ss)

0.0
0.5
1.0
1.5
2.0

0
5
10
15
20
25
30

08:00 12:00 16:00 20:00 00:00 04:00 08:00

C-budget (C-gain/C-loss g C·m⁻²)
**Table 4.2.** Whole plant NCER, transpiration, WUE, and C-budgets of two greenhouse cultivars of *A. majus* (GI, GIV) grown at 40 and 91 Pa CO$_2$. Each value represents the mean of 10 replicates. For transpiration each value represents the mean of 10 replicates. The values in parentheses represent ± se for each mean. Symbol (*) and (◊) indicate significant difference between cultivars during 40 and 91 Pa CO$_2$ growth conditions, respectively. Letters (a, b) and (A, B) indicate significant differences between ambient and enriched growth conditions in the GI and GIV cultivars, respectively.

<table>
<thead>
<tr>
<th>Whole Plant Parameters</th>
<th>GI CO$_2$</th>
<th>GIV CO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CO$_2$ and H$_2$O Exchanges</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Photosynthesis (μmol C.m$^{-2}$s$^{-1}$)</td>
<td>16.81 (0.32)$^a$</td>
<td>24.29 (0.36)$^b$</td>
</tr>
<tr>
<td>Dark Respiration (μmol C.m$^{-2}$s$^{-1}$)</td>
<td>-2.77 (0.13)$^a$</td>
<td>-2.76 (0.18)$^b$</td>
</tr>
<tr>
<td>Transpiration (mmol H$_2$O.m$^{-2}$s$^{-1}$)</td>
<td>1.70 (0.04)$^a$</td>
<td>1.66 (0.09)$^b$</td>
</tr>
<tr>
<td>WUE (μmol C/ mmol H$_2$O)</td>
<td>10.70 (0.60)$^a$</td>
<td>13.49 (0.76)$^b$</td>
</tr>
<tr>
<td><strong>C-Budgets</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-gain (g C.m$^{-2}$)</td>
<td>8.53 (0.16)$^a$</td>
<td>12.25 (0.24)$^b$</td>
</tr>
<tr>
<td>C-loss (g C.m$^{-2}$)</td>
<td>1.41</td>
<td>1.20</td>
</tr>
<tr>
<td>Daily C-gain (g C.m$^{-2}$day$^{-1}$)</td>
<td>7.12 (0.15)$^b$</td>
<td>11.30 (0.08)$^a$</td>
</tr>
<tr>
<td>Statistical analyses appended in Tables A.24.1 to A.24.7.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 4.2. Long and short-term CO$_2$ treatments of two greenhouse cultivars of *A. majus* for whole plant transpiration (A, B, C, and D), photosynthesis (E, F, G, and H), and WUE (I, J, K, and L). Whole plant photosynthesis values represent mean ± se of 12 replicates (A and B), transpiration and WUE values represent mean ± se of 10 replicates (C and D). Letters (a, b, c) and (A, B, C) indicate significant differences ($\alpha$=0.05) between treatments in GI and GIV plants, respectively. Symbol (*) indicate significant differences ($\alpha$=0.05) between cultivars. Statistical analyses appended in Tables A.25.1 to A.25.3.
<table>
<thead>
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<th>CO₂ Grow (Control) and CO₂ Transient Switch (TS) Condition (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control 1</td>
</tr>
<tr>
<td>40=&gt;40</td>
</tr>
</tbody>
</table>

**Transpiration (mmol H₂O m⁻² s⁻¹)**

<table>
<thead>
<tr>
<th>Data point</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>b</td>
<td>a</td>
<td>b</td>
<td>b</td>
</tr>
<tr>
<td>0.5</td>
<td>a</td>
<td>c</td>
<td>b</td>
<td>b</td>
</tr>
<tr>
<td>1.0</td>
<td>b</td>
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<tr>
<td>1.5</td>
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<tr>
<td>2.0</td>
<td>b</td>
<td>b</td>
<td>b</td>
<td>b</td>
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</tbody>
</table>

**Photosynthesis (µmol C·m⁻²·s⁻¹)**

<table>
<thead>
<tr>
<th>Data point</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
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<td>b</td>
<td>a</td>
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<tr>
<td>5</td>
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<tr>
<td>30</td>
<td>a</td>
<td>a</td>
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</tbody>
</table>

**WUE (µmol CO₂/mmol H₂O)**

<table>
<thead>
<tr>
<th>Data point</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
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<td>a</td>
<td>a</td>
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<tr>
<td>5</td>
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<tr>
<td>30</td>
<td>a</td>
<td>a</td>
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</table>
however similar rates were observed in the GIV cultivar. Whole plant photosynthesis significantly decreased for the TS2 (91=>40) treatment compared to Control 2 (91=>91) plants in both cultivars (Fig. 4.2E-H). Whole plant photosynthesis was significantly higher in GIV Control 2 (91=>91) plants compared to the GI Control 2 (91=>91) plants (Fig. 4.2F and H). Whole plant WUE showed similar patterns to photosynthesis for long and short-term CO2 treatments (Fig. 4.2).

Figure 4.3 shows parallel studies to Figure 4.2 for source leaf measurements of the GI and GIV A. majus cultivars. Leaf transpiration decreased for both TS1 (40=>91) and Control 2 (91=>91) treatments in cultivars compared to Control 1 (40=>40) and TS2 (91=>40) treatments (Fig. 4.3A-D). Leaf photosynthetic rates and patterns were similar to whole plant photosynthesis; in the Control 2 (91=>91) treatment the photosynthetic rate were significantly decreased from the TS1 (40=>91) treatment in the GI cultivar but not in the GIV cultivar (Fig. 4.3E-H). Leaf WUE showed similar patterns to leaf photosynthesis. The highest 14C-export rate was observed for Control 2 (91=>91) treatment with rates of 19.38 ± 1.70 and 22.19 ± 1.66 mmol C·m⁻²·s⁻¹ in GI and GIV cultivars, respectively (Fig. 4.3I-L). Export rate was significantly lower for Control 1 (40 =>40) and TS2 (91=>40) treatments compared to the other treatments. Relative export flux was maintained in Control 2 (91=>91) and TS2 (91=>40) and was higher than for Control 1 (40=>40) and TS1 (40=>91) treatments (Fig. 4.3J and L). Figure 4.4, shows leaf stomatal conductance (GCO2) and internal CO2 concentrations (Ci). GCO2 was significantly lower whereas Ci was significantly higher for the TS2 (40=>91) and Control 2 (91=>91) treatments in both cultivars (Fig 4.4).
**Figure 4.3.** Long and short-term CO$_2$ treatments of two greenhouse cultivars of *A. majus* for transpiration (A, B, C, and D), photosynthesis and WUE (E, F, G, and H), and export rate and relative export expressed as a % of NCER (I, J, K, and L). Letters (a, b, c) and (A, B, C) indicate significant differences (α=0.05) between treatment for the GI and the GIV cultivar, respectively. Each value represents the mean ± se of 6 replicates. Letters (x, y, z) and (X, Y, Z) indicate significant differences (α=0.05) between treatment in the GI and the GIV cultivars, respectively. Symbol (*) indicate significant differences (α=0.05) between cultivars. Data expressed as percentage were arcsine square root transformed prior to analysis. Values for percent data were back-transformed to the original scale. Statistical analyses appended in Tables A.26.1 to A.26.5.
Control 1 TS 1 | Control 2 TS 2
Export (μmol m⁻²s⁻¹)
0
5
10
15
20
25
Export
Relative Export
Transpiration (mmol H₂O m⁻²s⁻¹)
0
0.5
1.0
1.5
2.0
2.5
3.0
Photosynthesis (μmol m⁻²s⁻¹)
0
5
10
15
20
25
30
WUE (μmol C/ mmol H₂O)
0
5
10
15
20
25
30

CO₂ Grow (Control) and CO₂ Transient Switch (TS) Condition (Pa)
Control 1 TS 1 | Control 2 TS 2
Control 2 TS 2
Control 1 TS 1
Relative Export (% of Photosynthesis)
0
20
40
60
80
100

GI
GIV

Photosynthesis
WUE

Figure 4.4. Long and short-term CO₂ treatments of two greenhouse cultivars of *A. majus* (GI, GIV) for stomatal conductance (G) (A, B, C, and D), and internal CO₂ concentration (Ci) (E, F, G, and H). Symbol (*) indicate significant differences (α=0.05) between cultivars. Each value represents the mean ± se of 6 replicates. Letters (a, b) and (A, B) indicate significant differences (α=0.05) between transient switch parameters in the GI and GIV cultivars, respectively. Statistical analyses appended in Tables A.27.1 to A.27.2.
4.4.2 Long-term CO\textsubscript{2} and transient switch effects on $^{14}$C-partitioning in A. majus

Long and short-term CO\textsubscript{2} treatments on the $^{14}$C-partitioning into the ethanol-insoluble fraction (primarily starch) and metabolites in the soluble fraction in the leaf laminar tissues are shown in Table 4.3. The tissues outside of the feed area (petioles) were also analyzed and the % of $^{14}$C-recovered as sucrose, sugars and antirrhinoside are found in Table 4.3. The highest amount of $^{14}$C-retained in the ethanol-insoluble fraction (starch) was under TS1 (40=>91) and Control 2 (91=>91) treatments in both cultivars and was significantly higher than Control 1 (40=>40) and TS2 (91=>40) treatments (Table 4.3). The highest amount of $^{14}$C was recovered in the soluble fraction of source leaves was in sucrose and was significantly higher for TS1 (40=>91) treatments when compared to the other treatments (Table 4.3). $^{14}$C-partitioning into the monosaccharides, glucose and fructose, was similar in Control 1 (40=>40) and TS1 (91=>91) treatments. The second largest amount of $^{14}$C was recovered in the IGs. Like $^{14}$C-sucrose, more $^{14}$C-antirrhinoside and $^{14}$C-antirrhide were recovered under TS1 (91=>40) treatments in the GIV cultivar; however, similar label was retained in $^{14}$C-antirrhinoside in the GIV cultivar (Table 4.3). Significantly more $^{14}$C was retained in IGs and sucrose in the GIV cultivar during TS1 (40=>91) treatments than GI plants (Table 4.3).

In petioles a higher percentage of $^{14}$C-surose was partitioned in petiole tissues during the Control 2 (91=>91) treatment when compared to other treatments (Table 4.3). The %-antirrhinoside recovered was similar for all treatments; however, a higher percentage of $^{14}$C-antirrhinoside was partitioned in petiole tissues under TS2 (91=>40) treatments in both cultivars when photosynthesis and export was reduced compared to the Control 2 (91=>91) treatment.

Table 4.4 show ratios of different fractions and metabolites of $^{14}$C-partitioning in source leaves and petiole tissues. The $^{14}$C-sucrose to $^{14}$C-insoluble (starch) ratio decreased during Control 2 (91=>91) and TS2 (91=>40) treatments in the GIV cultivar and was the lowers during the Control 2 (91=>91) treatment in the GI cultivar (Table 4.4). The $^{14}$C-sucrose to $^{14}$C-antirrhinoside ratio in source leaves was significantly
higher in TS1 (40=>91) treatments compared to the other treatments in both cultivars (Table 4.4). The % ¹⁴C-sucrose to ¹⁴C-antirrhinoside ratio was the higher for the TS1 (40=>91) and Control 2 (91=>91) treatments in both cultivars (Table 4.4).
Table 4.3. Long and short-term CO$_2$ treatments of two greenhouse cultivars of *A. majus* (GI, GIV) on $^{14}$C-partitioning among selected metabolites recovered from source leaves and petiole tissues. Each value represents the mean of a minimum 6 replicates. The values in parentheses represent ± se for each mean. Letters (a, b, c) and (A, B, C) indicate significant differences ($\alpha$=0.05) between treatments in the GI and GIV cultivars, respectively. Symbol (*) indicate significant differences ($\alpha$=0.05) between cultivars. Data expressed as percentage were arcsine square root transformed prior to analysis. Values for percent data were back-transformed to the original scale.

<table>
<thead>
<tr>
<th>14C-Partitioning</th>
<th>GI</th>
<th>Transient Switch</th>
<th>GIV</th>
<th>Transient Switch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control 1</td>
<td>Control 2</td>
<td>Transient Switch 1</td>
<td>Transient Switch 2</td>
</tr>
<tr>
<td></td>
<td>40=&gt;40</td>
<td>40=&gt;91</td>
<td>91=&gt;91</td>
<td>91=&gt;40</td>
</tr>
<tr>
<td>14C-Leaf tissues (mmol C·m$^{-2}$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insoluble (Starch)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.91 (1.71)$^a$</td>
<td>52.71 (4.91)$^b$</td>
<td>48.67 (45.69)$^b$</td>
<td>28.53 (2.84)$^a$</td>
<td>24.86 (2.35)$^A$</td>
</tr>
<tr>
<td>Soluble</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sucrose</td>
<td>16.78 (1.67)$^a$</td>
<td>40.62 (5.17)$^b$</td>
<td>11.41 (1.62)$^a$</td>
<td>10.61 (0.99)$^a$</td>
</tr>
<tr>
<td>Glucose</td>
<td>14.04 (3.49)$^b$</td>
<td>11.54 (1.90)$^a$</td>
<td>8.33 (0.88)$^b$</td>
<td>5.00 (0.64)$^a$</td>
</tr>
<tr>
<td>Fructose</td>
<td>11.64 (2.79)$^b$</td>
<td>8.21 (11.80)$^a$</td>
<td>11.55 (1.14)$^b$</td>
<td>4.20 (0.65)$^a$</td>
</tr>
<tr>
<td>Antirrhinoside</td>
<td>10.17 (1.87)$^b$</td>
<td>6.80 (0.18)$^a$</td>
<td>7.03 (0.56)$^a$</td>
<td>7.50 (0.79)$^a$</td>
</tr>
<tr>
<td>Antirride</td>
<td>4.61 (0.97)$^ab$</td>
<td>5.51 (2.00)$^b$</td>
<td>2.71 (0.25)$ab$</td>
<td>3.41 (0.19)$a$</td>
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<tr>
<td>14C-Petiole (%-label)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugars</td>
<td>87.67 (1.23)$^b$</td>
<td>89.24 (0.51)$^b$</td>
<td>85.63 (0.25)$^b$</td>
<td>80.76 (0.19)$a$</td>
</tr>
<tr>
<td>Sucrose</td>
<td>30.41 (1.23)$^a$</td>
<td>36.47 (0.51)$^a$</td>
<td>52.15 (0.25)$^b$</td>
<td>37.41 (0.19)$a$</td>
</tr>
<tr>
<td>Antirrhinoside</td>
<td>12.33 (1.23)$^a$</td>
<td>10.76 (0.51)$^a$</td>
<td>14.37 (0.25)$a$</td>
<td>19.24 (0.19)$b$</td>
</tr>
</tbody>
</table>

Statistical analyses appended in Tables A.28.1 to A.28.9.
Table 4.4. Long and short-term CO$_2$ treatments of in two greenhouse cultivars of *A. majus* (GI, GIV). CO$_2$ effects on ratios among metabolites recovered from source leaves and petiole tissues. Each value represents the mean of a minimum 6 replicates. The values in parentheses represent ± se for each mean. Letters (a, b, c) and (A, B, C) indicate significant differences ($\alpha$=0.05) between treatments in the GI and GIV cultivars, respectively. Symbol (*) indicate significant differences ($\alpha$=0.05) between cultivars.

<table>
<thead>
<tr>
<th>Ratios</th>
<th>GI Transient Switch</th>
<th>GIV Transient Switch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control 1 40=&gt;40</td>
<td>TS 1 40=&gt;91</td>
</tr>
<tr>
<td><strong>14C-Leaf Tissues</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sucrose: Insoluble</td>
<td>0.60 (0.08)$^b$</td>
<td>0.89 (0.18)$^b$</td>
</tr>
<tr>
<td>Antirrhinoside: Antirrhide</td>
<td>2.00 (0.08)$^a$</td>
<td>1.94 (0.08)$^a$</td>
</tr>
<tr>
<td>Sucrose:</td>
<td>1.88 (0.35)$^a$</td>
<td>4.40 (0.70)$^b$</td>
</tr>
<tr>
<td><strong>14C-Petiole</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sucrose:</td>
<td>2.58 (0.29)$^a$</td>
<td>3.63 (0.54)$^b$</td>
</tr>
<tr>
<td>Antirrhinoside</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Statistical analyses appended in Tables A.29.1 to A.29.4.
4.5 Discussion

In most C₃ plant species short-term CO₂ enrichment often results in an immediate response, primarily increasing the C-fixation rates, whereas long-term CO₂ enrichment can diminish photosynthetic and growth rates in a species-specific manner (Leonardos and Grodzinski, 2011). Sage et al. (1989) examined the response of individual leaves of five C₃ species under enriched CO₂ (91 Pa). They found that Solanum tuberosum has higher leaf photosynthetic rates when acclimated to enriched CO₂ whereas Chenopodium album and Phaseolus vulgaris are unchanged and Brassica oleracea and Solanum melongena displayed decreased photosynthetic rate. The authors concluded that none of the species show the same measurable effect to acclimated CO₂ enrichment. In this study we tested the effect of prolonged exposure to elevated CO₂ of two cultivars of A. majus recommended for production of their cut flower stems in commercial greenhouses. The whole plant and leaf photosynthetic responses were examined in the GI and the GIV cultivar of A. majus plants. In addition to estimating whole plant and leaf functions as well as metabolite levels during ¹⁴C-labelling at ambient and enriched growth conditions (Control 1 (40=>40) and Control 2 (91=>91), a series of experiments termed transient switches (TS) were performed. During short-term TS studies ambient grown plants were assayed at 91 Pa CO₂ (TS2 (40=>91)) and plants grown during enriched CO₂ (91 Pa) were assayed at 40 Pa CO₂ (TS2 (91=>40)).

Similar responses for net photosynthesis rates were found when comparing whole plant and leaf measurements (Fig 4.2; Fig 4.3). As in Chapter 3, the GIV cultivar had significantly higher whole plant photosynthetic rates under 40 and 91 Pa CO₂ growth conditions, further indicating that they are more vigorous in high light than the GI cultivar (Gutierrez, 2003; Cloutier, 2008). Another explanation for the lower whole plant photosynthetic rate observed in the GI cultivar compared to the GIV cultivar could be that due to the larger whole plant canopy area in the GI cultivar (Table 4.1) there may have been more mutual shading. The whole plant dark respiration rate was similar between ambient and long-term CO₂ growth conditions in both cultivars. Much controversy exists whether nighttime respiration rate is decreased during CO₂
enrichment. The observed decrease in previous studies may be an artifact of chamber seals and leakage of CO$_2$ (Janke and Kewitt, 2002; Long et al., 2004). A study using an alternative method by measuring O$_2$ evolution showed that dark respiration is insensitive to changes in the CO$_2$ concentration up to 203 KPa (Davery et al., 2004).

Whole plant and leaf photosynthesis increased during long-term CO$_2$ growth when compared to ambient growth conditions in both cultivars (Table 4.2; Fig. 4.2). Photosynthesis also increased during short-term CO$_2$ enrichment (TS 1 (40=>90)) when compared to ambient CO$_2$ growth conditions. The photosynthetic rates under short and long-term CO$_2$ conditions decreased in the GI cultivar but were similar in the GIV cultivar (Fig. 4.2). Even though, the photosynthetic rate was the highest under the short-term CO$_2$ enrichment (TS1 (40=>91)), the export rate was higher during long-term CO$_2$ enrichment (Control 2 (91=>91)), especially in the GIV cultivar (Fig. 4.2). In addition, the relative export flux was highest for plants grown under 91 Pa CO$_2$ (Control 2 (91=>91) and TS 2 (91=>21)), indicating that under long-term CO$_2$ conditions there was an increase in sink demand since high rates of export were maintained and the relative export rate was over 75% in both cultivars. This increase in export rate of plants grown under 91 Pa CO$_2$ was also associated with higher daily C-gain for both cultivars grown under 91 Pa CO$_2$ compared to growth under 40 Pa CO$_2$ (Table 4.2). These results indicate that both greenhouse cultivars of A. majus were able to utilize carbon in sink tissues and increase the carbon flux from source leaves.

During short-term CO$_2$ enrichment the accumulation of sucrose and IGs as well as insoluble (starch) was observed in A. majus source leaves however there was an up-regulation of photosynthesis and export rate from the ambient condition. The immediate response to elevated CO$_2$ is often seen in plants; however, during long-term CO$_2$ conditions end product inhibition can occur and diminish photosynthetic rates (Arp. 1991). To maintain photosynthesis under acclimated CO$_2$ high metabolic activity or storage in sinks is essential. End product inhibition of photosynthesis can occur when source supply and sink demand are imbalanced and is often associated with the build-up of starch and sucrose (Arp, 1991). End product inhibition did not occur in the two A. majus cultivars, starch accumulated in similar amounts as during short-term CO$_2$
enrichment; however, the amount of antirrhinoside and antirrhide were not altered when compared to ambient conditions and less sucrose was recovered in source leaves than during ambient and short-term CO₂ conditions (Table 4.4). The shift of metabolites is most likely due to the increased sink capacity and export (Table 4.4).

Moore et al. (1997) found that a garden cultivar of *A. majus*, Liberty Scarlet grown under 101 Pa CO₂ has increased leaf area and flower production. In addition, the authors showed that under elevated CO₂ growth starch, glucose, fructose more than doubles while sucrose remains unchanged. In the same study, the amount of starch also increases in tobacco plants grown at enriched CO₂, as well as in parsley; however, the amount of sucrose and mannitol also increased. Starch accumulation generally occurs within hours of elevated CO₂ enrichment and is maintained under elevated CO₂ growth (Paul and Foyer, 2001). Alterations in starch are usually more severe than changes in soluble sugars under enriched CO₂. Several studies have shown that the accumulation of starch is concomitant with the inhibition of photosynthesis in some species (Stitt, 1991). However, the ability to synthesize starch under elevated CO₂ allows for higher photosynthetic rates since triose phosphates are utilized in starch synthesis (Paul and Foyer, 1991).

The synthesis of secondary metabolites can be altered under CO₂ enrichment. Since secondary metabolism is connected to primary metabolism, increasing CO₂ levels alter photosynthesis that can increase the amount of substrate and allocate substrate to secondary metabolites (Sharafzadeh and Ordookhani, 2001). For alkaloids the decarboxylation of amino acids and in phenylpropanoid synthesis the enzyme L-phenylalanine ammonia-lyase marks an important interface between primary and secondary compounds and competes directly with secondary metabolism (Modolo et al., 2009; Sharafzadeh and Ordookhani, 2001). This distinction is not as easily defined for terpenoids. Terpenoids constitute both primary and secondary products that encompass primary constituents, such as the light-trapping carotenoids and hormones (Modolo et al., 2001). Sallas et al. (2003) found that terpenoid concentration in Scots pine needles decreased with long-term CO₂ enrichment. Peñuelas and Llusia (1997) did not find significant alterations in terpenoid emissions and concentrations in
Rosemary plants under high CO$_2$. Monoterpene emissions from *Quercus ilex* are reduced by 68% under 71 Pa CO$_2$ growth and monoterpene synthases are also down regulated. The amount of IGs in both *A. majus* cultivars remained unchanged under 91 Pa CO$_2$ growth conditions compared to growth under 40 Pa CO$_2$ even though they increased during short-term CO$_2$ conditions (Table 4.3). However, the amount of $^{14}$C-sucrose to $^{14}$C-antirrhinoside ratio decreased under 90 Pa CO$_2$ compared to 40 Pa CO$_2$ due to a reduced $^{14}$C-partitioning into sucrose. Petiole studies indicate that sucrose was exported over antirrhinoside when plants were grown under 91 Pa CO$_2$.

In summary, leaf and whole plant photosynthesis increased under long-term CO$_2$ growth conditions. The $^{14}$C-export rate also increased under 91 Pa CO$_2$ growth condition in both cultivars. A high export rate was maintained due to high sink demand and the ability to utilize carbohydrates. Sucrose was the main carbohydrate that contributed to the increase in export rate. Partitioning into the IGs was similar and slightly decreased between ambient and long-term CO$_2$ conditions. The increase in export and photosynthesis was associated with a 30% increase of the daily C-gain in both cultivars during enriched CO$_2$. 

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CHAPTER 5

General Summary

The main objective of this thesis was to examine whether IGs, such as antirrhinoside, are directly synthesized from $^{14}$CO$_2$ and are translocated in the phloem as major photoassimilates in addition to sucrose. *A. majus* and *P. lanceolata* were chosen as case studies since *A. majus* has been reclassified into the Plantaginaceae family on the basis of DNA sequence studies (Albach et al., 2005). The related species synthesize chemical IG analogues. Previous studies have shown that antirrhinoside and antirrhide synthesized by *A. majus* are $^{14}$C-labelled from photosynthesis and that antirrhinoside accounts for a large fraction of the $^{14}$C-recovered in the phloem (Cloutier, 2008). This study is original in that it is the first to relate photosynthesis and C-gain to $^{14}$C-export rates and $^{14}$C-partitioning of major metabolites at the whole plant and leaf level. To my knowledge no studies exist where IGs in *P. lanceolata* have been $^{14}$C-labelled directly from $^{14}$CO$_2$. Furthermore, this is the first study to examine the above parameters under varying short-term CO$_2$ and O$_2$ levels.

The results showed that the two well-known IGs, catalpol and aucubin, that are chemical analogues to antirrhinoside and antirrhide, respectively, were not directly $^{14}$C-labelled from photosynthesis in *P. lanceolata* leaves. Lamina and petiole tissues were examined under different temperatures, CO$_2$, and O$_2$ conditions, as well as under different feed durations; however, only background $^{14}$C-levels were recovered. However, unlabelled catalpol was found in some leaf samples. Previous studies have shown that a number of factors can influence IG content in *P. lanceolata* (Bowers et al., 1992; Klockars et al., 1993; Staddon et al., 1999; Marak et al., 2000; Parádi et al., 2003). Substantial differences in genetic, morphological and IG concentrations have been noted between and within populations of *P. lanceolata* (Bowers et al., 1992, Marak et al., 2000). One explanation for the inability to label catalpol and aucubin in these studies is that an ecotype that readily makes these IGs was not selected. Two main ecotypes, hayfield and pasture, have been identified to have canopy differences (Marak et al., 2000). High and low IG selection studies have been conducted. High IG
selection lines are characteristic of hayfield population types, whereas low IG selection lines are more prevalent in pasture populations (Marak et al., 2000). A three-to-four-fold difference of IG content was found between the two lines; in other words, in low selection lines IGs can be undetectable, whereas IGs can make up to 10% of the total dry weight in high selection lines (Wolff and Van Delden, 1987; Marak et al., 2000). The ecotype that was used originated from the lawn (open areas) at the University of Guelph. Attempts to locate other reliable seed sources were unsuccessful but further selection and testing is warranted.

Leaf and plant age can also significantly influence IG content in *P. lanceolata*. Young leaves can contain up to 20% of IGs on a dry weight basis while mature leaves contain none (Bowers et al., 1992). In this study, a newly expanded leaf from the inner and mid rosette of *P. lanceolata* plants was selected for labelling experiments. Neighbouring species can also affect biomass and IG production in *P. lanceolata* (Barton and Bowers, 2006). Another important environmental factor to consider is the presence of mutualists, such as AMF, that can form symbiotic associations that enhance plant growth and survival (Bennet and Bever, 2007). Bennet and Bever (2007) examined three different AMF symbiotic associations of *P. lanceolata* and showed distinct relations to plant-growth response and plant-herbivory interaction due to AMF type. More recently, three studies examined AMF symbiosis between *Glomus intraradices* and *P. lanceolata*; one study found that this association did not affect the production of IGs and another found that AMF associations can increase carbon-based defences (Gange and West, 2009; De Deyen et al., 2009; Fontana et al., 2009).

Although there are several plausible explanations for the inability to recover label from catalpol and aucubin in *P. lanceolata*, it may be that catalpol and aucubin are derived from an alternative pathway to their chemical analogues, antirrhinoside and antirrhide, recovered in *A. majus*. Catalpol and aucubin could be synthesized by the cytosolic MEVP and therefore not readily labelled from the chloroplastic DOXP.

Conversely, the sugar alcohol, sorbitol was directly labelled from photosynthesis in *P. lanceolata* laminar and petiole tissues. During certain conditions up to 30% of the
total $^{14}$C in the soluble fraction was retained in sorbitol. The synthesis of alcohol sugars is common among the Plantaginaceae, since both sorbitol and mannitol are found in the family. All members of the *Plantago* genera produce sorbitol (Rønstead et al., 2000; Rønstead et al., 2003, Taskova et al., 2005; Voitsekhovskaja et al., 2006, Reidel et al., 2009, Szucs et al., 2011). $^{14}$C-Sorbitol was the highest in leaf laminar tissues at the two higher temperatures; however, no major changes were observed with exposure to short-term enriched CO$_2$ and low O$_2$. Petiole studies indicate that during low O$_2$ conditions the flux of sorbitol increased relative to sucrose when the export rate was the fastest. However during all conditions more sucrose was exported than sorbitol (Fig. 5.1). Studies have shown that the production of auxiliary sugars along with sucrose may contribute to higher export rates in C$_3$ species (Jiao and Grodzinski, 1996; Grodzinski et al., 1998).

As stated in previous chapters in other members of the Plantaginaceae the IG, antirrhinoside, is directly labelled from $^{14}$CO$_2$ and can account for a significant percentage of the total carbon in the laminar tissues and the phloem (Gowan et al., 1995, Voitsekhovskaja et al., 2006, Beninger et al., 2007, Szucs et al., 2011). The main role of alcohol sugars and antirrhinoside has been attributed to osmoregulation (Loescher, 1987; Voitsekhovskaja et al., 2006; Cheng et al., 2005). However, it may be that even though related species synthesize analogous compounds they may use different strategies to maintain homeostasis. A major limitation of this study is that only one ecotype was examined. I tried to obtain *P. lanceolata* seed from other sources but was unsuccessful. Future studies examining the $^{14}$C-partitioning into IGs in *P. lanceolata* should look at different ecotypes or try to select for high IG lines (Wolff and Van Delden, 1987; Marak et al., 2000). Why catalpol and aucubin were not $^{14}$C-labelled is not fully understood from this study; however, the ability of plants to transport auxiliary metabolites, IGs or alcohol sugars, along with sucrose may be advantageous in acclimating to varying temperature conditions.

*A. majus* was used as a model to study IGs in Chapters 3 and 4 since previous studies have shown that the IGs, antirrhinoside and antirrhide, are directly labelled from
$^{14}$CO$_2$. One objectives of Chapter 3 and 4 were to confirm that the IGs, antirrhinoside and antirrhide, synthesized by A. majus were directly labelled from photosynthesis and that the transport of these IGs are altered by varying temperature, short- and long-term CO$_2$ and O$_2$ exposure. Unlike catalpol and aucubin, up to 60% of the $^{14}$C was recovered in IGs relative to sucrose in laminar tissues when plants were exposed to certain conditions. Only $^{14}$C-antirrhinoside was recovered in petiole tissues; consistent with findings from Beninger et al. (2007) and was recovered in percentages up to 20% of the soluble fraction. In A. majus the IGs are major photoassimilate products and antirrhinoside readily contributes to the export rate (Fig. 5.1). In this study two A. majus climatic cultivars were examined, a GI and a GIV cultivar, Maryland White Ivory and Protomac Ivory White, respectively. Both cultivars retained more $^{14}$C in antirrhinoside at higher temperatures when photosynthetic and export rates were the highest. This was consistent during short-term enriched CO$_2$ exposure. The accumulation of antirrhinoside in source leaves at higher temperatures may contribute to the maintenance of homeostasis in a range of environmental conditions.

During low O$_2$ exposure an alteration in the synthesis of IGs was observed. The antirrhinoside to antirrhide ratio consistently decreased with low O$_2$ exposure at the higher temperatures. Localization studies may determine where antirrhide is stored in leaves. In addition the elucidation of the precursors of these two IGs and whether or not antirrhide is a precursor to antirrhinoside may explain why antirrhide accumulated in source leaves during these treatments. In addition, if antirrhide was the precursor of antirrhinoside a few steps in this conversion would involve oxygen dependent enzymes. It may be that during low O$_2$ key enzymes requiring higher amounts of O$_2$ do not readily convert antirrhide to antirrhinoside and the antirrhide levels accumulate. Another possibility is that the sites of synthesis for antirrhide and antirrhinoside are in separate subcellular compartments and O$_2$ is required for movement of antirrhinoside to the site of its conversion. It is noteworthy that the synthesis of other terpenoids, such as gibberellins, abscisic acid and carotenoids involve enzymes that are oxygen dependent (Hedden and Kamiya, 1997; Buchanan et al., 2000). An experiment in which source
leaves are exposed to a range of O$_2$ levels between 2 and 21 kPa may also aid in determining why and during what O$_2$ conditions antirrhide does accumulate.

During short-term CO$_2$ studies photosynthesis increased, export rate was maintained and $^{14}$C-parititioning increased in sucrose and antirrhinoside. In Chapter 4 A. majus cultivars were grown during enriched CO$_2$ to examine if photosynthetic and export rates decrease and if the major photoassimilates, especially the IGs are altered. Long-term CO$_2$ response is species-specific and can often result in the down-regulation of photosynthesis and plant growth due to low sink demand and utilization of carbon from source tissues (Sage et al., 1989; Leonardos and Grodzinski, 2011). Photosynthesis and export was up regulated in both greenhouse cultivars during long-term CO$_2$ enrichment relative to ambient grown plants. The relative export rates were the highest when plants were grown under elevated CO$_2$ indicative of increases in sink demand. These results are associated with a higher daily C-gain under enriched CO$_2$ growth conditions. High metabolic activity or storage in sinks is essential to maintain photosynthesis under acclimated CO$_2$. End product inhibition of photosynthesis can occur when source supply and sink demand are imbalanced and there is an increase in leaf carbohydrates (Arp, 1991; Moore et al., 1999; Leonardos and Grodzinski, 2011). The utilization of carbon in sink tissues can influence the transport rate of carbon from source tissues (Moore et al., 1999). The spatial partitioning of antirrhinoside and antirrhide and the storage or loading of these compounds are not known.

As stated in Chapter 1: my hypothesis is that IGs are synthesised from newly fixed CO$_2$ in Plantaginaceae species and that compounds, such as antirrhinoside and catalpol, are transported in the phloem. My hypothesis is rejected since catalpol and aucubin were not $^{14}$C-labelled in P. lanceolata as seen in Chapter 2. Figure 5.1 is a schematic of the C$_3$ and C$_2$ cycles and the synthesis and export of major photoassimilates and IGs in P. lanceolata and A. majus from photosynthesis in a photosynthetic cell to summarize the finding of this thesis. Figure 5.1 shows that catalpol and aucubin were not synthesized though the DOXP chloroplastic pathway in P. lanceolata, however antirrhinoside and antirrhide were labelled from newly fixed $^{14}$CO$_2$ in A. majus. Antirrhinoside was exported from source leaves along with sucrose
Figure 5.1. An overview of the C₃ and C₂ pathways and the carbohydrates synthesized in P. lanceolata and A. majus founded on results from Chapters 2, 3 and 4 of this thesis. ¹⁴C-labeling showed that starch, sucrose, glucose, fructose and sorbitol were readily labelled in P. lanceolata. ¹⁴C-labeling showed that starch, sucrose, antirrhinoside, antirrhide, glucose and fructose were readily labelled in A. majus. ADp-glu, adenosine 5-diphosphoglucone; F6P, fructose 6-phosphate; Glc, glycolate; Glc-P, P-glycolate; Glx, glyoxylate; Gly, glycine; Glyc, glycerate; G3P, glyceraldehyde-3-phosphate; Hexose-P, hexose phosphate; IPP, isopentenyl diphosphate; Mal, Maltose; RuBP, ribulose 1,5-bisphosphate; Ser, serine; TP, triose-phosphate; UDP-glu, uridine diphosphate glucose; 3-PGA, 3-phosphoglycerate. Modified from Cloutier (2008).
in *A. majus*. In *P. lanceolata* the alcohol sugar, sorbitol, was synthesized and exported whereas in *A. majus* little $^{14}$C-label was recovered in the alcohol sugar, mannitol, in source leaves but was not exported. In both Plantaginaceae species sucrose was the major transported photoassimilate. It is important to note that studies indicate that the synthesis of iridoid intermediates occur in the internal-phloem-associated parenchyma cells in *C. roseus* (Geu-Flores et al., 2012; Murata et al., 2008). The sites of synthesis of the IGs, antirrhinoside and antirrhide, in *A. majus* are unknown.

Previous studies show that many naturally occurring terpenoids are vital in plant growth and development. Taken together, the experiments in this thesis indicate that in species within the Plantaginaceae, such as *A. majus*, IGs may be functioning as a phloem-mobile photosynthate, like sucrose. Perhaps, these mobile terpenoids are precursors or intermediates to other complex terpenoids. Studies of *C. roseus* imply that secoiridoid precursors are synthesized in internal phloem-associate parenchyma cells and are transported to the epidermis for further modification and synthesis of MIA (Murata et al., 2008). Studies have also shown that IGs are deterrents to herbivores and are phytotoxic and antifungal (Beninger et al., 2007; Beninger et al., 2008). Voitsekhovskaja et al. (2006) has proposed the role of antirrhinoside in *A. barclaiana* to be an osmoregulator. IG may also be involved in carbohydrate signaling and maintenance of homeostasis. It may be that the IGs, antirrhinoside and antirrhide have more than one functional role. However, related species that have the ability to synthesize analogous compounds may not use the same strategy to maintain homeostasis or may have alternate roles. Future studies need to be conducted to determine whether other ecotypes of *P. lanceolata* readily synthesize IGs and whether the sugar alcohol, sorbitol, is a major photoassimilate in these ecotypes. Since there are some differences in the partitioning of major photoassimilates and IGs in the two *A. majus* cultivars it is likely that differences are apparent among *P. lanceolata* ecotypes. Elucidating the intermediates and the enzymes involved in the synthesis of IGs in *P. lanceolata* and *A. majus* may indicate why catalpol and aucubin were not readily synthesized in *P. lanceolata*. It would also be beneficial to conduct $^{14}$C-labelling studies in other members of the Plantaginaceae, such as toadflax that synthesizes the IGs,
antirrhinoside and linarioside (Jamieson and Bowers, 2010). Furthermore, the localization of these IGs and precursors as well as iridoid synthase enzymes could reveal their site of synthesis. Determining if these precursors are further modified at other sites could aid in determining their roles. Questions about phloem loading in the Plantaginaceae are still unanswered; however, it is likely that they are loaded apoplectically in A. majus due to the minor vein structure (Gamalei, 1991). In addition, in other species that synthesize antirrhinoside higher concentrations are observed in the phloem sap than the cytoplasm of mesophyll cells, further indicating that antirrhinoside loading is energized (Voitsekhovskaja et al., 2006). It is still not known how important IGs are in species; however, in A. majus they are primary photoassimilates that are readily transported and may contribute to maintaining homeostasis in a range of environmental conditions.
LITERATURE CITED


APPENDIX

Statistical Analyses

Analyses of variance (ANOVA) and multiple comparisons (LS Means) conducted for tables and figures in Chapters 2, 3, and 4 are shown for each study but not for all parameters assessed. The probability of a Type I error rate was set at 0.05% for all analyses. To examine the assumptions for the ANOVA a diagnostics plot of the residuals in PROC GLM was conducted. The Shapiro Wilkes test of residuals was also computed to determine if the distributions were normal. To verify if outliers were present, standardized residuals were calculated and assessed against Lund’s critical value. In Chapter 2 multiple comparisons (LS means) and one-way ANOVA was performed using GLM procedure in SAS to determine differences between temperatures and CO₂; O₂ treatments (Ho: treatment means are equal). In Chapter 3 multiple comparisons (LS means) and two-way ANOVA were performed using GLM procedure in SAS to determine differences between temperatures. Contrast and estimate statements were used to examine differences between cultivars and O₂ exposure within the GLM procedure. In Chapter 4 multiple comparisons (LS means) and two-way ANOVAS were performed using GLM procedure in SAS to determine differences between long-term CO₂ treatments. Contrast and estimate statements were used to examine differences between cultivars and long-term CO₂ treatments within the GLM procedure. Data expressed as percentage were transformed using arcsine square root or log transformations prior to analysis. Data transformations, arcsine square root and log, were selected for the specific data sets as per recommendations from Bowley (1999). Values for percent data were back-transformed to the original scale. The standard errors of these means were not back-transformed and are not represented in tables or graphs since these statistics are not relevant on the original scale (Bowley, 1999).
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Table A.1.1A. One-way analysis of variance for whole plant photosynthesis (µmol C·m\(^{-2}·s^{-1}\)) of *P. lanceolata* exposed to three temperatures Table 2.1.

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<th>Source</th>
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<th>Pr&gt;F</th>
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</table>

\(^\top\) Sum of squares for model parameters are those of type III (SAS)

Table A.1.1B. Multiple mean comparisons for whole plant photosynthesis (µmol C·m\(^{-2}·s^{-1}\)) of *P. lanceolata* exposed to three temperatures Table 2.1.

| Temp | NCELER\(\text{Ad}\) | LSMEAN       | Standard Error | Pr > |t| | LSMEAN Number |
|------|----------------------|---------------|----------------|-------|---|----------------|
| 15   | 7.71708400           | 0.33617996    | <.0001         | 1     | |
| 25   | 7.96774400           | 0.33617996    | <.0001         | 2     | |
| 35   | 7.18602167           | 0.30688891    | <.0001         | 3     | |

Table A.1.2A. One-way analysis of variance for whole plant dark respiration (µmol C·m\(^{-2}·s^{-1}\)) of *P. lanceolata* exposed to three temperatures Table 2.1.

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<th>(R^2)</th>
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\(^\top\) Sum of squares for model parameters are those of type III (SAS)

Table A.1.2B. Multiple mean comparisons for whole plant dark respiration (µmol C·m\(^{-2}·s^{-1}\)) of *P. lanceolata* exposed to three temperatures Table 2.1.

| Temp | NCELER\(\text{n}\) | LSMEAN       | Standard Error | Pr > |t| | LSMEAN Number |
|------|---------------------|---------------|----------------|-------|---|----------------|
| 15   | -0.79466500         | 0.06743997    | <.0001         | 1     | |
| 25   | -1.19974500         | 0.06743997    | <.0001         | 2     | |
| 35   | -1.11842600         | 0.07387678    | <.0001         | 3     | |

Table A.1.2C. Least Squares Means for effect Temp Pr > |t| for H0: LSMean(i)=LSMean(j) Dependent Variable: NCELER\(\text{n}\)

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<th>i/j</th>
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<th>2</th>
<th>3</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0008</td>
<td>0.0060</td>
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<td>2</td>
<td>0.0008</td>
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<td>0.4299</td>
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<tr>
<td>3</td>
<td>0.0060</td>
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Table A.1.3A. One-way analysis of variance for whole plant transpiration (mmol H$_2$O·m$^{-2}$·s$^{-1}$) of *P. lanceolata* exposed to three temperatures Table 2.1.

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<tr>
<th>Source</th>
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<th>CV</th>
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*Sum of squares for model parameters are those of type III (SAS)*

Table A.1.3B. Multiple mean comparisons for whole plant transpiration (mmol H$_2$O·m$^{-2}$·s$^{-1}$) of *P. lanceolata* exposed to three temperatures Table 2.1.

| Temp | Transd LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|------|---------------|----------------|------|--------|----------------|
| 15   | 1.06789800    | 0.07296491     | <.0001 | 1    |
| 25   | 1.38581800    | 0.07296491     | <.0001 | 2    |
| 35   | 2.05341600    | 0.07296491     | <.0001 | 3    |

Table A.1.4A. One-way analysis of variance for whole plant WUE (µmol C/mmol H$_2$O) of *P. lanceolata* exposed to three temperatures Table 2.1.

<table>
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<th>Source</th>
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<th>R$^2$</th>
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<td>0.7135</td>
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<td>Corrected Total</td>
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<td>49.44</td>
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</tr>
</tbody>
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*Sum of squares for model parameters are those of type III (SAS)*

Table A.1.4B. Multiple mean comparisons for whole plant WUE (µmol C/mmol H$_2$O) of *P. lanceolata* exposed to three temperatures Table 2.1.

| Temp | WUEd LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|------|-------------|----------------|------|--------|----------------|
| 15   | 7.12706118  | 0.48584869     | <.0001 | 1    |
| 25   | 6.10101383  | 0.48584869     | <.0001 | 2    |
| 35   | 3.48473175  | 0.48584869     | <.0001 | 3    |
Table A.1.5A. One-way analysis of variance for whole plant C-gain (g C·m⁻²·s⁻¹) of *P. lanceolata* exposed to three temperatures Table 2.1.

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<th>Source</th>
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<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
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<tr>
<td>Model</td>
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<td>0.93</td>
<td>2.44</td>
<td>0.1231</td>
<td>0.2586</td>
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¹Sum of squares for model parameters are those of type III (SAS)

Table A.1.5B. Multiple mean comparisons for whole plant C-gain (g C·m⁻²·s⁻¹) of *P. lanceolata* exposed to three temperatures Table 2.1.

<table>
<thead>
<tr>
<th>Temp</th>
<th>Cgain LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
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<tbody>
<tr>
<td>15</td>
<td>3.83058193</td>
<td>0.19914967</td>
<td>&lt;.0001</td>
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<td>25</td>
<td>4.28524550</td>
<td>0.19914967</td>
<td>&lt;.0001</td>
<td>2</td>
</tr>
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<td>35</td>
<td>3.72842550</td>
<td>0.19914967</td>
<td>&lt;.0001</td>
<td>3</td>
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</tbody>
</table>

Least Squares Means for effect Temp  
Pr > | for H0: LSMean(i)=LSMean(j)  
Dependent Variable: Cgain  
i/j | 1 | 2 | 3 |
---|---|---|---|
1  | 0.1273 | 0.7219 |
2  | 0.1273 | 0.0667 |
3  | 0.7219 | 0.0667 |

Table A.1.6A. One-way analysis of variance for whole plant C-loss (g C·m⁻²·s⁻¹) of *P. lanceolata* exposed to three temperatures Table 2.1.

<table>
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<th>Source</th>
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<th>Pr&gt;F</th>
<th>R²</th>
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<tr>
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<td>0.0056</td>
<td>0.4989</td>
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<td>Error</td>
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<tr>
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¹Sum of squares for model parameters are those of type III (SAS)

Table A.1.6B. Multiple mean comparisons for whole plant C-loss (g C·m⁻²·s⁻¹) of *P. lanceolata* exposed to three temperatures Table 2.1.

<table>
<thead>
<tr>
<th>Temp</th>
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<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
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<td>15</td>
<td>0.41321623</td>
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<td>&lt;.0001</td>
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<tr>
<td>25</td>
<td>0.62336406</td>
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<td>35</td>
<td>0.53264367</td>
<td>0.03857434</td>
<td>&lt;.0001</td>
<td>3</td>
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</tbody>
</table>

Least Squares Means for effect Temp  
Pr > | for H0: LSMean(i)=LSMean(j)  
Dependent Variable: Closs  
i/j | 1 | 2 | 3 |
---|---|---|---|
1  | 0.0016 | 0.0448 |
2  | 0.0016 | 0.1171 |
3  | 0.0448 | 0.1171 |
Table A.1.7A. One-way analysis of variance for whole plant Daily C-gain (g C·m⁻²·day⁻¹) of *P. lanceolata* exposed to three temperatures Table 2.1.

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<th>R²</th>
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¹Sum of squares for model parameters are those of type III (SAS)

Table A.1.7B. Multiple mean comparisons for whole plant Daily C-gain (g C·m⁻²·day⁻¹) of *P. lanceolata* exposed to three temperatures Table 2.1.

| Temp | Cbudget LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|------|----------------|----------------|------|---|----------------|
| 15   | 3.35657857     | 0.20837314     | <.0001| 1|
| 25   | 3.66189079     | 0.20837314     | <.0001| 2|
| 35   | 3.18482565     | 0.20837314     | <.0001| 3|

Least Squares Means for effect Temp
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: Cbudget

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Table A.2.1A. One-way analysis of variance for leaf WUE (µmol C/mmol H₂O) of *P. lanceolata* exposed to four temperatures Figure 2.5.

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¹Sum of squares for model parameters are those of type III (SAS)

Table A.2.1B. Multiple mean comparison for leaf WUE (µmol C/mmol H₂O) of *P. lanceolata* exposed to four temperatures Figure 2.5.

| Temp | WUE LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|------|------------|----------------|------|---|----------------|
| 15   | 6.95169375 | 0.27161007     | <.0001| 1|
| 25   | 4.74948375 | 0.27161007     | <.0001| 2|
| 35   | 2.96128250 | 0.27161007     | <.0001| 3|
| 45   | 1.47997250 | 0.27161007     | <.0001| 4|

Least Squares Means for effect Temp
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: WUE

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Table A.2.2A. One-way analysis of variance for leaf photosynthesis (µmol C·m⁻²·s⁻¹) of P. lanceolata exposed to four temperatures Figure 2.5.

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¹Sum of squares for model parameters are those of type III (SAS)

Table A.2.2B. Multiple mean comparison for leaf photosynthesis (µmol C·m⁻²·s⁻¹) of P. lanceolata exposed to four temperatures Figure 2.5.

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<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
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<td>&lt;.0001</td>
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</tr>
<tr>
<td>45</td>
<td>7.6488333</td>
<td>0.5896724</td>
<td>&lt;.0001</td>
<td>4</td>
</tr>
</tbody>
</table>

Least Squares Means for effect Temp
Pr > | for H0: LSMean(i)=LSMean(j)

<table>
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<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3965</td>
<td>&lt;.0001</td>
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</tr>
<tr>
<td>2</td>
<td>0.3965</td>
<td>0.0005</td>
<td>0.3917</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>&lt;.0001</td>
<td>0.0005</td>
<td>0.0001</td>
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<tr>
<td>4</td>
<td>0.9657</td>
<td>0.3917</td>
<td>0.0001</td>
<td></td>
</tr>
</tbody>
</table>

Table A.2.3A. One-way analysis of variance for leaf export rate (mmol C·m⁻²) of P. lanceolata exposed to four temperatures Figure 2.5.

<table>
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<tr>
<th>Source</th>
<th>DF</th>
<th>SS ¹</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
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<td>Model</td>
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<td>&lt;.0001</td>
<td>0.6336</td>
<td>18.47</td>
</tr>
<tr>
<td>Error</td>
<td>27</td>
<td>42.72</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
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<td>116.56</td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

¹Sum of squares for model parameters are those of type III (SAS)

Table A.2.3B. Multiple mean comparison for leaf export rate (µmol C·m⁻²·s⁻¹) of P. lanceolata exposed to four temperatures Figure 2.5.

<table>
<thead>
<tr>
<th>Temp</th>
<th>Exp LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>5.90438571</td>
<td>0.47540807</td>
<td>&lt;.0001</td>
<td>1</td>
</tr>
<tr>
<td>25</td>
<td>6.51811250</td>
<td>0.44470353</td>
<td>&lt;.0001</td>
<td>2</td>
</tr>
<tr>
<td>35</td>
<td>9.33432500</td>
<td>0.44470353</td>
<td>&lt;.0001</td>
<td>3</td>
</tr>
<tr>
<td>45</td>
<td>5.37566250</td>
<td>0.44470353</td>
<td>&lt;.0001</td>
<td>4</td>
</tr>
</tbody>
</table>

Least Squares Means for effect Temp
Pr > | for H0: LSMean(i)=LSMean(j)

<table>
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<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.3542</td>
<td>&lt;.0001</td>
<td>0.4238</td>
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</tr>
</tbody>
</table>
Table A.2.4A. One-way analysis of variance for leaf relative export rate (% of photosynthesis) of *P. lanceolata* exposed to four temperatures Figure 2.5. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS†</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>3</td>
<td>0.03</td>
<td>8.49</td>
<td>0.0004</td>
<td>0.4948</td>
<td>2.98</td>
</tr>
<tr>
<td>Error</td>
<td>26</td>
<td>0.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>29</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*R^Sum of squares for model parameters are those of type III (SAS)*

Table A.2.4B. Multiple mean comparisons for leaf relative export rate (% of photosynthesis) of *P. lanceolata* exposed to four temperatures Figure 2.5. Data expressed as percentage were arcsine square root transformed prior to analysis.

| Temp | Ratio | LSMEAN | Standard Error | Pr>|t| | LSMEAN Number |
|------|-------|--------|----------------|------|-----------|
| 15   | 15.7826375 | 2.2773965 | <.0001            | 1    |
| 25   | 17.5391625 | 2.2773965 | <.0001            | 2    |
| 35   | 18.8151625 | 2.2773965 | <.0001            | 2    |
| 45   | 19.0921625 | 2.2773965 | <.0001            | 4    |

Table A.3.1A. One-way analyses of variance for 14C-starch (mmol C·m⁻²) retained in leaves of *P. lanceolata* plants exposed to four temperatures in Table 2.2.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS†</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>3</td>
<td>382.12</td>
<td>3.07</td>
<td>0.0440</td>
<td>0.2475</td>
<td>45.97</td>
</tr>
<tr>
<td>Error</td>
<td>28</td>
<td>1161.78</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>31</td>
<td>1543.90</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

*R^Sum of squares for model parameters are those of type III (SAS)*

Table A.3.1B. Multiple mean comparison for 14C-starch (mmol C·m⁻²) retained in leaves of *P. lanceolata* plants exposed to four temperatures in Table 2.2.

| Temp | C14Insol | LSMEAN | Standard Error | Pr>|t| | LSMEAN Number |
|------|----------|--------|----------------|------|-----------|
| 15   | 15.7826375 | 2.2773965 | <.0001            | 1    |
| 25   | 17.5391625 | 2.2773965 | <.0001            | 2    |
### Table A.3.2A. One-way analyses of variance for $^{14}C$-sucrose (mmol C·m$^{-2}$) retained in leaves of *P. lanceolata* plants exposed to four temperatures in Table 2.2.

| Temp°C | C14Insol LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|--------|-----------------|----------------|-------|---|----------------|
| 35     | 14.3764000      | 2.2773965      | <.0001|   | 3              |
| 45     | 8.3502000       | 2.2773965      | .0010 |   | 4              |

**Least Squares Means for effect Temp**

Pr > |t| for H0: LSMean(i)=LSMean(j)  
Dependent Variable: C14Insol

<table>
<thead>
<tr>
<th>i/j</th>
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<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.5898</td>
<td>0.6657</td>
<td>0.0286</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.5898</td>
<td>0.3345</td>
<td>0.0081</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.6657</td>
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<tr>
<td>4</td>
<td>0.0286</td>
<td>0.0081</td>
<td>0.0718</td>
<td></td>
</tr>
</tbody>
</table>

Table A.3.2B. Multiple mean comparison for $^{14}C$-sucrose (mmol C·m$^{-2}$) retained in leaves of *P. lanceolata* plants exposed to four temperatures in Table 2.2.

| Temp°C | C14Suc LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|--------|---------------|----------------|-------|---|----------------|
| 15     | 12.6953143    | 1.0980734      | <.0001|   | 1              |
| 25     | 6.1807714     | 1.0980734      | <.0001|   | 2              |
| 35     | 7.2728500     | 1.0271536      | <.0001|   | 3              |
| 45     | 11.9775000    | 1.0271536      | <.0001|   | 4              |

**Least Squares Means for effect Temp**

Pr > |t| for H0: LSMean(i)=LSMean(j)  
Dependent Variable: C14Suc

<table>
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<tr>
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<th>4</th>
</tr>
</thead>
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<td>0.0003</td>
<td>0.0013</td>
<td>0.6371</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.0003</td>
<td>0.4741</td>
<td>0.0007</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.0013</td>
<td>0.4741</td>
<td>0.0033</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.6371</td>
<td>0.0007</td>
<td>0.0033</td>
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</table>

Table A.3.3A. One-way analyses of variance for $^{14}C$-glucose (mmol C·m$^{-2}$) retained in leaves of *P. lanceolata* plants exposed to four temperatures in Table 2.2.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS†</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>3</td>
<td>237.33</td>
<td>9.37</td>
<td>&lt;.0001</td>
<td>0.5196</td>
<td>30.46</td>
</tr>
<tr>
<td>Error</td>
<td>26</td>
<td>219.45</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>29</td>
<td>456.78</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.3.3B. One-way analyses of variance for $^{14}C$-glucose (mmol C·m$^{-2}$) retained in leaves of *P. lanceolata* plants exposed to four temperatures in Table 2.2.

<table>
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<tr>
<th>Source</th>
<th>DF</th>
<th>SS†</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>3</td>
<td>65.09</td>
<td>14.28</td>
<td>&lt;.0001</td>
<td>0.6048</td>
<td>25.69</td>
</tr>
<tr>
<td>Error</td>
<td>28</td>
<td>42.52</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)
Table A.3.3B. Multiple mean comparison for $^{14}$C-glucose (mmol C·m$^{-2}$) retained in leaves of $P. lanceolata$ plants exposed to four temperatures in Table 2.2.

| Temp | C14Glurid LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|------|------------------|----------------|------|---|----------------|
| 15   | 4.62839250       | 0.43570597     | <.0001 | 1 |
| 25   | 5.49109375       | 0.43570597     | <.0001 | 2 |
| 35   | 6.47000000       | 0.43570597     | <.0001 | 3 |
| 45   | 2.59993250       | 0.43570597     | <.0001 | 4 |

Least Squares Means for effect Temp
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: C14Glurid

<table>
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</thead>
<tbody>
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<td>1</td>
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<td>0.0058</td>
<td>0.0027</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.1725</td>
<td>0.1234</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.0058</td>
<td>0.1234</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.0027</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
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</tr>
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</table>

Table A.3.4A. One-way analyses of variance for $^{14}$C-fructose (mmol C·m$^{-2}$) retained in leaves of $P. lanceolata$ plants exposed to four temperatures in Table 2.2.

One -way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
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<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
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</thead>
<tbody>
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<td>40.99</td>
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<td>&lt;.0001</td>
<td>0.6303</td>
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<tr>
<td>Corrected Total</td>
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<td>65.04</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.3.4B. Multiple mean comparison for $^{14}$C-fructose (mmol C·m$^{-2}$) retained in leaves of $P. lanceolata$ plants exposed to four temperatures in Table 2.2.

| Temp | C14Fru LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|------|---------------|----------------|------|---|----------------|
| 15   | 2.84830750    | 0.33998473     | <.0001 | 1 |
| 25   | 4.64875167    | 0.39258055     | <.0001 | 2 |
| 35   | 5.02784500    | 0.33998473     | <.0001 | 3 |
| 45   | 2.29526625    | 0.33998473     | <.0001 | 4 |

Least Squares Means for effect Temp
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: C14Fru

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>1</td>
<td>0.0018</td>
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<td>0.2605</td>
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<tr>
<td>2</td>
<td>0.0018</td>
<td>0.4719</td>
<td>0.0001</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.0001</td>
<td>0.4719</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.2605</td>
<td>0.0001</td>
<td>&lt;.0001</td>
<td></td>
</tr>
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</table>
Table A.3.5A. One-way analyses of variance for $^{14}$C-sorbitol (mmol C·m$^{-2}$) retained in leaves of *P. lanceolata* plants exposed to four temperatures in Table 2.2.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS $^1$</th>
<th>Value</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>139.13</td>
<td>25.85</td>
<td>&lt;.0001</td>
<td>0.7417</td>
<td>18.22</td>
</tr>
<tr>
<td>Error</td>
<td>27</td>
<td>48.44</td>
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<td></td>
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</tr>
<tr>
<td>Corrected Total</td>
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<td>187.57</td>
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</tr>
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</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.3.5B. Multiple means comparison for $^{14}$C-sorbitol (mmol C·m$^{-2}$) retained in leaves of *P. lanceolata* plants exposed to four temperatures in Table 2.2.

| Temp | C14Sorb LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|------|----------------|----------------|-------|---|----------------|
| 15   | 5.13143750     | 0.47358420     | <.0001| 1 |                |
| 25   | 5.21317143     | 0.50628281     | <.0001| 2 |                |
| 35   | 9.21548750     | 0.47358420     | <.0001| 3 |                |
| 45   | 9.58460000     | 0.47358420     | <.0001| 4 |                |

Least Squares Means for effect Temp
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: C14Sorb

<table>
<thead>
<tr>
<th>i/j</th>
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<th>2</th>
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<th>4</th>
</tr>
</thead>
<tbody>
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<td>&lt;.0001</td>
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<tr>
<td>2</td>
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<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.5861</td>
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</tr>
<tr>
<td>4</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.5861</td>
<td></td>
</tr>
</tbody>
</table>

Table A.3.6A. One-way analyses of variance for $^{14}$C-sucrose to sorbitol (mmol C·m$^{-2}$) retained in leaves of *P. lanceolata* plants exposed to four temperatures in Table 2.2.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS $^1$</th>
<th>Value</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>4.73</td>
<td>10.23</td>
<td>0.0002</td>
<td>0.5717</td>
<td>31.88</td>
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<tr>
<td>Error</td>
<td>23</td>
<td>3.55</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>26</td>
<td>8.28</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.3.6B. Multiple mean comparison for $^{14}$C-sucrose to sorbitol (mmol C·m$^{-2}$) retained in leaves of *P. lanceolata* plants exposed to four temperatures in Table 2.2.

| Temp | SucSorb LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|------|----------------|----------------|-------|---|----------------|
| 15   | 2.12380236     | 0.19635695     | <.0001| 1 |                |
| 25   | 1.17965315     | 0.14843190     | <.0001| 2 |                |
| 35   | 0.79549227     | 0.13884533     | <.0001| 3 |                |
| 45   | 1.26847927     | 0.13884533     | <.0001| 4 |                |

Least Squares Means for effect Temp
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: SucSorb

<table>
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<tr>
<th>i/j</th>
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<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.0008</td>
<td>&lt;.0001</td>
<td>0.0017</td>
<td></td>
</tr>
</tbody>
</table>

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Table A.4.1A. One-way analyses of variance for leaf photosynthesis (µmol C·m⁻²·s⁻¹) of *P. lanceolata* exposed to CO₂ and O₂ treatments % relative to the ambient condition in Table 2.3. Data expressed as percentage were log transformed prior to analysis.

<table>
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<tr>
<th>Source</th>
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<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
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</thead>
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<td>28</td>
<td>2.32</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>31</td>
<td>3.85</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.4.1B. Multiple mean comparisons for leaf photosynthesis (µmol C·m⁻²·s⁻¹) of *P. lanceolata* exposed to CO₂ and O₂ treatments % relative to the ambient condition in Table 2.3. Data expressed as percentage were log transformed prior to analysis.

<table>
<thead>
<tr>
<th>CO2</th>
<th>NCERp LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>40;21</td>
<td>4.60517019</td>
<td>0.10176267</td>
<td>&lt;.0001</td>
<td>1</td>
</tr>
<tr>
<td>40;2</td>
<td>4.84865487</td>
<td>0.10176267</td>
<td>&lt;.0001</td>
<td>2</td>
</tr>
<tr>
<td>91;21</td>
<td>4.96628431</td>
<td>0.10176267</td>
<td>&lt;.0001</td>
<td>3</td>
</tr>
<tr>
<td>91;2</td>
<td>5.21244598</td>
<td>0.10176267</td>
<td>&lt;.0001</td>
<td>4</td>
</tr>
</tbody>
</table>

Table A.4.2A. One-way analyses of variance for leaf transpiration (mmol H₂O·m⁻²·s⁻¹) of *P. lanceolata* exposed to CO₂ and O₂ treatments % relative to the ambient condition in Table 2.3. Data expressed as percentage were log transformed prior to analysis.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS†</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>3</td>
<td>0.57</td>
<td>2.98</td>
<td>0.0486</td>
<td>0.2417</td>
<td>5.60</td>
</tr>
<tr>
<td>Error</td>
<td>28</td>
<td>1.80</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>31</td>
<td>2.37</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.4.2B. Multiple mean comparison for leaf transpiration (mmol H₂O·m⁻²·s⁻¹) of *P. lanceolata* exposed to CO₂ and O₂ treatments % relative to the ambient condition in Table 2.3. Data expressed as percentage were log transformed prior to analysis.

<table>
<thead>
<tr>
<th>CO2</th>
<th>Transp LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>40;21</td>
<td>4.60517019</td>
<td>0.08963309</td>
<td>&lt;.0001</td>
<td>1</td>
</tr>
<tr>
<td>40;2</td>
<td>4.65690545</td>
<td>0.08963309</td>
<td>&lt;.0001</td>
<td>2</td>
</tr>
<tr>
<td>91;21</td>
<td>4.30673857</td>
<td>0.08963309</td>
<td>&lt;.0001</td>
<td>3</td>
</tr>
<tr>
<td>CO2</td>
<td>Transp LSMEAN</td>
<td>Standard Error</td>
<td>Pr &gt;</td>
<td>t</td>
</tr>
<tr>
<td>-----</td>
<td>---------------</td>
<td>----------------</td>
<td>--------</td>
<td>----</td>
</tr>
<tr>
<td>91;2</td>
<td>4.54130304</td>
<td>0.08963309</td>
<td>&lt;.0001</td>
<td></td>
</tr>
</tbody>
</table>

**Least Squares Means for effect CO2**

Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: Transp

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.6863</td>
<td>0.0258</td>
<td>0.6183</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.6863</td>
<td>0.0100</td>
<td>0.3696</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.0258</td>
<td>0.0100</td>
<td>0.0748</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.6183</td>
<td>0.3696</td>
<td>0.0748</td>
<td></td>
</tr>
</tbody>
</table>

Table A.4.3A. One-way analyses of variance for leaf WUE (µmol C/mmol H\(_2\)O) of *P. lanceolata* exposed to CO\(_2\) and O\(_2\) treatments % relative to the ambient condition in Table 2.3. Data expressed as percentage were arcsine square root transformed prior to analysis.

**One-way ANOVA**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS(^1)</th>
<th>Value</th>
<th>Pr&gt;F</th>
<th>R(^2)</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>3</td>
<td>2.39</td>
<td>84.35</td>
<td>&lt;.0001</td>
<td>0.9078</td>
<td>1.95</td>
</tr>
<tr>
<td>Error</td>
<td>26</td>
<td>0.24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>29</td>
<td>2.63</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)Sum of squares for model parameters are those of type III (SAS)

Table A.4.3B. One-way analyses of variance for leaf WUE (µmol C/mmol H\(_2\)O) of *P. lanceolata* exposed to CO\(_2\) and O\(_2\) treatments % relative to the ambient condition in Table 2.3. Data expressed as percentage were log transformed prior to analysis.

| CO2 | WUEp LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|-----|--------------|----------------|--------|----|----------------|
| 40;21 | 4.60517019 | 0.03415823 | <.0001 | | 1 |
| 40;2 | 4.79682491 | 0.03415823 | <.0001 | | 2 |
| 91;21 | 5.20389098 | 0.03944253 | <.0001 | | 3 |
| 91;2 | 5.27889672 | 0.03415823 | <.0001 | | 4 |

**Least Squares Means for effect CO2**

Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: WUEp

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0005</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.0005</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.1625</td>
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</tr>
<tr>
<td>4</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.1625</td>
<td></td>
</tr>
</tbody>
</table>

Table A.4.4A. One-way analyses of variance for leaf Export (µmol C·m\(^{-2}\)) of *P. lanceolata* exposed to CO\(_2\) and O\(_2\) treatments % relative to the ambient condition in Table 2.3. Data expressed as percentage were arcsine square root transformed prior to analysis.

**Two-way ANOVA**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS(^1)</th>
<th>Value</th>
<th>Pr&gt;F</th>
<th>R(^2)</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>3</td>
<td>3.14</td>
<td>7.91</td>
<td>0.0006</td>
<td>0.4679</td>
<td>7.78</td>
</tr>
<tr>
<td>Error</td>
<td>27</td>
<td>3.57</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>30</td>
<td>6.71</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)Sum of squares for model parameters are those of type III (SAS)
Table A.4.4B. Multiple mean comparison for leaf Export (µmol C·m\(^{-2}\)) of \textit{P. lanceolata} exposed to CO\(_2\) and O\(_2\) treatments % relative to the ambient condition in Table 2.3. Data expressed as percentage were log transformed prior to analysis.

| CO2   | Expp  | LSMEAN  | Standard Error | Pr > |l| | LSMEAN Number |
|-------|-------|---------|----------------|------|---|----------------|
| 40;21 | 40.21 | 4.60517019 | 0.12860569  | <.0001 | 1 |
| 40;2  | 4.84677431 | 0.12860569 | <.0001 | 2 |
| 91;21 | 4.84677431 | 0.12860569 | <.0001 | 3 |
| 91;2  | 5.02970576 | 0.12860569 | <.0001 | 4 |

Least Squares Means for effect CO2
Pr > |l| for H0: LSMean(i)=LSMean(j)
Dependent Variable: Expp

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.1952</td>
<td>0.0254</td>
<td>0.0273</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.1952</td>
<td>0.0011</td>
<td>0.3234</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.0254</td>
<td>0.0011</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.0273</td>
<td>0.3234</td>
<td>&lt;.0001</td>
<td></td>
</tr>
</tbody>
</table>

Table A.5.1A. One-way analyses of variance for \(^{14}\)C-starch (mmol C·m\(^{-2}\)) retained in leaves of \textit{P. lanceolata} plants exposed to CO\(_2\) and O\(_2\) treatments in Table 2.4.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS(^1)</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R(^2)</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>3</td>
<td>82999.81</td>
<td>3.99</td>
<td>0.0233</td>
<td>0.3862</td>
<td>34.63</td>
</tr>
<tr>
<td>Error</td>
<td>19</td>
<td>13190.66</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>22</td>
<td>21490.47</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)Sum of squares for model parameters are those of type III (SAS)

Table A.5.1B. One-way analyses of variance for \(^{14}\)C-starch (mmol C·m\(^{-2}\)) retained in leaves of \textit{P. lanceolata} plants exposed to CO\(_2\) and O\(_2\) treatments in Table 2.4.

| CO2   | C14Insol | LSMEAN  | Standard Error | Pr > |l| | LSMEAN Number |
|-------|----------|---------|----------------|------|---|----------------|
| 40;21 | 40.21    | 60.288500 | 10.756746  | <.0001 | 1 |
| 40;2  | 56.353833 | 10.756746 | <.0001 | 2 |
| 91;21 | 91.484167 | 10.756746 | <.0001 | 3 |
| 91;2  | 101.472800 | 11.783425 | <.0001 | 4 |

Least Squares Means for effect CO2
Pr > |l| for H0: LSMean(i)=LSMean(j)
Dependent Variable: C14Insol

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.7987</td>
<td>0.0618</td>
<td>0.0183</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.7987</td>
<td>0.0370</td>
<td>0.0107</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.0618</td>
<td>0.0370</td>
<td>0.4993</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.0183</td>
<td>0.0107</td>
<td>0.4993</td>
<td></td>
</tr>
</tbody>
</table>
Table A.5.2A. One-way analyses of variance for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in leaves of *P. lanceolata* plants exposed to CO$_2$ and O$_2$ treatments in Table 2.4.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS†</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>3</td>
<td>1935.15</td>
<td>7.78</td>
<td>0.002</td>
<td>0.6576</td>
<td>24.55</td>
</tr>
<tr>
<td>Error</td>
<td>19</td>
<td>1007.49</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>22</td>
<td>2942.64</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)*

Table A.5.2B. Multiple mean comparison for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in leaves of *P. lanceolata* plants exposed to CO$_2$ and O$_2$ treatments in Table 2.4.

<table>
<thead>
<tr>
<th>CO2</th>
<th>C14Suc LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>40:21</td>
<td>16.0224200</td>
<td>3.3457874</td>
<td>0.0001</td>
<td>1</td>
</tr>
<tr>
<td>40:2</td>
<td>33.4325000</td>
<td>3.3457874</td>
<td>&lt;.0001</td>
<td>2</td>
</tr>
<tr>
<td>91:21</td>
<td>28.3636167</td>
<td>3.0542721</td>
<td>&lt;.0001</td>
<td>3</td>
</tr>
<tr>
<td>91:2</td>
<td>42.1674667</td>
<td>3.0542721</td>
<td>&lt;.0001</td>
<td>4</td>
</tr>
</tbody>
</table>

Table A.5.3A. One-way analyses of variance for $^{14}$C-sorbitol (mmol C·m$^{-2}$) retained in leaves of *P. lanceolata* plants exposed to CO$_2$ and O$_2$ treatments in Table 2.4.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS†</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>3</td>
<td>61.47</td>
<td>0.73</td>
<td>0.5480</td>
<td>0.1083</td>
<td>28.11</td>
</tr>
<tr>
<td>Error</td>
<td>18</td>
<td>505.91</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>21</td>
<td>567.38</td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)*

Table A.5.3A. Multiple mean comparisons for $^{14}$C-sorbitol (mmol C·m$^{-2}$) retained in leaves of *P. lanceolata* plants exposed to CO$_2$ and O$_2$ treatments in Table 2.4.

<table>
<thead>
<tr>
<th>CO2</th>
<th>C14Sorb LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>40:21</td>
<td>21.2972600</td>
<td>2.3709129</td>
<td>&lt;.0001</td>
<td>1</td>
</tr>
<tr>
<td>40:2</td>
<td>19.4249333</td>
<td>2.1643375</td>
<td>&lt;.0001</td>
<td>2</td>
</tr>
<tr>
<td>91:2</td>
<td>16.6729500</td>
<td>2.1643375</td>
<td>&lt;.0001</td>
<td>3</td>
</tr>
<tr>
<td>91:21</td>
<td>18.3796000</td>
<td>2.3709129</td>
<td>&lt;.0001</td>
<td>4</td>
</tr>
</tbody>
</table>

Table A.5.3B. Least Squares Means for effect CO2

<table>
<thead>
<tr>
<th>CO2</th>
<th>C14Sor LMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMean Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>40:21</td>
<td>21.2972600</td>
<td>2.3709129</td>
<td>&lt;.0001</td>
<td>1</td>
</tr>
<tr>
<td>40:2</td>
<td>19.4249333</td>
<td>2.1643375</td>
<td>&lt;.0001</td>
<td>2</td>
</tr>
<tr>
<td>91:2</td>
<td>16.6729500</td>
<td>2.1643375</td>
<td>&lt;.0001</td>
<td>3</td>
</tr>
<tr>
<td>91:21</td>
<td>18.3796000</td>
<td>2.3709129</td>
<td>&lt;.0001</td>
<td>4</td>
</tr>
</tbody>
</table>

Table A.5.3B. Least Squares Means for effect C14Suc

<table>
<thead>
<tr>
<th>CO2</th>
<th>C14Suc LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMean Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>40:21</td>
<td>16.0224200</td>
<td>3.3457874</td>
<td>0.0001</td>
<td>1</td>
</tr>
<tr>
<td>40:2</td>
<td>33.4325000</td>
<td>3.3457874</td>
<td>&lt;.0001</td>
<td>2</td>
</tr>
<tr>
<td>91:21</td>
<td>28.3636167</td>
<td>3.0542721</td>
<td>&lt;.0001</td>
<td>3</td>
</tr>
<tr>
<td>91:2</td>
<td>42.1674667</td>
<td>3.0542721</td>
<td>&lt;.0001</td>
<td>4</td>
</tr>
</tbody>
</table>

Table A.5.3B. Least Squares Means for effect C14Sorb

<table>
<thead>
<tr>
<th>CO2</th>
<th>C14Sor LMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMean Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>40:21</td>
<td>21.2972600</td>
<td>2.3709129</td>
<td>&lt;.0001</td>
<td>1</td>
</tr>
<tr>
<td>40:2</td>
<td>19.4249333</td>
<td>2.1643375</td>
<td>&lt;.0001</td>
<td>2</td>
</tr>
<tr>
<td>91:2</td>
<td>16.6729500</td>
<td>2.1643375</td>
<td>&lt;.0001</td>
<td>3</td>
</tr>
<tr>
<td>91:21</td>
<td>18.3796000</td>
<td>2.3709129</td>
<td>&lt;.0001</td>
<td>4</td>
</tr>
</tbody>
</table>

Table A.5.3B. Least Squares Means for effect C14Suc
Table A.5.4A. One-way analysis of variance for $^{14}$C-sucrose to sorbitol (mmol C·m$^{-2}$) retained in leaves of *P. lanceolata* plants exposed to CO$_2$ and O$_2$ treatments in Table 2.4.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>7.77</td>
<td>51.77</td>
<td>&lt;.0001</td>
<td>0.9013</td>
<td>14.44</td>
</tr>
<tr>
<td>Error</td>
<td>17</td>
<td>0.85</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>20</td>
<td>8.62</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.5.4B. Multiple mean comparison for $^{14}$C-sucrose to sorbitol (mmol C·m$^{-2}$) retained in leaves of *P. lanceolata* plants exposed to CO$_2$ and O$_2$ treatments in Table 2.4.

<table>
<thead>
<tr>
<th>CO2</th>
<th>SucSorb</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>40;21</td>
<td>0.75108748</td>
<td>0.09130416</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>40;2</td>
<td>1.56238477</td>
<td>0.10001870</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>91;21</td>
<td>1.68031252</td>
<td>0.09130416</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>91;2</td>
<td>2.52926812</td>
<td>0.11182431</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Table A.5.5A. One-way analysis of variance for $^{14}$C-Sucrose recovered from petiole tissues of *P. lanceolata* plants exposed to CO$_2$ and O$_2$ treatments in Table 2.4. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>3</td>
<td>0.02</td>
<td>2.01</td>
<td>0.1442</td>
<td>0.2321</td>
<td>4.42</td>
</tr>
<tr>
<td>Error</td>
<td>20</td>
<td>0.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>23</td>
<td>0.07</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.5.5B. Multiple mean comparisons for $^{14}$C-Sucrose recovered from petiole tissues of *P. lanceolata* plants exposed to CO$_2$ and O$_2$ treatments in Table 2.4. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>CO2</th>
<th>TotalSuc100</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>40;21</td>
<td>1.22548652</td>
<td>0.02175666</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>40;2</td>
<td>1.19091951</td>
<td>0.02175666</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>
Table A.5.6A. One-way analysis of variance for $^{14}$C-sorbitol recovered from petiole tissues of *P. lanceolata* plants exposed to CO$_2$ and O$_2$ treatments in Table 2.4. Data expressed as percentage were arcsine square root transformed prior to analysis.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>3</td>
<td>0.01</td>
<td>1.92</td>
<td>0.1591</td>
<td>0.2235</td>
<td>14.02</td>
</tr>
<tr>
<td>Error</td>
<td>20</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.5.6B. Multiple mean comparisons for $^{14}$C-sorbitol recovered from petiole tissues of *P. lanceolata* plants exposed to CO$_2$ and O$_2$ treatments in Table 2.4. Data expressed as percentage were arcsine square root transformed prior to analysis.

Least Squares Means for effect CO2

<table>
<thead>
<tr>
<th>CO2 TotalSorb100 LSMEAN Standard Error Pr &gt;</th>
<th>t</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>91;21 1.23426725 0.02175666 &lt;.0001 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>91;2  1.6775244 0.02175666 &lt;.0001 4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Least Squares Means for effect CO2

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.2746</td>
<td>0.7783</td>
<td>0.0753</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.2746</td>
<td>0.1742</td>
<td>0.4603</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.7783</td>
<td>0.1742</td>
<td>0.0429</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.0753</td>
<td>0.4603</td>
<td>0.0429</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table A.5.7A. One-way analysis of variance for $^{14}$C-sucrose to sorbitol recovered from petiole tissues of *P. lanceolata* plants exposed to CO$_2$ and O$_2$ treatments in Table 2.4. Data expressed as percentage were arcsine square root transformed prior to analysis.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>3</td>
<td>33.66</td>
<td>2.11</td>
<td>0.1315</td>
<td>0.2401</td>
<td>32.04</td>
</tr>
<tr>
<td>Error</td>
<td>20</td>
<td>106.52</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^2$Sum of squares for model parameters are those of type III (SAS)
Table A.5.7B. Multiple mean comparisons for $^{14}$C-sucrose to sorbitol recovered from petiole tissues of *P. lanceolata* plants exposed to CO$_2$ and O$_2$ treatments in Table 2.4.

| CO2 | SucSorb LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|-----|----------------|----------------|------|    |----------------|
| 40;21 | 7.41757348 | 0.94215012 | <.0001 | 1 |
| 40;2 | 6.78467454 | 0.94215012 | <.0001 | 2 |
| 91;21 | 8.94320780 | 0.94215012 | <.0001 | 3 |
| 91;2 | 5.66666383 | 0.94215012 | <.0001 | 4 |

Least Squares Means for effect CO2

Pr > |t| for H0: LSMean(i)=LSMean(j)

<table>
<thead>
<tr>
<th>Dependent Variable: SucSorb</th>
</tr>
</thead>
<tbody>
<tr>
<td>i/j</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
</tbody>
</table>

Table A.6.1A. Two-way analysis of variance for whole plant photosynthesis (µmol C·m$^{-2}$·s$^{-1}$) to compare GI and GIV exposed to three different temperatures in Table 3.1.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>178.22</td>
<td>21.02</td>
<td>&lt;.0001</td>
<td>0.6178</td>
<td>7.35</td>
</tr>
<tr>
<td>Error</td>
<td>65</td>
<td>110.24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>70</td>
<td>288.47</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>71.28</td>
<td>42.09</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>106.10</td>
<td>31.28</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*Temp</td>
<td>2</td>
<td>0.42</td>
<td>0.12</td>
<td>0.8846</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)*

Table A.6.1B. Numerical difference and standard error of the estimate for whole plant photosynthesis (µmol C·m$^{-2}$·s$^{-1}$) to compare GI and GIV *A. majus* exposed to three different temperatures in Table 3.1.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>Photosynthesis</td>
<td>15°C</td>
<td>1.85</td>
<td>0.53</td>
<td>3.49</td>
<td>0.0009</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Photosynthesis</td>
<td>25°C</td>
<td>2.22</td>
<td>0.54</td>
<td>4.08</td>
<td>0.0001</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Photosynthesis</td>
<td>35°C</td>
<td>1.95</td>
<td>0.53</td>
<td>3.66</td>
<td>0.0005</td>
</tr>
</tbody>
</table>

Table A.6.1C. Multiple mean comparisons for whole plant photosynthesis (µmol C·m$^{-2}$·s$^{-1}$) to compare GI and GIV exposed to three different temperatures in Table 3.1.

| CV | Trt | NCERd LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|----|-----|--------------|----------------|------|    |----------------|
| GI | 15  | 15.1952342   | 0.3759512 | <.0001 | 1  |
| GI | 25  | 16.8096402   | 0.3926683 | <.0001 | 2  |
| GI | 35  | 18.0994013   | 0.3759512 | <.0001 | 3  |
| GIV| 15  | 17.0491965   | 0.3759512 | <.0001 | 4  |
| GIV| 25  | 19.0275016   | 0.3759512 | <.0001 | 5  |
| GIV| 35  | 20.0469114   | 0.3759512 | <.0001 | 6  |

Least Squares Means for effect CV*trt

Pr > |t| for H0: LSMean(i)=LSMean(j)

<table>
<thead>
<tr>
<th>Dependent Variable: NCERd</th>
</tr>
</thead>
<tbody>
<tr>
<td>i/j</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
</tbody>
</table>

171
Table A.6.2A. Two-way analysis of variance for whole plant dark respiration (µmol C·m⁻²·s⁻¹) to compare GI and GIV exposed to three different temperatures in Table 3.1.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS ¹</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>6.34</td>
<td>8.10</td>
<td>&lt;.0001</td>
<td>0.3874</td>
<td>14.02</td>
</tr>
<tr>
<td>Error</td>
<td>64</td>
<td>10.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>69</td>
<td>16.36</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>3.07</td>
<td>19.61</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>2.12</td>
<td>6.76</td>
<td>0.0022</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*Temp</td>
<td>2</td>
<td>1.02</td>
<td>3.26</td>
<td>0.0448</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹Sum of squares for model parameters are those of type III (SAS)

Table A.6.2B. Numerical difference and standard error of the estimate for whole plant dark respiration (µmol C·m⁻²·s⁻¹) to compare GI and GIV. *A. majus* exposed to three different temperatures in Table 3.1.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>Dark-Respiration</td>
<td>15°C</td>
<td>0.69</td>
<td>0.16</td>
<td>4.32</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Dark-Respiration</td>
<td>25°C</td>
<td>0.11</td>
<td>0.16</td>
<td>0.67</td>
<td>0.5071</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Dark-Respiration</td>
<td>35°C</td>
<td>0.45</td>
<td>0.16</td>
<td>2.72</td>
<td>0.0084</td>
</tr>
</tbody>
</table>

Table A.6.2C. Multiple mean comparisons for whole dark respiration (µmol C·m⁻²·s⁻¹) to compare GI and GIV exposed to three different temperatures in Table 3.1.

<table>
<thead>
<tr>
<th>CV Temp</th>
<th>NCREn</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td>15</td>
<td>-2.22841006</td>
<td>0.11421718</td>
<td>&lt;.0001</td>
<td>1</td>
</tr>
<tr>
<td>GI</td>
<td>25</td>
<td>-2.90339091</td>
<td>0.11929595</td>
<td>&lt;.0001</td>
<td>2</td>
</tr>
<tr>
<td>GI</td>
<td>35</td>
<td>-2.70345168</td>
<td>0.11929595</td>
<td>&lt;.0001</td>
<td>3</td>
</tr>
<tr>
<td>GIV</td>
<td>15</td>
<td>-2.92686516</td>
<td>0.11421718</td>
<td>&lt;.0001</td>
<td>4</td>
</tr>
<tr>
<td>GIV</td>
<td>25</td>
<td>-3.01355833</td>
<td>0.11421718</td>
<td>&lt;.0001</td>
<td>5</td>
</tr>
<tr>
<td>GIV</td>
<td>35</td>
<td>-3.15229535</td>
<td>0.11421718</td>
<td>&lt;.0001</td>
<td>6</td>
</tr>
</tbody>
</table>

Table A.6.2D. Least Squares Means for effect CV*trt

<table>
<thead>
<tr>
<th>Pr &gt;</th>
<th>LSMEAN</th>
<th>Dependent Variable: NCREn</th>
</tr>
</thead>
<tbody>
<tr>
<td>i/j</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>0.0001</td>
<td>0.0055</td>
</tr>
<tr>
<td>2</td>
<td>0.0055</td>
<td>0.2404</td>
</tr>
<tr>
<td>3</td>
<td>0.2404</td>
<td>0.1809</td>
</tr>
<tr>
<td>4</td>
<td>&lt;.0001</td>
<td>0.8874</td>
</tr>
</tbody>
</table>
Table A.6.3A. Two-way analysis of variance for whole plant transpiration (mmol H$_2$O·m$^{-2}$·s$^{-1}$) to compare GI and GIV exposed to three different temperatures in Table 3.1.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>$^2$F</th>
<th>Pr&gt;F</th>
<th>$^2$R</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>15.67</td>
<td>43.59</td>
<td>&lt;.0001</td>
<td>0.8257</td>
<td>15.09</td>
</tr>
<tr>
<td>Error</td>
<td>46</td>
<td>3.31</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>51</td>
<td>18.97</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>0.37</td>
<td>4.55</td>
<td>0.0281</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>15.17</td>
<td>105.51</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*Temp</td>
<td>2</td>
<td>0.17</td>
<td>1.19</td>
<td>0.3128</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.6.3B. Numerical difference and standard error of the estimate for whole plant transpiration (mmol H$_2$O·m$^{-2}$·s$^{-1}$) to compare GI and GIV A. majus exposed to three different temperatures in Table 3.1.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>Transpiration</td>
<td>15°C</td>
<td>0.18</td>
<td>0.13</td>
<td>1.77</td>
<td>0.1906</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Transpiration</td>
<td>25°C</td>
<td>0.03</td>
<td>0.12</td>
<td>0.35</td>
<td>0.8206</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Transpiration</td>
<td>35°C</td>
<td>0.30</td>
<td>0.13</td>
<td>1.53</td>
<td>0.0284</td>
</tr>
</tbody>
</table>

Table A.6.3C. Multiple mean comparisons for whole plant transpiration (mmol H$_2$O·m$^{-2}$·s$^{-1}$) to compare GI and GIV exposed to three different temperatures in Table 3.1.

| CV | Temp | Transd LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|----|------|--------------|----------------|-------|------|----------------|
| GI | 15   | 1.04289250   | 0.09478549     | <.0001|     | 1              |
| GI | 25   | 1.69919900   | 0.08477872     | <.0001|     | 2              |
| GI | 35   | 2.35109875   | 0.09478549     | <.0001|     | 3              |
| GIV| 15   | 1.22096750   | 0.09478549     | <.0001|     | 4              |
| GIV| 25   | 1.72803400   | 0.08477872     | <.0001|     | 5              |
| GIV| 35   | 2.65436250   | 0.09478549     | <.0001|     | 6              |

Table A.6.3D. Least squares means for effect CV*Temp for H0: LSMean(i)=LSMean(j) for whole plant transpiration (mmol H$_2$O·m$^{-2}$·s$^{-1}$) to compare GI and GIV exposed to three different temperatures in Table 3.1.

Least Squares Means for effect CV*Temp
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: Transd

<table>
<thead>
<tr>
<th>i/j</th>
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<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.1906</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0005</td>
<td>0.8206</td>
<td>&lt;.0001</td>
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</tr>
<tr>
<td>3</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0284</td>
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</tr>
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<td>4</td>
<td>0.1906</td>
<td>0.0005</td>
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<td>0.0002</td>
<td>&lt;.0001</td>
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<td>0.8206</td>
<td>&lt;.0001</td>
<td>0.0002</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0284</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
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</tr>
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</table>
Table A.6.4A. Two-way analysis of variance for whole plant WUE (µmol C/mmol H₂O) to compare GI and GIV exposed to three different temperatures in Table 3.1.

<table>
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<tr>
<th>Source</th>
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<th>P &gt; F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>353.69</td>
<td>21.24</td>
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<td>0.7024</td>
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</tr>
<tr>
<td>Error</td>
<td>45</td>
<td>149.84</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>50</td>
<td>503.54</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>333.41</td>
<td>50.06</td>
<td>&lt;.0001</td>
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<td></td>
</tr>
<tr>
<td>CV*Temp</td>
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<td>14.73</td>
<td>2.21</td>
<td>0.1213</td>
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<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.6.4B. Numerical difference and standard error of the estimate for whole plant WUE (µmol C/mmol H₂O) to compare GI and GIV * A. majus exposed to three different temperatures in Table 3.1.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>WUE</td>
<td>15°C</td>
<td>1.35</td>
<td>0.94</td>
<td>1.43</td>
<td>0.1584</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>WUE</td>
<td>25°C</td>
<td>1.25</td>
<td>0.82</td>
<td>1.54</td>
<td>0.1317</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>WUE</td>
<td>35°C</td>
<td>0.13</td>
<td>0.91</td>
<td>0.14</td>
<td>0.887</td>
</tr>
</tbody>
</table>

Table A.6.4C. Multiple mean comparisons for whole plant WUE (µmol C/mmol H₂O) to compare GI and GIV exposed to three different temperatures in Table 3.1.

<table>
<thead>
<tr>
<th>CV</th>
<th>Temp</th>
<th>WUED</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td>15</td>
<td>14.8554091</td>
<td>0.6451590</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>25</td>
<td>9.9606006</td>
<td>0.5770477</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>35</td>
<td>7.6769368</td>
<td>0.6451590</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>15</td>
<td>13.5008021</td>
<td>0.6897039</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>25</td>
<td>11.2134787</td>
<td>0.5770477</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>35</td>
<td>7.5484933</td>
<td>0.6451590</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

Table A.6.5A. Two-way analysis of variance for whole plant C-gain (g C·m⁻²) to compare GI and GIV exposed to three different temperatures in Table 3.1.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>P &gt; F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>46.10</td>
<td>20.82</td>
<td>&lt;.0001</td>
<td>0.6156</td>
<td>7.26</td>
</tr>
<tr>
<td>Error</td>
<td>65</td>
<td>28.78</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>70</td>
<td>74.89</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
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<td>17.71</td>
<td>40.00</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
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<td>28.31</td>
<td>31.96</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*Temp</td>
<td>2</td>
<td>0.01</td>
<td>0.02</td>
<td>0.9843</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)
Table A.6.5B. Numerical difference and standard error of the estimate for whole plant C-gain (g C·m⁻²) to compare GI and GIV *majus exposed to three different temperatures in Table 3.1.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>C-gain</td>
<td>15°C</td>
<td>0.96</td>
<td>0.27</td>
<td>3.54</td>
<td>0.0007</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>C-gain</td>
<td>25°C</td>
<td>1.03</td>
<td>0.28</td>
<td>3.70</td>
<td>0.0004</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>C-gain</td>
<td>35°C</td>
<td>1.01</td>
<td>0.27</td>
<td>3.71</td>
<td>0.0004</td>
</tr>
</tbody>
</table>

Table A.6.5C. Multiple mean comparisons for whole plant C-gain (g C·m⁻²) to compare GI and GIV exposed to three different temperatures in Table 3.1.

<table>
<thead>
<tr>
<th>CV</th>
<th>Temp</th>
<th>Cgain LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td>15</td>
<td>7.8841213</td>
<td>0.1920995</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>25</td>
<td>8.7197669</td>
<td>0.2006414</td>
<td>&lt;.0001</td>
<td>2</td>
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<td></td>
</tr>
<tr>
<td>GI</td>
<td>35</td>
<td>9.3915230</td>
<td>0.1920995</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>15</td>
<td>8.8453176</td>
<td>0.1920995</td>
<td>&lt;.0001</td>
<td>4</td>
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<tr>
<td>GIV</td>
<td>25</td>
<td>9.7477901</td>
<td>0.1920995</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>35</td>
<td>10.4005913</td>
<td>0.1920995</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table A.6.6A. Two-way analysis of variance for whole plant C-loss (g C·m⁻²) to compare GI and GIV exposed to three different temperatures in Table 3.1.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>1.74</td>
<td>8.37</td>
<td>&lt;.0001</td>
<td>0.3993</td>
<td>12.89</td>
</tr>
<tr>
<td>Error</td>
<td>63</td>
<td></td>
<td>2.61</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>68</td>
<td>4.35</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>25.93</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Temp</td>
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<td>6.30</td>
<td>0.0030</td>
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</tr>
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<td>CV*Temp</td>
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<td>0.4401</td>
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</table>

1Sum of squares for model parameters are those of type III (SAS)

Table A.6.6B. Numerical difference and standard error of the estimate for whole plant C-loss (g C·m⁻²) to compare GI and GIV *majus exposed to three different temperatures in Table 3.1.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>C-loss</td>
<td>15°C</td>
<td>0.33</td>
<td>0.08</td>
<td>3.94</td>
<td>0.0002</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>C-loss</td>
<td>25°C</td>
<td>0.18</td>
<td>0.08</td>
<td>2.19</td>
<td>0.0350</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>C-loss</td>
<td>35°C</td>
<td>0.23</td>
<td>0.08</td>
<td>2.73</td>
<td>0.0083</td>
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</table>

Table A.6.6C. Multiple mean comparisons for whole plant C-loss (g C·m⁻²) to compare GI and GIV exposed to three different temperatures in Table 3.1.

<table>
<thead>
<tr>
<th>CV</th>
<th>Temp</th>
<th>Closs LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
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<td>2</td>
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</tr>
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</table>
### Table A.6.7A. Two-way analysis of variance for whole plant daily C-gain (g C·m⁻²·day⁻¹) to compare GI and GIV exposed to three different temperatures in Table 3.1.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
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</thead>
<tbody>
<tr>
<td>Model</td>
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<td>15.44</td>
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<td>0.5507</td>
<td>8.10</td>
</tr>
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<td>Error</td>
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</tr>
<tr>
<td>Corrected Total</td>
<td>68</td>
<td>55.22</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>11.82</td>
<td>30.01</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
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<td>17.47</td>
<td>22.18</td>
<td>&lt;.0001</td>
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</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)*

### Table A.6.7B. Numerical difference and standard error of the estimate for whole plant daily C-gain (g C·m⁻²·day⁻¹) to compare GI and GIV *A. majus* exposed to three different temperatures in Table 3.1.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>Daily C-gain</td>
<td>15°C</td>
<td>0.85</td>
<td>0.27</td>
<td>3.18</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Daily C-gain</td>
<td>25°C</td>
<td>0.84</td>
<td>0.26</td>
<td>3.23</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Daily C-gain</td>
<td>35°C</td>
<td>0.79</td>
<td>0.26</td>
<td>3.09</td>
</tr>
</tbody>
</table>

### Table A.6.7C. Multiple mean comparisons for whole plant daily C-gain (g C·m⁻²·day⁻¹) to compare GI and GIV exposed to three different temperatures in Table 3.1.

| CV | Temp | Cbudget LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|----|------|----------------|----------------|-------| |             |
| GI | 15   | 6.70900642     | 0.18115643     | .0001| | 1             |
| GI | 25   | 7.27804041     | 0.18921173     | .0001| | 2             |
| GI | 35   | 7.97299589     | 0.18115643     | .0001| | 3             |
| GIV| 15   | 7.56234334     | 0.19844693     | .0001| | 4             |
| GIV| 25   | 8.12290436     | 0.18115643     | .0001| | 5             |
| GIV| 35   | 8.76400866     | 0.18115643     | .0001| | 6             |
### Table A.7.1A. Two-way ANOVA for leaf WUE (µmol C/mmol H₂O) to compare GI and GIV exposed to three different temperatures in Figure 3.5.

<table>
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<tr>
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<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0336</td>
<td>&lt;.0001</td>
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<td>&lt;.0001</td>
<td>&lt;.0001</td>
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<tr>
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<td>0.0020</td>
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</tr>
<tr>
<td>3</td>
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<td>0.0030</td>
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</tr>
<tr>
<td>4</td>
<td>0.0023</td>
<td>0.3038</td>
<td>0.1314</td>
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<td></td>
</tr>
<tr>
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<td>0.5605</td>
<td>0.0410</td>
<td>0.0149</td>
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</tr>
<tr>
<td>6</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0030</td>
<td>&lt;.0001</td>
<td>0.0149</td>
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</tr>
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</table>

Two-way ANOVA

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<th>Mean Square</th>
<th>F</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>209.10</td>
<td>41.82</td>
<td>154.47</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
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<td>0.27</td>
<td>6.88</td>
<td>p-value</td>
</tr>
<tr>
<td>Corrected Total</td>
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<td>217.20</td>
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<td>&lt;.0001</td>
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<td>0.08</td>
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<td>5.04</td>
<td>0.0131</td>
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</tbody>
</table>

**Table A.7.1B.** Numerical difference and standard error of the estimate for leaf WUE (µmol C/mmol H₂O) to compare GI and GIV A. majus exposed to three different temperatures in Figure 3.5.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>WUE</td>
<td>15°C</td>
<td>0.95</td>
<td>0.37</td>
<td>2.59</td>
<td>0.0147</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>WUE</td>
<td>25°C</td>
<td>0.49</td>
<td>0.28</td>
<td>1.74</td>
<td>0.0920</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>WUE</td>
<td>35°C</td>
<td>0.17</td>
<td>0.28</td>
<td>0.60</td>
<td>0.5501</td>
</tr>
</tbody>
</table>

**Table A.7.1C.** Multiple mean comparisons for leaf WUE (µmol C/mmol H₂O) to compare GI and GIV exposed to three different temperatures in Figure 3.5.

<table>
<thead>
<tr>
<th>CV</th>
<th>Temp</th>
<th>WUE LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
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<td>10.9021000</td>
<td>0.2598198</td>
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<td>1</td>
</tr>
<tr>
<td>GI</td>
<td>25</td>
<td>8.0795875</td>
<td>0.1837203</td>
<td>&lt;.0001</td>
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</tr>
<tr>
<td>GI</td>
<td>35</td>
<td>5.1196000</td>
<td>0.1837203</td>
<td>&lt;.0001</td>
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</tr>
<tr>
<td>GIV</td>
<td>15</td>
<td>11.8535250</td>
<td>0.2598198</td>
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</tr>
<tr>
<td>GIV</td>
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<td>7.5911833</td>
<td>0.2121420</td>
<td>&lt;.0001</td>
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</tr>
<tr>
<td>GIV</td>
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<td>4.9499833</td>
<td>0.2121420</td>
<td>&lt;.0001</td>
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**Least Squares Means for effect CV*Temp**

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<th>5</th>
<th>6</th>
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<td>&lt;.0001</td>
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</tr>
<tr>
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<td>&lt;.0001</td>
<td>&lt;.0001</td>
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<td>&lt;.0001</td>
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<tr>
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<td>&lt;.0001</td>
<td>0.5501</td>
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<td>&lt;.0001</td>
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</table>
Table A.7.2A. Two-way analysis of variance for leaf photosynthesis (µmol C·m⁻²·s⁻¹) to compare GI and GIV exposed to three different temperatures in Figure 3.5.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>555.46</td>
<td>38.81</td>
<td>&lt;.0001</td>
<td>0.8584</td>
<td>9.49</td>
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<td>Error</td>
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<td>91.59</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
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<td>CV</td>
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<td>4.95</td>
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<td>0.1978</td>
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</tr>
<tr>
<td>Temp</td>
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<td>544.85</td>
<td>94.49</td>
<td>&lt;.0001</td>
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<td></td>
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<tr>
<td>CV*Temp</td>
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<td>8.85</td>
<td>1.55</td>
<td>0.2285</td>
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<td></td>
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</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.7.2B. Numerical difference and standard error of the estimate for leaf photosynthesis (µmol C·m⁻²·s⁻¹) to compare GI and GIV *A. majus* exposed to three different temperatures in Figure 3.5.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>Photosynthesis</td>
<td>15°C</td>
<td>1.70</td>
<td>0.98</td>
<td>1.74</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Photosynthesis</td>
<td>25°C</td>
<td>0.59</td>
<td>0.94</td>
<td>0.63</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Photosynthesis</td>
<td>35°C</td>
<td>1.06</td>
<td>0.94</td>
<td>1.13</td>
</tr>
</tbody>
</table>

Table A.7.2C. Multiple mean comparisons for leaf photosynthesis (µmol C·m⁻²·s⁻¹) to compare GI and GIV exposed to three different temperatures in Figure 3.5.

<table>
<thead>
<tr>
<th>CV</th>
<th>Temp</th>
<th>NCER</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td>15</td>
<td>11.50095000</td>
<td>0.6906615</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>25</td>
<td>21.3967143</td>
<td>0.6394283</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>35</td>
<td>19.1159429</td>
<td>0.6394283</td>
<td>&lt;.0001</td>
<td>3</td>
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</tr>
<tr>
<td>GIV</td>
<td>15</td>
<td>13.2042333</td>
<td>0.6906615</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>25</td>
<td>20.8028000</td>
<td>0.6906615</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>35</td>
<td>20.1779833</td>
<td>0.6906615</td>
<td>&lt;.0001</td>
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</table>

Table A.7.3A. Two-way analysis of variance for leaf export rate (mmol C·m⁻²) to compare GI and GIV exposed to three different temperatures in Figure 3.5.

<table>
<thead>
<tr>
<th>Source</th>
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<th>SS</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>10.10</td>
<td>&lt;.0001</td>
<td>0.6122</td>
<td>19.53</td>
</tr>
<tr>
<td>Error</td>
<td>32</td>
<td>180.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Corrected Total</td>
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<td>8.01</td>
<td>1.42</td>
<td>0.2418</td>
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<td></td>
</tr>
<tr>
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<td>255.46</td>
<td>22.69</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*Temp</td>
<td>2</td>
<td>18.08</td>
<td>1.61</td>
<td>0.2165</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)
Table A.7.3B. Numerical difference and standard error of the estimate for leaf export rate (mmol C·m⁻²) to compare GI and GIV A. majus exposed to three different temperatures in Figure 3.5.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>Export rate</td>
<td>15°C</td>
<td>0.78</td>
<td>1.37</td>
<td>0.57</td>
<td>0.5743</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Export rate</td>
<td>25°C</td>
<td>0.85</td>
<td>1.28</td>
<td>0.67</td>
<td>0.5091</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Export rate</td>
<td>35°C</td>
<td>2.69</td>
<td>1.37</td>
<td>1.97</td>
<td>0.0581</td>
</tr>
</tbody>
</table>

Table A.7.3C. Multiple mean comparisons for leaf export rate (mmol C·m⁻²) to compare GI and GIV exposed to three different temperatures in Figure 3.5.

<table>
<thead>
<tr>
<th>CV</th>
<th>Temp</th>
<th>Exp</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td>15</td>
<td>7.9561167</td>
<td>0.9685721</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>25</td>
<td>13.8838125</td>
<td>0.8388080</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>35</td>
<td>15.7012667</td>
<td>0.9685721</td>
<td>&lt;.0001</td>
<td>3</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>15</td>
<td>8.7335833</td>
<td>0.9685721</td>
<td>&lt;.0001</td>
<td>4</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>25</td>
<td>13.0282667</td>
<td>0.9685721</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>35</td>
<td>13.0092667</td>
<td>0.9685721</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
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<td></td>
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</table>

Table A.7.4A. Two-way analysis of variance for leaf relative export rate (% of photosynthesis) to compare GI and GIV exposed to three different temperatures in Figure 3.5. Data expressed as percentage were arcsine square root transformed prior to analysis.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
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</thead>
<tbody>
<tr>
<td>Model</td>
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<td>1.72</td>
<td>0.1581</td>
<td>0.2120</td>
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<tr>
<td>Error</td>
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<td>0.42</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
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</table>

1Sum of squares for model parameters are those of type III (SAS)

Table A.7.4B. Numerical difference and standard error of the estimate for leaf relative export rate (% of photosynthesis) to compare GI and GIV A. majus exposed to three different temperatures in Figure 3.5. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
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<tbody>
<tr>
<td>GI vs. GIV</td>
<td>Relative export</td>
<td>15°C</td>
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<td>0.57</td>
<td>0.57</td>
<td>0.5699</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Relative export</td>
<td>25°C</td>
<td>0.03</td>
<td>0.66</td>
<td>0.56</td>
<td>0.5770</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Relative export</td>
<td>35°C</td>
<td>0.11</td>
<td>1.61</td>
<td>1.61</td>
<td>0.1168</td>
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Table A.7.4C. Multiple mean comparisons for leaf relative export rate (% of photosynthesis) to compare GI and GIV exposed to three different temperatures in Figure 3.5. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>CV</th>
<th>Temp</th>
<th>Ratioi</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
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<th>LSMEAN Number</th>
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<td>GI</td>
<td>25</td>
<td>LSMEAN</td>
<td>13.8838125</td>
<td>0.8388080</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>35</td>
<td>LSMEAN</td>
<td>15.7012667</td>
<td>0.9685721</td>
<td>&lt;.0001</td>
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<td></td>
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<tr>
<td>GIV</td>
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<td>LSMEAN</td>
<td>8.7335833</td>
<td>0.9685721</td>
<td>&lt;.0001</td>
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<td>LSMEAN</td>
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<td>0.9685721</td>
<td>&lt;.0001</td>
<td>5</td>
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<td>GIV</td>
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<td>LSMEAN</td>
<td>13.0092667</td>
<td>0.9685721</td>
<td>&lt;.0001</td>
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<tr>
<td>CV</td>
<td>Temp</td>
<td>Ratioi</td>
<td>LSMEAN</td>
<td>Standard Error</td>
<td>Pr &gt;</td>
<td>t</td>
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<td>LSMEAN Number</td>
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<td>0.94289901</td>
<td>0.04697491</td>
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<td>6</td>
<td></td>
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<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Least Squares Means for effect CV*Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pr &gt;</td>
</tr>
<tr>
<td>Dependent Variable: Ratioi</td>
</tr>
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<td>i/j</td>
</tr>
<tr>
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</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
</tbody>
</table>

Table A.8.1A. Two-way analyses of variance for $^{14}$C-starch (mmol C·m$^{-2}$) retained in GI and GIV A. majus leaves exposed to three different temperatures in Table 3.2.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
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<th>F</th>
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<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>1831.97</td>
<td>17.85</td>
<td>&lt;.0001</td>
<td>0.7422</td>
<td>24.34</td>
</tr>
<tr>
<td>Error</td>
<td>31</td>
<td>636.26</td>
<td>0.01</td>
<td>0.9415</td>
<td>0.0003</td>
<td>0.0</td>
</tr>
<tr>
<td>Corrected Total</td>
<td>36</td>
<td>2468.23</td>
<td>0.01</td>
<td>0.9415</td>
<td>0.0003</td>
<td>0.0</td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>24.66</td>
<td>1.20</td>
<td>0.2815</td>
<td>0.1955</td>
<td>0.0</td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>1442.09</td>
<td>35.13</td>
<td>&lt;.0001</td>
<td>0.6892</td>
<td>24.34</td>
</tr>
<tr>
<td>CV*Temp</td>
<td>2</td>
<td>70.66</td>
<td>1.72</td>
<td>0.2815</td>
<td>0.1955</td>
<td>0.0</td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.8.1B. Numerical difference and standard error of the estimate for $^{14}$C-starch (mmol C·m$^{-2}$) retained in GI and GIV A. majus leaves exposed to three different temperatures in Table 3.2.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-starch</td>
<td>15°C</td>
<td>3.77</td>
<td>2.61</td>
<td>1.44</td>
<td>0.1587</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-starch</td>
<td>25°C</td>
<td>4.05</td>
<td>2.45</td>
<td>1.65</td>
<td>0.1080</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-starch</td>
<td>35°C</td>
<td>2.66</td>
<td>3.07</td>
<td>0.87</td>
<td>0.3928</td>
</tr>
</tbody>
</table>

Table A.8.1C. Multiple mean comparison for $^{14}$C-starch (mmol C·m$^{-2}$) retained in GI and GIV leaves exposed to three different temperatures in Table 3.2.
Table A.8.2A. Two-way analysis of variance for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in GI and GIV leaves exposed to three different temperatures in Table 3.2.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>908.77</td>
<td>6.40</td>
<td>0.0004</td>
<td>0.5162</td>
<td>32.26</td>
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<tr>
<td>Error</td>
<td>30</td>
<td>851.67</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Corrected Total</td>
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<td>1760.44</td>
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<td></td>
<td></td>
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<td>0.0051</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
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<td>659.08</td>
<td>11.61</td>
<td>0.0002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*Temp</td>
<td>2</td>
<td>99.70</td>
<td>1.76</td>
<td>0.1900</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)*

Table A.8.2B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in GI and GIV leaves exposed to three different temperatures in Table 3.2.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose 15°C</td>
<td>3.02</td>
<td>3.08</td>
<td>0.98</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose 25°C</td>
<td>10.22</td>
<td>3.04</td>
<td>3.36</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose 35°C</td>
<td>3.24</td>
<td>3.34</td>
<td>0.97</td>
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</tbody>
</table>

Table A.8.2C. Multiple mean comparison for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in GI and GIV leaves exposed to three different temperatures in Table 3.2.

<table>
<thead>
<tr>
<th>CV Temp</th>
<th>Suc LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI 15</td>
<td>9.9928333</td>
<td>2.1752079</td>
<td>&lt;.0001</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>GI 25</td>
<td>16.7816250</td>
<td>1.8837853</td>
<td>&lt;.0001</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>GI 35</td>
<td>15.8372857</td>
<td>2.0138512</td>
<td>&lt;.0001</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>GIV 15</td>
<td>13.0160000</td>
<td>2.1752079</td>
<td>&lt;.0001</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>GIV 25</td>
<td>27.0024000</td>
<td>2.3828209</td>
<td>&lt;.0001</td>
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<td>5</td>
</tr>
<tr>
<td>GIV 35</td>
<td>19.0825000</td>
<td>2.6640748</td>
<td>&lt;.0001</td>
<td></td>
<td>6</td>
</tr>
</tbody>
</table>

Least Squares Means for effect CV*Temp
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: Insol

<table>
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<tr>
<th>i/j</th>
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<th>2</th>
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<th>4</th>
<th>5</th>
<th>6</th>
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<tbody>
<tr>
<td>1</td>
<td>&lt;.0001</td>
<td>0.198</td>
<td>0.1587</td>
<td>0.0048</td>
<td>0.3029</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.1080</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.0198</td>
<td>&lt;.0001</td>
<td>0.3678</td>
<td>&lt;.0001</td>
<td>0.3928</td>
<td></td>
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<tr>
<td>4</td>
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<td>&lt;.0001</td>
<td>0.3678</td>
<td>&lt;.0001</td>
<td>0.8961</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.0048</td>
<td>0.1080</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0013</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.3029</td>
<td>&lt;.0001</td>
<td>0.3928</td>
<td>0.8961</td>
<td>0.0013</td>
<td></td>
</tr>
</tbody>
</table>

Least Squares Means for effect CV*Temp
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: Suc

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0250</td>
<td>0.0579</td>
<td>0.3336</td>
<td>&lt;.0001</td>
<td>0.0129</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.0250</td>
<td>0.7344</td>
<td>0.2066</td>
<td>0.0021</td>
<td>0.4861</td>
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</tr>
<tr>
<td>3</td>
<td>0.0579</td>
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<td>0.3390</td>
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</tr>
<tr>
<td>4</td>
<td>0.3336</td>
<td>0.2066</td>
<td>0.3488</td>
<td>0.0002</td>
<td>0.0879</td>
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</tr>
</tbody>
</table>
Table A.8.3A. Two-way analysis of variance for $^{14}$C-glucose (mmol C·m$^{-2}$) retained in GI and GIV leaves exposed to three different temperatures in Table 3.2.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>$F$ Value</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
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<tbody>
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<td>Model</td>
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<td>4.74</td>
<td>0.0026</td>
<td>0.4411</td>
<td>57.20</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
<td>941.87</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>1.60</td>
<td>0.2163</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
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<td>706.72</td>
<td>11.26</td>
<td>0.0002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*Temp</td>
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<td>12.36</td>
<td>0.20</td>
<td>0.8233</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)

Table A.8.3B. Numerical difference and standard error of the estimate for $^{14}$C-glucose (mmol C·m$^{-2}$) retained in GI and GIV leaves exposed to three different temperatures in Table 3.2.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-glucose</td>
<td>15°C</td>
<td>2.54</td>
<td>3.23</td>
<td>0.79</td>
<td>0.4385</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-glucose</td>
<td>25°C</td>
<td>3.85</td>
<td>3.19</td>
<td>1.20</td>
<td>0.2379</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-glucose</td>
<td>35°C</td>
<td>0.87</td>
<td>3.51</td>
<td>0.25</td>
<td>0.8064</td>
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</table>

Table A.8.3C. Multiple mean comparison for $^{14}$C-glucose (mmol C·m$^{-2}$) retained in GI and GIV leaves exposed to three different temperatures in Table 3.2.

<table>
<thead>
<tr>
<th>CV</th>
<th>Temp</th>
<th>Glu LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td>15</td>
<td>4.6713833</td>
<td>2.2874922</td>
<td>0.0500</td>
<td>1</td>
</tr>
<tr>
<td>GI</td>
<td>25</td>
<td>14.0404375</td>
<td>1.9810264</td>
<td>&lt;.0001</td>
<td>2</td>
</tr>
<tr>
<td>GI</td>
<td>35</td>
<td>6.9174714</td>
<td>2.1178063</td>
<td>0.0027</td>
<td>3</td>
</tr>
<tr>
<td>GIV</td>
<td>15</td>
<td>7.2113167</td>
<td>2.2874922</td>
<td>0.0037</td>
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</tr>
<tr>
<td>GIV</td>
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<td>17.8876400</td>
<td>2.5058222</td>
<td>&lt;.0001</td>
<td>5</td>
</tr>
<tr>
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<td>2.8015943</td>
<td>0.0093</td>
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</tbody>
</table>

Table A.8.3D. Least squares means for effect CV*Temp $Pr > |t|$ for H0: LSMean(i)=LSMean(j).

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>&lt;.0001</td>
<td>0.0021</td>
<td>0.0012</td>
<td>0.0002</td>
<td>0.0344</td>
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<td>6</td>
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<td>0.4861</td>
<td>0.3390</td>
<td>0.0879</td>
<td>0.0344</td>
<td></td>
</tr>
</tbody>
</table>

Least Squares Means for effect CV*Temp
$Pr > |t|$ for H0: LSMean(i)=LSMean(j)
Dependent Variable: Glu
Table A.8.4A. Two-way analysis of variance for $^{14}$C-fructose (mmol C·m$^{-2}$) retained in GI and GIV leaves exposed to three different temperatures in Table 3.2.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>596.06</td>
<td>4.95</td>
<td>0.0020</td>
<td>0.4518</td>
<td>60.36</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
<td>723.14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
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<td>1319.19</td>
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<td></td>
</tr>
<tr>
<td>CV</td>
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<td>0.1417</td>
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</tr>
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<td>554.59</td>
<td>11.50</td>
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<td>14.00</td>
<td>0.28</td>
<td>0.7562</td>
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</tbody>
</table>

† Sum of squares for model parameters are those of type III (SAS)

Table A.8.4B. Numerical difference and standard error of the estimate for $^{14}$C-fructose (mmol C·m$^{-2}$) retained in GI and GIV leaves exposed to three different temperatures in Table 3.2.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-fructose</td>
<td>15°C</td>
<td>2.81</td>
<td>2.83</td>
<td>0.99</td>
<td>0.3292</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-fructose</td>
<td>25°C</td>
<td>3.95</td>
<td>2.80</td>
<td>1.41</td>
<td>0.1688</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-fructose</td>
<td>35°C</td>
<td>0.84</td>
<td>3.08</td>
<td>0.27</td>
<td>0.7871</td>
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Table A.8.4C. Multiple mean comparison for $^{14}$C-fructose (mmol C·m$^{-2}$) retained in GI and GIV leaves exposed to three different temperatures in Table 3.2.

<table>
<thead>
<tr>
<th>CV</th>
<th>Temp</th>
<th>Fru LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td>15</td>
<td>3.2641667</td>
<td>2.0043519</td>
<td>0.1139</td>
<td>1</td>
<td></td>
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<tr>
<td>GI</td>
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<td>11.6361250</td>
<td>1.7358197</td>
<td>&lt;.0001</td>
<td>2</td>
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<tr>
<td>GI</td>
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<td>5.6752429</td>
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<td>GIV</td>
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<td>0.0050</td>
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<tr>
<td>GIV</td>
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<td></td>
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<tr>
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Least Squares Means for effect CV*Temp
Pr > | t | for H0: LSMean(i)=LSMean(j)

Dependent Variable: Fru

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<tr>
<th>i/j</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0036</td>
<td>0.3844</td>
<td>0.3292</td>
<td>0.0003</td>
<td>0.3134</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.0036</td>
<td>0.0258</td>
<td>0.0445</td>
<td>0.1688</td>
<td>0.0988</td>
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</tr>
<tr>
<td>3</td>
<td>0.3844</td>
<td>0.0258</td>
<td>0.8845</td>
<td>0.0017</td>
<td>0.7871</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.3292</td>
<td>0.0445</td>
<td>0.8845</td>
<td>0.0033</td>
<td>0.8909</td>
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<td>0.0988</td>
<td>0.7871</td>
<td>0.8909</td>
<td>0.0099</td>
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</tbody>
</table>

Table A.8.5A. Two-way analysis of variance for $^{14}$C-antirrhinoside (mmol C·m$^{-2}$) retained in GI and GIV leaves exposed to three different temperatures in Table 3.2.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>526.58</td>
<td>8.99</td>
<td>&lt;.0001</td>
<td>0.6162</td>
<td>45.96</td>
</tr>
<tr>
<td>Error</td>
<td>28</td>
<td>327.96</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>33</td>
<td>854.53</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>24.00</td>
<td>2.05</td>
<td>0.1634</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>522.16</td>
<td>22.29</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*Temp</td>
<td>2</td>
<td>12.51</td>
<td>0.53</td>
<td>0.5921</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† Sum of squares for model parameters are those of type III (SAS)
Table A.8.5B. Numerical difference and standard error of the estimate for $^{14}$C-antirrhinoside (mmol C·m$^{-2}$) retained in GI and GIV leaves exposed to three different temperatures in Table 3.2.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhinoside</td>
<td>15°C</td>
<td>1.09</td>
<td>1.98</td>
<td>0.55</td>
<td>0.5852</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhinoside</td>
<td>25°C</td>
<td>3.49</td>
<td>2.21</td>
<td>1.67</td>
<td>0.1067</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhinoside</td>
<td>35°C</td>
<td>0.61</td>
<td>2.21</td>
<td>0.28</td>
<td>0.7838</td>
</tr>
</tbody>
</table>

Table A.8.5C. Multiple mean comparison for $^{14}$C-antirrhinoside (mmol C·m$^{-2}$) retained in GI and GIV leaves exposed to three different temperatures in Table 3.2.

| CV | Temp | Antirrhinoside LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|----|------|-----------------------|----------------|-------|---|----------------|
| GI | 15   | 1.9651000             | 1.3971836      | 0.1706|   | 1              |
| GI | 25   | 10.1707125            | 1.2099965      | <.0001|   | 2              |
| GI | 35   | 8.4578167             | 1.3971836      | <.0001|   | 3              |
| GIV| 15   | 3.0561333             | 1.3971836      | 0.0372|   | 4              |
| GIV| 25   | 13.6635000            | 1.7111934      | <.0001|   | 5              |
| GIV| 35   | 9.0696750             | 1.7111934      | <.0001|   | 6              |

Table A.8.6A. Two-way analysis of variance for $^{14}$C-antirrhide (mmol C·m$^{-2}$) in GI and GIV leaves exposed to three different temperatures in Table 3.2.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>Value</th>
<th>Pr&gt;F</th>
<th>R2</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>69.43</td>
<td>5.99</td>
<td>0.0006</td>
<td>0.4995</td>
<td>49.09</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
<td>69.57</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>35</td>
<td>139.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>4.91</td>
<td>2.12</td>
<td>0.1561</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>62.71</td>
<td>13.52</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*Temp</td>
<td>2</td>
<td>1.08</td>
<td>0.23</td>
<td>0.7936</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table A.8.6B. Numerical difference and standard error of the estimate for $^{14}$C-antirrhide (mmol C·m$^{-2}$) retained in GI and GIV leaves exposed to three different temperatures in Table 3.2.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhide</td>
<td>15°C</td>
<td>0.62</td>
<td>0.88</td>
<td>0.71</td>
<td>0.4843</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhide</td>
<td>25°C</td>
<td>0.39</td>
<td>0.87</td>
<td>0.45</td>
<td>0.6528</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhide</td>
<td>35°C</td>
<td>1.25</td>
<td>0.95</td>
<td>1.31</td>
<td>0.1988</td>
</tr>
</tbody>
</table>

Table A.8.6C. Multiple mean comparison for $^{14}$C-antirrhide (mmol C·m$^{-2}$) retained in GI and GIV leaves exposed to three different temperatures in Table 3.2.

| CV | Temp | Antirrhide LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|----|------|-------------------|----------------|-------|---|----------------|
| GI | 15   | 1.30335000        | 0.62167262     | 0.0446|   | 1              |
| GI | 25   | 4.61315000        | 0.53838428     | <.0001|   | 2              |
| CV | Temp | Antirrhide LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|----|------|------------------|----------------|-------|----|----------------|
| GI | 35   | 2.30341429       | 0.57555701     | 0.0004|   | 3              |
| GIV| 15   | 1.92590000       | 0.62167262     | 0.0042|   | 4              |
| GIV| 25   | 5.00764000       | 0.68100824     | <.0001|   | 5              |
| GIV| 35   | 3.55752500       | 0.76139035     | <.0001|   | 6              |

### Least Squares Means for effect CV*Temp

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0004</td>
<td>0.2471</td>
<td>0.4843</td>
<td>0.0004</td>
<td>0.0290</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.0004</td>
<td>0.0064</td>
<td>0.0027</td>
<td>0.6528</td>
<td>0.2666</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.2471</td>
<td>0.0064</td>
<td>0.6591</td>
<td>0.0050</td>
<td>0.1988</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.4843</td>
<td>0.0027</td>
<td>0.6591</td>
<td>0.0022</td>
<td>0.1073</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.0004</td>
<td>0.6528</td>
<td>0.0050</td>
<td>0.0022</td>
<td>0.1660</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.0290</td>
<td>0.2666</td>
<td>0.1988</td>
<td>0.1073</td>
<td>0.1660</td>
<td></td>
</tr>
</tbody>
</table>

Table A.8.7A. Two-way analysis of variance for % ^14C-sugars recovered in petiole tissues in GI and GIV exposed to three different temperatures in Table 3.2. Data expressed as percentage were arcsine square root transformed prior to analysis.

### Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>0.05</td>
<td>3.75</td>
<td>0.0091</td>
<td>0.3766</td>
<td>4.49</td>
</tr>
<tr>
<td>Error</td>
<td>31</td>
<td>0.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>36</td>
<td>0.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>CV</td>
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<td>0.03</td>
<td>0.003</td>
<td>0.3509</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>0.01</td>
<td>0.005</td>
<td>0.1828</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*Temp</td>
<td>2</td>
<td>0.04</td>
<td>0.02</td>
<td>0.0025</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

^1 Sum of squares for model parameters are those of type III (SAS)

Table A.8.7B. Numerical difference and standard error of the estimate for % ^14C-sugars recovered in petiole tissues in GI and GIV exposed to three different temperatures in Table 3.2. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>% ^14C-sugars</td>
<td>15°C</td>
<td>0.08</td>
<td>0.03</td>
<td>2.56</td>
<td>0.0154</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>% ^14C-sugars</td>
<td>25°C</td>
<td>0.06</td>
<td>0.03</td>
<td>2.17</td>
<td>0.0376</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>% ^14C-sugars</td>
<td>35°C</td>
<td>0.07</td>
<td>0.03</td>
<td>2.06</td>
<td>0.0475</td>
</tr>
</tbody>
</table>

Table A.8.7C. Multiple mean comparisons for % ^14C-sugars recovered in petiole tissues in GI and GIV exposed to three different temperatures in Table 3.2. Data expressed as percentage were arcsine square root transformed prior to analysis.

| CV | Temp | PSug LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|----|------|-------------|----------------|-------|----|----------------|
| GI | 15   | 1.17014971  | 0.02209528     | <.0001|   | 1              |
| GI | 25   | 1.21201729  | 0.01913507     | <.0001|   | 2              |
| GI | 35   | 1.25305245  | 0.02209528     | <.0001|   | 3              |
| GIV| 15   | 1.25025080  | 0.02209528     | <.0001|   | 4              |
| GIV| 25   | 1.14851384  | 0.02209528     | <.0001|   | 5              |
| GIV| 35   | 1.18541174  | 0.02420416     | <.0001|   | 6              |
Table A.8.8A. Two-way analysis of variance for % $^{14}$C-sucrose recovered in petiole tissues in GI and GIV exposed to three different temperatures in Table 3.3. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>$F$ Value</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>0.66</td>
<td>18.16</td>
<td>&lt;.0001</td>
<td>0.7454</td>
<td>12.06</td>
</tr>
<tr>
<td>Error</td>
<td>31</td>
<td>0.23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>36</td>
<td>0.89</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>2</td>
<td>0.02</td>
<td>2.27</td>
<td>0.1421</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>0.65</td>
<td>44.56</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*Temp</td>
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<td>0.01</td>
<td>1.04</td>
<td>0.3644</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.8.8B. Numerical difference and standard error of the estimate for % $^{14}$C-sucrose recovered in petiole tissues in GI and GIV A. majus exposed to three different temperatures in Table 3.2. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>% $^{14}$C-sucrose</td>
<td>15°C</td>
<td>0.02</td>
<td>0.05</td>
<td>0.37</td>
<td>0.7129</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>% $^{14}$C-sucrose</td>
<td>25°C</td>
<td>0.10</td>
<td>0.05</td>
<td>2.14</td>
<td>0.0401</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>% $^{14}$C-sucrose</td>
<td>35°C</td>
<td>0.01</td>
<td>0.05</td>
<td>0.21</td>
<td>0.8335</td>
</tr>
</tbody>
</table>

Table A.8.8C. Multiple mean comparisons for % $^{14}$C-sucrose recovered in petiole tissues in GI and GIV A. majus leaves exposed to three different temperatures in Table 3.2. Data expressed as percentage were arcsine square root transformed prior to analysis.

| CV | Temp | PSuc L $MEAN$ | Standard Error | Pr > |t| | LS$MEAN$ Number |
|----|------|---------------|----------------|------|---|----------------|
| GI | 15   | 0.81512659    | 0.03488069     | <.0001 | 1 |
| GI | 25   | 0.58416308    | 0.03020757     | <.0001 | 2 |
| GI | 35   | 0.81998721    | 0.03488069     | <.0001 | 3 |
| GIV| 15   | 0.79680598    | 0.03488069     | <.0001 | 4 |
| GIV| 25   | 0.48529064    | 0.03488069     | <.0001 | 5 |
| GIV| 35   | 0.80902238    | 0.03820989     | <.0001 | 6 |

Least Squares Means for effect CV*Temp
Pr > |t| for H0: L$SMEAN$(i)=L$SMEAN$(j)
Dependent Variable: PSug

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;.0001</td>
<td>0.9221</td>
<td>0.7129</td>
<td>&lt;.0001</td>
<td>0.9068</td>
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</tr>
<tr>
<td>2</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0401</td>
<td>&lt;.0001</td>
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</tr>
<tr>
<td>3</td>
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<td>&lt;.0001</td>
<td>0.6417</td>
<td>&lt;.0001</td>
<td>0.8335</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.7129</td>
<td>&lt;.0001</td>
<td>0.6417</td>
<td>&lt;.0001</td>
<td>0.8149</td>
<td></td>
</tr>
</tbody>
</table>

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The least squares means for the effect of CV*Temp for the dependent variable PSuc are shown in the table below. The values indicate the mean differences between the levels of CV and Temp, with the standard error and p-values provided for each comparison.

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>&lt;.0001</td>
<td>0.0401</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.9068</td>
<td>&lt;.0001</td>
<td>0.8335</td>
<td>0.8149</td>
<td>&lt;.0001</td>
<td></td>
</tr>
</tbody>
</table>

The table above shows the least squares means for the effect of CV*Temp for the dependent variable PSuc.

Table A.8.9A. Two-way analysis of variance for %^{14}C-antirrhinoside recovered in petiole tissues in GI and GIV exposed to three different temperatures in Table 3.2. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R^2</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>0.05</td>
<td>3.75</td>
<td>0.0091</td>
<td>0.3766</td>
<td>14.76</td>
</tr>
<tr>
<td>Error</td>
<td>31</td>
<td>0.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>36</td>
<td>0.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>0.003</td>
<td>0.90</td>
<td>0.2509</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
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<td>0.01</td>
<td>1.80</td>
<td>0.1828</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*Temp</td>
<td>2</td>
<td>0.04</td>
<td>7.29</td>
<td>0.0252</td>
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<td></td>
</tr>
</tbody>
</table>

Table A.8.9B. Numerical difference and standard error of the estimate for %^{14}C-antirrhinoside recovered in petiole tissues in GI and GIV A. majus exposed to three different temperatures in Table 3.2. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>%^{14}C-antirrhinoside</td>
<td>15°C</td>
<td>0.08</td>
<td>0.03</td>
<td>2.56</td>
<td>0.0154</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>%^{14}C-antirrhinoside</td>
<td>25°C</td>
<td>0.06</td>
<td>0.03</td>
<td>2.17</td>
<td>0.0376</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>%^{14}C-antirrhinoside</td>
<td>35°C</td>
<td>0.07</td>
<td>0.03</td>
<td>2.06</td>
<td>0.0475</td>
</tr>
</tbody>
</table>

Table A.8.9C. Multiple mean comparisons for %^{14}C-antirrhinoside recovered in petiole tissues in GI and GIV A. majus exposed to three different temperatures in Table 3.2. Data expressed as percentage were arcsine square root transformed prior to analysis.

| CV Temp | Pantirrhinoside LSMEAN | Standard Error | Pr > |l| | LSMEAN Number |
|---------|------------------------|----------------|-------|---|----------------|
| GI      | 15                     | 0.40064662     | 0.02209528 | <.0001 | 1 |
| GI      | 25                     | 0.35877903     | 0.01913507 | <.0001 | 2 |
| GI      | 35                     | 0.31774387     | 0.02209528 | <.0001 | 3 |
| GIV     | 15                     | 0.32054553     | 0.02209528 | <.0001 | 4 |
| GIV     | 25                     | 0.42228249     | 0.02209528 | <.0001 | 5 |
| GIV     | 35                     | 0.38538458     | 0.02420416 | <.0001 | 6 |

The least squares means for the effect of CV*Temp for the dependent variable Pantirrhinoside are shown in the table below. The values indicate the mean differences between the levels of CV and Temp, with the standard error and p-values provided for each comparison.

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.1620</td>
<td>0.0125</td>
<td>0.0154</td>
<td>0.4938</td>
<td>0.6447</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.1620</td>
<td>0.1703</td>
<td>0.2005</td>
<td>0.0376</td>
<td>0.3951</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.0125</td>
<td>0.1703</td>
<td>0.9291</td>
<td>0.0022</td>
<td>0.0475</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.0154</td>
<td>0.2005</td>
<td>0.9291</td>
<td>0.0027</td>
<td>0.0568</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.4938</td>
<td>0.0376</td>
<td>0.0022</td>
<td>0.0027</td>
<td>0.2689</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.6447</td>
<td>0.3951</td>
<td>0.0475</td>
<td>0.0568</td>
<td>0.2689</td>
<td></td>
</tr>
</tbody>
</table>
Table A.9.1A. Two-way analysis of variance for $^{14}$C-sucrose to starch ratio retained in GI and GIV leaves exposed to three different temperatures in Table 3.3.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>11.42</td>
<td>9.81</td>
<td>&lt;.0001</td>
<td>0.6052</td>
<td>40.95</td>
</tr>
<tr>
<td>Error</td>
<td>32</td>
<td>7.44</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>37</td>
<td>18.87</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>0.86</td>
<td>3.72</td>
<td>0.0626</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>10.56</td>
<td>22.68</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*Temp</td>
<td>2</td>
<td>0.29</td>
<td>0.61</td>
<td>0.5473</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.9.1B. Numerical difference and standard error of the estimate $^{14}$C-sucrose to starch ratio retained in GI and GIV *A. majus* leaves exposed to three different temperatures in Table 3.3.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose: starch</td>
<td>15°C</td>
<td>0.35</td>
<td>0.28</td>
<td>1.27</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose: starch</td>
<td>25°C</td>
<td>0.50</td>
<td>0.27</td>
<td>1.81</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose: starch</td>
<td>35°C</td>
<td>0.07</td>
<td>0.27</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Table A.9.1C. Multiple mean comparisons for $^{14}$C-sucrose to starch ratio retained in GI and GIV *A. majus* leaves exposed to three different temperatures in Table 3.3.

| CV | Temp | SucStarch LSMEAN | Standard Error | Pr>|t| | LSMEAN Number |
|----|------|------------------|----------------|-----|----------------|
| GI | 15   | 0.63722306       | 0.19694994     | 0.0028 | 1  |
| GI | 25   | 0.60263330       | 0.17056365     | 0.0013 | 2  |
| GI | 35   | 1.87093621       | 0.17056365     | <.0001 | 3  |
| GIV | 15 | 0.99057770       | 0.19694994     | <.0001 | 4  |
| GIV | 25 | 1.09943968       | 0.21574785     | <.0001 | 5  |
| GIV | 35 | 1.94383353       | 0.21574785     | <.0001 | 6  |

Table A.9.2A. Two-way analysis of variance for $^{14}$C-sucrose to antirrhinoside ratio retained in GI and GIV leaves exposed to three different temperatures in Table 3.3.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>62.19</td>
<td>11.51</td>
<td>&lt;.0001</td>
<td>0.6281</td>
<td>36.09</td>
</tr>
<tr>
<td>Error</td>
<td>33</td>
<td>36.82</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>34</td>
<td>99.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>1.49</td>
<td>1.33</td>
<td>0.2564</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>61.14</td>
<td>27.40</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*Temp</td>
<td>2</td>
<td>0.21</td>
<td>0.10</td>
<td>0.9085</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)
Table A.9.2B. Numerical difference and standard error of the estimate $^{14}$C-sucrose to antirrhinoside ratio retained in GI and GIV A. majus leaves exposed to three different temperatures in Table 3.3.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>15°C</td>
<td>0.59</td>
<td>0.61</td>
<td>0.97</td>
<td>0.3403</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>25°C</td>
<td>0.37</td>
<td>0.60</td>
<td>0.62</td>
<td>0.5382</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>35°C</td>
<td>0.22</td>
<td>0.57</td>
<td>0.31</td>
<td>0.6965</td>
</tr>
</tbody>
</table>

Table A.9.2C. Multiple mean comparison in $^{14}$C-sucrose to antirrhinoside ratio retained in GI and GIV A. majus leaves exposed to three different temperatures in Table 3.3.

<table>
<thead>
<tr>
<th>CV</th>
<th>Temp</th>
<th>SucAnti LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td>15</td>
<td>5.09056548</td>
<td>0.43125716</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>25</td>
<td>2.25012221</td>
<td>0.37347966</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>35</td>
<td>2.18289710</td>
<td>0.37347966</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>15</td>
<td>4.50047230</td>
<td>0.43125716</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>25</td>
<td>1.87553648</td>
<td>0.47241855</td>
<td>0.0004</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>35</td>
<td>1.95842569</td>
<td>0.43125716</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Least Squares Means for effect CV*Temp
Pr > |t| for H0: LSMean(i)=LSMean(j)

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.3403</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.3403</td>
</tr>
<tr>
<td>2</td>
<td>&lt;.0001</td>
<td>0.8995</td>
<td>0.0004</td>
<td>0.5382</td>
<td>0.6125</td>
<td>0.0004</td>
</tr>
<tr>
<td>3</td>
<td>&lt;.0001</td>
<td>0.8995</td>
<td>0.0003</td>
<td>0.6132</td>
<td>0.6965</td>
<td>0.0004</td>
</tr>
<tr>
<td>4</td>
<td>0.3403</td>
<td>0.0004</td>
<td>0.0003</td>
<td>0.0003</td>
<td>0.0002</td>
<td>0.0002</td>
</tr>
<tr>
<td>5</td>
<td>&lt;.0001</td>
<td>0.5382</td>
<td>0.6132</td>
<td>0.0003</td>
<td>0.8977</td>
<td>0.0004</td>
</tr>
<tr>
<td>6</td>
<td>&lt;.0001</td>
<td>0.6125</td>
<td>0.6965</td>
<td>0.0002</td>
<td>0.8977</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

Table A.9.3A. Two-way analysis of variance for $^{14}$C-antirrhinoside to antirrhide ratio retained in GI and GIV leaves exposed to three different temperatures in Table 3.3.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>$^1$</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R^2</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>22.39</td>
<td>5.35</td>
<td>0.0010</td>
<td>0.4475</td>
<td>36.81</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>33</td>
<td>27.64</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>38</td>
<td>50.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>0.31</td>
<td>0.38</td>
<td>0.5424</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>13.98</td>
<td>8.35</td>
<td>0.0012</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>CV*Temp</td>
<td>2</td>
<td>6.84</td>
<td>4.08</td>
<td>0.0261</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.9.3B. Numerical difference and standard error of the estimate $^{14}$C-antirrhinoside to antirrhide ratio retained in GI and GIV A. majus leaves exposed to three different temperatures in Table 3.3.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhinoside: antirrhide</td>
<td>15°C</td>
<td>0.05</td>
<td>0.53</td>
<td>0.09</td>
<td>0.9305</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhinoside: antirrhide</td>
<td>25°C</td>
<td>0.70</td>
<td>0.52</td>
<td>1.35</td>
<td>0.1863</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhinoside: antirrhide</td>
<td>35°C</td>
<td>1.30</td>
<td>0.49</td>
<td>2.65</td>
<td>0.0129</td>
</tr>
</tbody>
</table>

Table A.9.3C. Multiple mean comparison for $^{14}$C-antirrhinoside to antirrhide ratio retained in GI and GIV A. majus leaves exposed to three different temperatures in Table 3.3.

<table>
<thead>
<tr>
<th>CV</th>
<th>Temp</th>
<th>AntiAntirrhide LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td>15</td>
<td>1.56691234</td>
<td>0.37362955</td>
<td>0.0002</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>25</td>
<td>2.40117981</td>
<td>0.32357269</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>Temp</td>
<td>AntiAntirrhide LSMEAN</td>
<td>Standard Error</td>
<td>Pr &gt;</td>
<td>t</td>
<td></td>
<td>LSMEAN Number</td>
</tr>
<tr>
<td>----</td>
<td>------</td>
<td>----------------------</td>
<td>----------------</td>
<td>------</td>
<td>---</td>
<td>--------------</td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>35</td>
<td>3.63976356</td>
<td>0.32357269</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>15</td>
<td>1.61336381</td>
<td>0.37362955</td>
<td>0.0001</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>25</td>
<td>3.10535034</td>
<td>0.40929067</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>35</td>
<td>2.34005501</td>
<td>0.37362955</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Least Squares Means for effect CV*Temp

<table>
<thead>
<tr>
<th>Pr &gt;</th>
<th>t</th>
<th>for H0: LSMean(i)=LSMean(j)</th>
<th>Dependent Variable: AntiAntirrhide</th>
</tr>
</thead>
<tbody>
<tr>
<td>i/j</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>0.1009</td>
<td>0.0002</td>
<td>0.9305</td>
</tr>
<tr>
<td>2</td>
<td>0.0107</td>
<td>0.0107</td>
<td>0.0003</td>
</tr>
<tr>
<td>3</td>
<td>0.0002</td>
<td>0.1205</td>
<td>0.0003</td>
</tr>
<tr>
<td>4</td>
<td>0.9305</td>
<td>0.1205</td>
<td>0.0003</td>
</tr>
<tr>
<td>5</td>
<td>0.0090</td>
<td>0.1863</td>
<td>0.3132</td>
</tr>
<tr>
<td>6</td>
<td>0.1529</td>
<td>0.9023</td>
<td>0.0129</td>
</tr>
</tbody>
</table>

Table A.9.4A. Two-way analysis of variance for % $^{14}$C-sucrose to antirrhinoside ratio recovered in petiole tissues in GI and GIV exposed to three different temperatures in Table 3.3.

**Two-way ANOVA**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>120.73</td>
<td>4.94</td>
<td>0.0019</td>
<td>0.4434</td>
<td>56.86</td>
</tr>
<tr>
<td>Error</td>
<td>31</td>
<td>151.52</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>36</td>
<td>272.25</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>7.24</td>
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<td>0.2326</td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
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<td>3.302</td>
<td>3.38</td>
<td>0.0471</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)*

Table A.9.4B. Numerical difference and standard error of the estimate % $^{14}$C-sucrose to antirrhinoside ratio recovered in petiole tissues in GI and GIV *A. majus* exposed to three different temperatures in Table 3.3.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>% $^{14}$C-sucrose: antirrhinoside</td>
<td>15°C</td>
<td>1.64</td>
<td>1.28</td>
<td>1.29</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>% $^{14}$C-sucrose: antirrhinoside</td>
<td>25°C</td>
<td>1.21</td>
<td>1.19</td>
<td>1.02</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>% $^{14}$C-sucrose: antirrhinoside</td>
<td>35°C</td>
<td>3.11</td>
<td>3.33</td>
<td>2.32</td>
</tr>
</tbody>
</table>

Table A.9.4C. Multiple mean comparisons for % $^{14}$C-sucrose to antirrhinoside ratio recovered in petiole tissues in GI and GIV exposed to three different temperatures in Table 3.3.

| CV Temp | SucAntIP LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|---------|-----------------|----------------|------|---|--------------|
| GI 15   | 3.70239116      | 0.90256685     | 0.0003 | 1 |
| GI 25   | 2.57853333      | 0.78164582     | 0.0024 | 2 |
| GI 35   | 6.93729326      | 0.90256685     | <.0001 | 3 |
| GIV 15  | 5.34590100      | 0.90256685     | <.0001 | 4 |
| GIV 25  | 1.36332934      | 0.90256685     | 0.1410 | 5 |
| GIV 35  | 3.82879695      | 0.98871245     | 0.0005 | 6 |
Table A.10.1A. Two-way analysis of variance for leaf photosynthesis (µmol C·m$^{-2}$·s$^{-1}$) to compare GI and GIV exposed to CO$_2$ and O$_2$ treatments in Table 3.4.

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3539</td>
<td>0.0165</td>
<td>0.2074</td>
<td>0.0765</td>
<td>0.9254</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.3539</td>
<td>0.0010</td>
<td>0.0272</td>
<td>0.3166</td>
<td>0.3289</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.0165</td>
<td>0.0010</td>
<td>0.2218</td>
<td>0.0001</td>
<td>0.0270</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.2074</td>
<td>0.0272</td>
<td>0.2218</td>
<td>0.0039</td>
<td>0.2658</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.0765</td>
<td>0.3166</td>
<td>0.0001</td>
<td>0.0039</td>
<td>0.0751</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.9254</td>
<td>0.3289</td>
<td>0.0270</td>
<td>0.2658</td>
<td>0.0751</td>
<td></td>
</tr>
</tbody>
</table>

Two-way ANOVA

<table>
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<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>Value</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>1909.51</td>
<td>45.31</td>
<td>&lt;.0001</td>
<td>0.9058</td>
<td>9.19</td>
</tr>
<tr>
<td>Error</td>
<td>33</td>
<td>198.69</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>40</td>
<td>2108.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>1.43</td>
<td>0.24</td>
<td>0.6289</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO$_2$O$_2$</td>
<td>3</td>
<td>1850.88</td>
<td>102.47</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*CO$_2$O$_2$</td>
<td>3</td>
<td>44.45</td>
<td>2.46</td>
<td>0.0799</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.10.1B. Numerical difference and standard error of the estimate for leaf photosynthesis (µmol C·m$^{-2}$·s$^{-1}$) to compare GI and GIV A. majus plants exposed CO$_2$ and O$_2$ treatments in Table 3.4.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>Photosynthesis</td>
<td>40 Pa CO$_2$; 21 kPa O$_2$</td>
<td>1.06</td>
<td>1.36</td>
<td>0.78</td>
<td>0.4421</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Photosynthesis</td>
<td>40 Pa CO$_2$; 2 kPa O$_2$</td>
<td>0.36</td>
<td>1.73</td>
<td>0.21</td>
<td>0.8361</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Photosynthesis</td>
<td>91 Pa CO$_2$; 21 kPa O$_2$</td>
<td>3.63</td>
<td>1.42</td>
<td>2.56</td>
<td>0.0152</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Photosynthesis</td>
<td>91 Pa CO$_2$; 2 kPa O$_2$</td>
<td>1.39</td>
<td>1.73</td>
<td>0.80</td>
<td>0.4274</td>
</tr>
</tbody>
</table>

Table A.10.1C. Multiple mean comparisons for leaf photosynthesis (µmol C·m$^{-2}$·s$^{-1}$) to compare GI and GIV exposed to CO$_2$ and O$_2$ treatments in Table 3.4.

<table>
<thead>
<tr>
<th>CV</th>
<th>CO2;O2</th>
<th>NCER</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td>40;21</td>
<td>19.1159429</td>
<td>0.9274233</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>GI</td>
<td>40;2</td>
<td>24.1690000</td>
<td>1.2268657</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>GI</td>
<td>91;21</td>
<td>30.0790500</td>
<td>1.0017316</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>GI</td>
<td>91;2</td>
<td>37.8339750</td>
<td>1.2268657</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>GIV</td>
<td>40;21</td>
<td>20.1779833</td>
<td>1.0017316</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>GIV</td>
<td>40;2</td>
<td>23.8072250</td>
<td>1.2268657</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
<td></td>
<td>6</td>
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<tr>
<td>GIV</td>
<td>91;21</td>
<td>26.4503667</td>
<td>1.0017316</td>
<td>&lt;.0001</td>
<td>7</td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>GIV</td>
<td>90;2</td>
<td>39.2283250</td>
<td>1.2268657</td>
<td>&lt;.0001</td>
<td>8</td>
<td></td>
<td></td>
<td>8</td>
</tr>
</tbody>
</table>

Least Squares Means for effect CV*CO$_2$O$_2$

| Pr > |t| for H0: LSMean(i)=LSMean(j) | Dependent Variable: NCER |
|------|----------------|--------------------------|
| i/j  | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     |
| 1    | 0.0024| <.0001| <.0001| 0.4421| 0.0045| <.0001| <.0001| <.0001|
| 2    | 0.0024| 0.0007| <.0001| 0.0168| 0.8361| 0.1592| <.0001| <.0001|
| 3    | <.0001| 0.0007| <.0001| 0.0004| 0.0152| <.0001| <.0001| <.0001|
### Least Squares Means for effect CV*CO2;O2

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.4274</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.4421</td>
<td>0.0168</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0285</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.0045</td>
<td>0.8361</td>
<td>0.0004</td>
<td>&lt;.0001</td>
<td>0.0285</td>
<td>0.1046</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>&lt;.0001</td>
<td>0.1592</td>
<td>0.0152</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.1046</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.4274</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Table A.10.2A. Two-way analysis of variance for leaf transpiration (mmol H₂O·m⁻²·s⁻¹) to compare GI and GIV exposed to CO₂ and O₂ treatments in Table 3.4.

### Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>10.20</td>
<td>9.51</td>
<td>&lt;.0001</td>
<td>0.6754</td>
<td>11.66</td>
</tr>
<tr>
<td>Error</td>
<td>32</td>
<td>4.90</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>39</td>
<td>15.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
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<td>0.01</td>
<td>0.09</td>
<td>0.7607</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂;O₂</td>
<td>3</td>
<td>9.53</td>
<td>20.05</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*CO₂;O₂</td>
<td>3</td>
<td>0.97</td>
<td>2.11</td>
<td>0.1190</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.10.2B. Numerical difference and standard error of the estimate for leaf transpiration (mmol H₂O·m⁻²·s⁻¹) to compare GI and GIV A. majus plants exposed CO₂ and O₂ treatments in Table 2B.4.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>Transpiration</td>
<td>40 Pa CO₂; 21 kPa O₂</td>
<td>0.50</td>
<td>0.21</td>
<td>2.35</td>
<td>0.0252</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Transpiration</td>
<td>40 Pa CO₂; 2 kPa O₂</td>
<td>0.05</td>
<td>0.28</td>
<td>0.20</td>
<td>0.8428</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Transpiration</td>
<td>91 Pa CO₂; 21 kPa O₂</td>
<td>0.25</td>
<td>0.25</td>
<td>1.01</td>
<td>0.3220</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Transpiration</td>
<td>91 Pa CO₂; 2 kPa O₂</td>
<td>0.15</td>
<td>0.28</td>
<td>0.53</td>
<td>0.6004</td>
</tr>
</tbody>
</table>

Table A.10.3C. Multiple mean comparisons for leaf transpiration (mmol H₂O·m⁻²·s⁻¹) to compare GI and GIV exposed to CO₂ and O₂ treatments in Table 3.4.

<table>
<thead>
<tr>
<th>CV Feed</th>
<th>Trans LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI 40:21</td>
<td>3.57797625</td>
<td>0.13838039</td>
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<td>1</td>
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</tr>
<tr>
<td>GI 40:2</td>
<td>3.69007750</td>
<td>0.19569942</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>GI 91:21</td>
<td>2.77103200</td>
<td>0.17503888</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>GI 91:2</td>
<td>3.19824500</td>
<td>0.19569942</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>GIV 40:21</td>
<td>4.07442333</td>
<td>0.15978791</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>GIV 40:2</td>
<td>3.74541500</td>
<td>0.19569942</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>GIV 91:21</td>
<td>2.52204200</td>
<td>0.17503888</td>
<td>&lt;.0001</td>
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<td></td>
</tr>
<tr>
<td>GIV 91:2</td>
<td>3.05180500</td>
<td>0.19569942</td>
<td>&lt;.0001</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

### Least Squares Means for effect CV*Feed

<table>
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<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.6432</td>
<td>0.0010</td>
<td>0.1230</td>
<td>0.0252</td>
<td>0.4899</td>
<td>&lt;.0001</td>
<td>0.0355</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.6432</td>
<td>0.0014</td>
<td>0.0851</td>
<td>0.1380</td>
<td>0.8428</td>
<td>&lt;.0001</td>
<td>0.0277</td>
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</table>
Table A.10.4A. Two-way analysis of variance for leaf WUE (µmol C/mmol H\textsubscript{2}O) to compare GI and GIV exposed to CO\textsubscript{2} and O\textsubscript{2} treatments in Table 3.4.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>Value</th>
<th>Pr&gt;F</th>
<th>R\textsuperscript{2}</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>351.65</td>
<td>147.94</td>
<td>&lt;.0001</td>
<td>0.9682</td>
<td>7.13</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>11.55</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>41</td>
<td>363.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>0.15</td>
<td>0.43</td>
<td>0.5141</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO\textsubscript{2}\textsuperscript{2}O\textsubscript{2}</td>
<td>3</td>
<td>347.36</td>
<td>340.97</td>
<td>&lt;.0001</td>
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<td></td>
</tr>
<tr>
<td>CV*CO\textsubscript{2}\textsuperscript{2}O\textsubscript{2}</td>
<td>3</td>
<td>2.50</td>
<td>2.45</td>
<td>0.0801</td>
<td></td>
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</tr>
</tbody>
</table>

\textsuperscript{1} Sum of squares for model parameters are those of type III (SAS)

Table A.10.4B. Numerical difference and standard error of the estimate for leaf WUE (µmol C/mmol H\textsubscript{2}O) to compare GI and GIV A. \textit{majus} plants exposed CO\textsubscript{2} and O\textsubscript{2} treatments in Table 2B.4.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>WUE</td>
<td>40 Pa CO\textsubscript{2}; 21 kPa O\textsubscript{2}</td>
<td>0.17</td>
<td>0.31</td>
<td>0.54</td>
<td>0.5934</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>WUE</td>
<td>40 Pa CO\textsubscript{2}; 2 kPa O\textsubscript{2}</td>
<td>0.19</td>
<td>0.41</td>
<td>0.45</td>
<td>0.6551</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>WUE</td>
<td>91 Pa CO\textsubscript{2}; 21 kPa O\textsubscript{2}</td>
<td>0.21</td>
<td>0.34</td>
<td>0.62</td>
<td>0.5371</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>WUE</td>
<td>91 Pa CO\textsubscript{2}; 2 kPa O\textsubscript{2}</td>
<td>1.05</td>
<td>0.41</td>
<td>2.56</td>
<td>0.0151</td>
</tr>
</tbody>
</table>

Table A.10.4C. Multiple mean comparisons for leaf WUE (µmol C/mmol H\textsubscript{2}O) to compare GI and GIV exposed to CO\textsubscript{2} and O\textsubscript{2} treatments in Table 3.4.

<table>
<thead>
<tr>
<th>CV</th>
<th>Feed</th>
<th>WUE LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td>40;21</td>
<td>5.1196000</td>
<td>0.2060280</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>40;2</td>
<td>6.5476500</td>
<td>0.2913676</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>91;21</td>
<td>10.3001833</td>
<td>0.2379007</td>
<td>&lt;.0001</td>
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<tr>
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<td>91;2</td>
<td>11.8232250</td>
<td>0.2913676</td>
<td>&lt;.0001</td>
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<tr>
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<td>40;21</td>
<td>4.9499833</td>
<td>0.2379007</td>
<td>&lt;.0001</td>
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<td>6.3619750</td>
<td>0.2913676</td>
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<tr>
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<td>91;21</td>
<td>10.0904167</td>
<td>0.2379007</td>
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<td>91;2</td>
<td>12.8781000</td>
<td>0.2913676</td>
<td>&lt;.0001</td>
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Least Squares Means for effect CV*Feed
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: WUE

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<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
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Table A.10.5A. Two-way analysis of variance for leaf export rate (mmol C·m\(^{-2}\)) to compare GI and GIV exposed to CO\(_2\) and O\(_2\) treatments in Table 3.4.

### Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
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<th>F</th>
<th>Pr&gt;F</th>
<th>R(^2)</th>
<th>CV</th>
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<tbody>
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<td>Model</td>
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<td>273.31</td>
<td>3.67</td>
<td>0.0051</td>
<td>0.4453</td>
<td>20.32</td>
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<tr>
<td>Error</td>
<td>32</td>
<td>340.49</td>
<td></td>
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<tr>
<td>Corrected Total</td>
<td>39</td>
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<tr>
<td>CV</td>
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<td>10.36</td>
<td>0.97</td>
<td>0.3313</td>
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<tr>
<td>CO(_2):O(_2)</td>
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<td>5.44</td>
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<td>CV:CO(_2):O(_2)</td>
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\(^1\)Sum of squares for model parameters are those of type III (SAS)

Table A.10.5B. Numerical difference and standard error of the estimate for leaf export rate (mmol C·m\(^{-2}\)) to compare GI and GIV \textit{A. majus} plants exposed CO\(_2\) and O\(_2\) treatments in Table 2B.4.

<table>
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<tr>
<th>Contrast</th>
<th>Variable</th>
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<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>Export rate</td>
<td>40 Pa CO(_2); 21 kPa O(_2)</td>
<td>2.69</td>
<td>1.88</td>
<td>1.43</td>
<td>0.1626</td>
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<tr>
<td>GI vs. GIV</td>
<td>Export rate</td>
<td>40 Pa CO(_2); 2 kPa O(_2)</td>
<td>0.54</td>
<td>2.31</td>
<td>0.23</td>
<td>0.8177</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Export rate</td>
<td>91 Pa CO(_2); 21 kPa O(_2)</td>
<td>4.27</td>
<td>1.88</td>
<td>2.27</td>
<td>0.0300</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Export rate</td>
<td>91 Pa CO(_2); 2 kPa O(_2)</td>
<td>3.35</td>
<td>2.31</td>
<td>1.45</td>
<td>0.1560</td>
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</table>

Table A.10.5C. Multiple mean comparisons for leaf export rate (mmol C·m\(^{-2}\)) to compare GI and GIV exposed to CO\(_2\) and O\(_2\) treatments in Table 3.4.

<table>
<thead>
<tr>
<th>CV</th>
<th>Feed</th>
<th>Exp</th>
<th>Exp</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>LSMEAN</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
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<td>15.7012667</td>
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</tr>
<tr>
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<td></td>
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</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>GIV</td>
<td>40;21</td>
<td>13.0092667</td>
<td>1.3316817</td>
<td>&lt;.0001</td>
<td>5</td>
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<tr>
<td>GIV</td>
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Least Squares Means for effect CV*Feed
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: Exp

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<th>8</th>
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<td>&lt;.0001</td>
<td>0.0002</td>
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<td>&lt;.0001</td>
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<td>&lt;.0001</td>
<td>0.5371</td>
<td>&lt;.0001</td>
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<td>&lt;.0001</td>
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<td>&lt;.0001</td>
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Table A.11.1A. Two-way analysis of variance for $^{14}$C-stach (mmol C·m$^{-2}$) retained in leaves of GI and GIV A. majus exposed to CO$_2$ and O$_2$ treatments in Table 3.5.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
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<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
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<td>1771.99</td>
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</tr>
<tr>
<td>Corrected Total</td>
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<td>24362.95</td>
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<td></td>
</tr>
<tr>
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<td>104.00</td>
<td>&lt;.0001</td>
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</tr>
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<td>505.15</td>
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</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.11.1B. Numerical difference and standard error of the estimate for $^{14}$C-stach (mmol C·m$^{-2}$) retained in leaves of GI and GIV A. majus exposed to CO$_2$ and O$_2$ treatments in Table 3.5.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
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<tbody>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-stach</td>
<td>40 Pa CO$_2$; 21 kPa O$_2$</td>
<td>2.65</td>
<td>5.29</td>
<td>0.50</td>
<td>0.6192</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-stach</td>
<td>40 Pa CO$_2$; 2 kPa O$_2$</td>
<td>14.27</td>
<td>5.97</td>
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<td>0.0236</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-stach</td>
<td>91 Pa CO$_2$; 21 kPa O$_2$</td>
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<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-stach</td>
<td>91 Pa CO$_2$; 2 kPa O$_2$</td>
<td>18.11</td>
<td>5.97</td>
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Table A.11.1C. Multiple mean comparisons for $^{14}$C-stach (mmol C·m$^{-2}$) retained in leaves of GI and GIV A. majus exposed to CO$_2$ and O$_2$ treatments in Table 3.5.

<table>
<thead>
<tr>
<th>CV</th>
<th>CO2</th>
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<th>Standard Error</th>
<th>Pr &gt;</th>
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<td>GI</td>
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<tr>
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<tr>
<td>GI</td>
<td>91;21</td>
<td>59.5318667</td>
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<td>&lt;.0001</td>
<td>3</td>
<td></td>
</tr>
<tr>
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<td>91;2</td>
<td>87.6312000</td>
<td>4.5130551</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
</tr>
<tr>
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<td>40;21</td>
<td>13.5590667</td>
<td>4.5130551</td>
<td>0.0054</td>
<td>5</td>
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<tr>
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<td>40;2</td>
<td>30.5292750</td>
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<tr>
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<td>53.7546833</td>
<td>3.1912188</td>
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<tr>
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<td>69.5130000</td>
<td>3.9084203</td>
<td>&lt;.0001</td>
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</table>
### Table A.11.2A. Two-way analysis of variance for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in leaves of GI and GIV *A. majus* exposed to CO$_2$ and O$_2$ treatments in Table 3.5.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>Value</th>
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<th>R$^2$</th>
<th>CV</th>
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<td></td>
</tr>
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*Sum of squares for model parameters are those of type III (SAS)*

### Table A.11.2B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in leaves of GI and GIV *A. majus* exposed to CO$_2$ and O$_2$ treatments in Table 3.5.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
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<td>$^{14}$C-sucrose</td>
<td>40 Pa CO$_2$; 21 kPa O$_2$</td>
<td>3.24</td>
<td>6.70</td>
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<td>0.6316</td>
</tr>
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<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose</td>
<td>40 Pa CO$_2$; 2 kPa O$_2$</td>
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<td>7.56</td>
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<td>0.9973</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose</td>
<td>91 Pa CO$_2$; 21 kPa O$_2$</td>
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<tr>
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<td>$^{14}$C-sucrose</td>
<td>91 Pa CO$_2$; 2 kPa O$_2$</td>
<td>16.30</td>
<td>8.16</td>
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Table A.11.2C. Multiple mean comparisons for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in leaves of GI and GIV *A. majus* exposed to CO$_2$ and O$_2$ treatments in Table 3.5.

<table>
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<th>Suc</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
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<tr>
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<tr>
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<td>40.1950000</td>
<td>5.3434477</td>
<td>&lt;.0001</td>
<td>2</td>
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<tr>
<td>GI</td>
<td>91:21</td>
<td>50.1763333</td>
<td>4.3629068</td>
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<td>91:2</td>
<td>68.6796667</td>
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<td>39.8466667</td>
<td>4.3629068</td>
<td>&lt;.0001</td>
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<td>52.3817500</td>
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<td>8</td>
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</tr>
</tbody>
</table>

### Table A.11.2D. Least Squares Means for effect CV*CO2

<table>
<thead>
<tr>
<th>Pr &gt;</th>
<th>LSMEAN(i)=LSMEAN(j)</th>
<th>Dependent Variable: Suc</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>
### Table A.11.3A. Two-way analysis of variance for $^{14}$C-antirrhinoside (mmol C·m$^{-2}$) retained in leaves of GI and GIV *A. majus* exposed to CO$_2$ and O$_2$ treatments in Table 3.5.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>612.22</td>
<td>7.73</td>
<td>&lt;.0001</td>
<td>0.6590</td>
<td>22.46</td>
</tr>
<tr>
<td>Error</td>
<td>31</td>
<td>314.73</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>0.12</td>
<td>0.01</td>
<td>0.9173</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO$_2$</td>
<td>3</td>
<td>560.25</td>
<td>16.51</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*CO$_2$</td>
<td>3</td>
<td>44.64</td>
<td>1.32</td>
<td>0.2890</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

### Table A.11.3B. Numerical difference and standard error of the estimate for $^{14}$C-antirrhinoside (mmol C·m$^{-2}$) retained in leaves of GI and GIV *A. majus* exposed to CO$_2$ and O$_2$ treatments in Table 3.5.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhinoside</td>
<td>40 Pa CO$_2$; 21 kPa O$_2$</td>
<td>0.61</td>
<td>2.17</td>
<td>0.28</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhinoside</td>
<td>40 Pa CO$_2$; 2 kPa O$_2$</td>
<td>3.21</td>
<td>2.57</td>
<td>1.25</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhinoside</td>
<td>91 Pa CO$_2$; 21 kPa O$_2$</td>
<td>1.38</td>
<td>1.94</td>
<td>0.71</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhinoside</td>
<td>91 Pa CO$_2$; 2 kPa O$_2$</td>
<td>3.49</td>
<td>2.57</td>
<td>1.46</td>
</tr>
</tbody>
</table>

### Table A.11.3C. Multiple mean comparisons for $^{14}$C-antirrhinoside (mmol C·m$^{-2}$) retained in leaves of GI and GIV *A. majus* exposed to CO$_2$ and O$_2$ treatments in Table 3.5.

| CV CO2 Antirrhinoside LSMEAN Standard Error Pr > |t| LSMEAN Number |
|--------|--------|----------------|----------------|----------------|----------------|
| GI     | 40;21  | 8.4578167 | 1.3730591 | <.0001 | 1 |
| GI     | 40;2   | 18.5812333 | 1.9417988 | <.0001 | 2 |
| GI     | 91;21  | 17.5615333 | 1.3730591 | <.0001 | 3 |
| GI     | 91;2   | 17.4158000 | 1.6816471 | <.0001 | 4 |
| GIV    | 40;21  | 9.0696750 | 1.6816471 | <.0001 | 5 |
| GIV    | 40;2   | 15.3737750 | 1.6816471 | <.0001 | 6 |
| GIV    | 91;21  | 16.1771000 | 1.3730591 | <.0001 | 7 |
| GIV    | 91;2   | 20.9077000 | 1.9417988 | <.0001 | 8 |

Least Squares Means for effect CV*CO2

Pr > |t| for H0: LSMean(l)=LSMean(j)

<table>
<thead>
<tr>
<th>i/j</th>
<th>1 2 3 4 5 6 7 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0002 &lt;.0001 0.0003 0.7801 0.0035 0.0004 &lt;.0001</td>
</tr>
</tbody>
</table>
Table A.11.4A. Two-way analysis of variance for $^{14}$C-antirrhine (mmol C·m$^{-2}$) retained in leaves of GI and GIV A. majus exposed to CO$_2$ and O$_2$ treatments in Table 3.5.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>902.08</td>
<td>12.53</td>
<td>&lt;.0001</td>
<td>0.7515</td>
<td>36.67</td>
</tr>
<tr>
<td>Error</td>
<td>29</td>
<td>298.22</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>36</td>
<td>1200.30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>51.97</td>
<td>5.05</td>
<td>0.0323</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO$_2$:O$_2$</td>
<td>3</td>
<td>644.55</td>
<td>20.89</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*CO$_2$:O$_2$</td>
<td>3</td>
<td>120.73</td>
<td>3.91</td>
<td>0.0184</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.11.4B. Numerical difference and standard error of the estimate for $^{14}$C-antirrhine (mmol C·m$^{-2}$) retained in leaves of GI and GIV A. majus exposed to CO$_2$ and O$_2$ treatments in Table 3.5.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhine</td>
<td>40 Pa CO$_2$; 21 kPa O$_2$</td>
<td>1.25</td>
<td>2.01</td>
<td>0.62</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhine</td>
<td>40 Pa CO$_2$; 2 kPa O$_2$</td>
<td>3.11</td>
<td>2.26</td>
<td>1.37</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhine</td>
<td>91 Pa CO$_2$; 21 kPa O$_2$</td>
<td>0.61</td>
<td>1.94</td>
<td>0.31</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhine</td>
<td>91 Pa CO$_2$; 2 kPa O$_2$</td>
<td>8.53</td>
<td>2.45</td>
<td>3.48</td>
</tr>
</tbody>
</table>

Table A.11.4C. Multiple mean comparisons for $^{14}$C-antirrhine (mmol C·m$^{-2}$) retained in leaves of GI and GIV A. majus exposed to CO$_2$ and O$_2$ treatments in Table 3.5.

<table>
<thead>
<tr>
<th>CV</th>
<th>CO2</th>
<th>Antirrhine</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td>40:21</td>
<td>2.3034143</td>
<td>1.2120508</td>
<td>0.0674</td>
<td>1</td>
</tr>
<tr>
<td>GI</td>
<td>40:2</td>
<td>13.0170250</td>
<td>1.6033925</td>
<td>&lt;.0001</td>
<td>2</td>
</tr>
<tr>
<td>GI</td>
<td>91:21</td>
<td>8.3176167</td>
<td>1.3091645</td>
<td>&lt;.0001</td>
<td>3</td>
</tr>
<tr>
<td>GI</td>
<td>91:2</td>
<td>8.19436500</td>
<td>1.6033925</td>
<td>&lt;.0001</td>
<td>4</td>
</tr>
<tr>
<td>GIV</td>
<td>40:21</td>
<td>3.5575250</td>
<td>1.6033925</td>
<td>0.0345</td>
<td>5</td>
</tr>
<tr>
<td>GIV</td>
<td>40:2</td>
<td>9.9026500</td>
<td>1.6033925</td>
<td>&lt;.0001</td>
<td>6</td>
</tr>
<tr>
<td>GIV</td>
<td>91:21</td>
<td>8.9247600</td>
<td>1.4341178</td>
<td>&lt;.0001</td>
<td>7</td>
</tr>
<tr>
<td>GIV</td>
<td>91:2</td>
<td>10.4100333</td>
<td>1.8514382</td>
<td>&lt;.0001</td>
<td>8</td>
</tr>
</tbody>
</table>
### Table A.11.5A. Two-way analysis of variance for % 14C-sugars recovered in petiole tissues of GI and GIV A. majus exposed to CO₂ and O₂ treatments in Table 3.5. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>0.05</td>
<td>3.63</td>
<td>0.0057</td>
<td>0.4503</td>
<td>3.44</td>
</tr>
<tr>
<td>Error</td>
<td>31</td>
<td>0.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>38</td>
<td>0.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>0.01</td>
<td>5.70</td>
<td>0.0232</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>3</td>
<td>0.03</td>
<td>5.68</td>
<td>0.0032</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂*O₂</td>
<td>3</td>
<td>0.01</td>
<td>1.19</td>
<td>0.03297</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† Sum of squares for model parameters are those of type III (SAS)

### Table A.11.5B. Numerical difference and standard error of the estimate % 14C-sugars recovered in petiole tissues of GI and GIV A. majus exposed to CO₂ and O₂ treatments in Table 3.5. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>% 14C-sugars</td>
<td>40 Pa CO₂; 21 kPa O₂</td>
<td>0.07</td>
<td>0.03</td>
<td>2.61</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>% 14C-sugars</td>
<td>40 Pa CO₂; 2 kPa O₂</td>
<td>0.04</td>
<td>0.03</td>
<td>1.2</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>% 14C-sugars</td>
<td>91 Pa CO₂; 21 kPa O₂</td>
<td>0.0003</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>% 14C-sugars</td>
<td>91 Pa CO₂; 2 kPa O₂</td>
<td>0.03</td>
<td>0.03</td>
<td>0.96</td>
</tr>
</tbody>
</table>

### Table A.11.5C. Multiple mean comparisons for % 14C-sugars recovered in petiole tissues of GI and GIV A. majus exposed to CO₂ and O₂ treatments in Table 3.5. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>CV</th>
<th>CO₂</th>
<th>PSug</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td>400</td>
<td></td>
<td>1.25305245</td>
<td>0.01747200</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>402</td>
<td></td>
<td>1.29915854</td>
<td>0.02139875</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>900</td>
<td></td>
<td>1.22076535</td>
<td>0.01747200</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>902</td>
<td></td>
<td>1.28818403</td>
<td>0.02139875</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>400</td>
<td></td>
<td>1.18541174</td>
<td>0.01913962</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>402</td>
<td></td>
<td>1.26283144</td>
<td>0.02139875</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>900</td>
<td></td>
<td>1.22049633</td>
<td>0.01747200</td>
<td>&lt;.0001</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>902</td>
<td></td>
<td>1.25919134</td>
<td>0.02139875</td>
<td>&lt;.0001</td>
<td>8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table A.11.6A. Two-way analysis of variance for % $^{14}$C-sucrose recovered in petiole tissues of GI and GIV A. majus exposed to CO$_2$ and O$_2$ treatments in Table 3.5. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>0.03</td>
<td>0.99</td>
<td>0.4562</td>
<td>0.1828</td>
<td>7.84</td>
</tr>
<tr>
<td>Error</td>
<td>31</td>
<td>0.13</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>38</td>
<td>0.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>0.01</td>
<td>1.51</td>
<td>0.2291</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO$_2$O$_2$</td>
<td>3</td>
<td>0.01</td>
<td>0.84</td>
<td>0.4849</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*CO$_2$O$_2$</td>
<td>3</td>
<td>0.01</td>
<td>0.81</td>
<td>0.4985</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.11.6B. Numerical difference and standard error of the estimate % $^{14}$C-sucrose recovered in petiole tissues of GI and GIV A. majus exposed to CO$_2$ and O$_2$ treatments in Table 3.5. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>GI vs. GIV</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>% $^{14}$C-sucrose</td>
<td>40 Pa CO$_2$; 21 kPa O$_2$</td>
<td>0.01</td>
<td>0.04</td>
<td>0.28</td>
<td>0.7804</td>
</tr>
<tr>
<td>% $^{14}$C-sucrose</td>
<td>91 Pa CO$_2$; 2 kPa O$_2$</td>
<td>0.07</td>
<td>0.04</td>
<td>1.92</td>
<td>0.0644</td>
</tr>
</tbody>
</table>

Table A.11.6C. Multiple mean comparisons for % $^{14}$C-sucrose recovered in petiole tissues of GI and GIV A. majus exposed to CO$_2$ and O$_2$ treatments in Table 3.5. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>CV</th>
<th>CO2</th>
<th>P Suc</th>
<th>LS MEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LS MEAN</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td>400</td>
<td>0.81998721</td>
<td>0.02628867</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>402</td>
<td>0.78785220</td>
<td>0.03219692</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>900</td>
<td>0.87297564</td>
<td>0.02628867</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>902</td>
<td>0.85136214</td>
<td>0.03219692</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>400</td>
<td>0.80902238</td>
<td>0.02879780</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>402</td>
<td>0.82011547</td>
<td>0.03219692</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>900</td>
<td>0.80169309</td>
<td>0.02628867</td>
<td>&lt;.0001</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>902</td>
<td>0.81633387</td>
<td>0.03219692</td>
<td>&lt;.0001</td>
<td>8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Least Squares Means for effect CV*CO2
Pr > |t| for HO: LSMean(i)=LSMean(j)
Dependent Variable: PSuc
### Table A.11.7A

Two-way analysis of variance for % $^{14}$C-antirrhinoside recovered in petiole tissues of GI and GIV *A. majus* exposed to CO$_2$ and O$_2$ treatments in Table 3.5. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS $^1$</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>0.05</td>
<td>3.63</td>
<td>0.0057</td>
<td>0.4503</td>
<td>13.11</td>
</tr>
<tr>
<td>Error</td>
<td>31</td>
<td>0.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>38</td>
<td>0.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>0.01</td>
<td>5.70</td>
<td>0.0232</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO$_2$</td>
<td>3</td>
<td>0.03</td>
<td>5.68</td>
<td>0.0032</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*CO$_2$</td>
<td>3</td>
<td>0.006</td>
<td>1.19</td>
<td>0.3297</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

### Table A.11.7B

Numerical difference and standard error of the estimate % $^{14}$C-antirrhinoside recovered in petiole tissues of GI and GIV *A. majus* exposed to CO$_2$ and O$_2$ treatments in Table 3.5. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhinoside</td>
<td>40 Pa CO$_2$; 21 kPa O$_2$</td>
<td>0.07</td>
<td>0.03</td>
<td>2.61</td>
<td>0.0138</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhinoside</td>
<td>40 Pa CO$_2$; 2 kPa O$_2$</td>
<td>0.04</td>
<td>0.03</td>
<td>1.20</td>
<td>0.2391</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhinoside</td>
<td>91 Pa CO$_2$; 21 kPa O$_2$</td>
<td>0.0003</td>
<td>0.02</td>
<td>0.01</td>
<td>0.9914</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhinoside</td>
<td>91 Pa CO$_2$; 2 kPa O$_2$</td>
<td>0.03</td>
<td>0.03</td>
<td>0.96</td>
<td>0.3455</td>
</tr>
</tbody>
</table>

### Table A.11.7C

Multiple mean comparisons for % $^{14}$C-antirrhinoside recovered in petiole tissues of GI and GIV *A. majus* exposed to CO$_2$ and O$_2$ treatments in Table 3.5. Data expressed as percentage were arcsine square root transformed prior to analysis.

| CV | CO2 | Pantirrhinoside LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|----|-----|------------------------|----------------|-------|---|----------------|
| GI | 400 | 0.31774387             | 0.01747200     | <.0001 | 1 |
| GI | 402 | 0.27163779             | 0.02139875     | <.0001 | 2 |
| GI | 900 | 0.35003098             | 0.01747200     | <.0001 | 3 |
| GI | 902 | 0.28261230             | 0.02139875     | <.0001 | 4 |
| GIV| 400 | 0.38538458             | 0.01913962     | <.0001 | 5 |
| GIV| 402 | 0.30796489             | 0.02139875     | <.0001 | 6 |
| GIV| 900 | 0.35029999             | 0.01747200     | <.0001 | 7 |
| GIV| 902 | 0.31160498             | 0.02139875     | <.0001 | 8 |

Least Squares Means for effect CV*CO2

$Pr > |t|$ for H0: LSMean(i)=LSMean(j)

| i/j | Pr > |t| |
|-----|-----|---|
| 1   | 0.1052 | 0.2009 | 0.2129 | 0.0138 | 0.7257 | 0.1973 | 0.8256 |
| Least Squares Means for effect CV*CO2  
| Pr > |t| for H0: LSMean(i)=LSMean(j)  
<p>| Dependent Variable: Pantirrhinoside |</p>
<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.1052</td>
<td>0.0079</td>
<td>0.7193</td>
<td>0.0004</td>
<td>0.2391</td>
<td>0.0078</td>
<td>0.1963</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.2009</td>
<td>0.0079</td>
<td>0.0206</td>
<td>0.1823</td>
<td>0.1380</td>
<td>0.9914</td>
<td>0.1741</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.2129</td>
<td>0.7193</td>
<td>0.0206</td>
<td>0.0012</td>
<td>0.4086</td>
<td>0.0201</td>
<td>0.3455</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.0138</td>
<td>0.0004</td>
<td>0.1823</td>
<td>0.0012</td>
<td>0.1112</td>
<td>0.1856</td>
<td>0.1712</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.7257</td>
<td>0.2391</td>
<td>0.1380</td>
<td>0.4086</td>
<td>0.1356</td>
<td>0.9050</td>
<td>0.1712</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.1973</td>
<td>0.0078</td>
<td>0.0206</td>
<td>0.1823</td>
<td>0.0112</td>
<td>0.1356</td>
<td>0.1712</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.8256</td>
<td>0.1963</td>
<td>0.1741</td>
<td>0.3455</td>
<td>0.0152</td>
<td>0.9050</td>
<td>0.1712</td>
<td></td>
</tr>
</tbody>
</table>

Table A.12.1A. Two-way analysis of variance for $^{14}$C-sucrose: starch retained in source leaves of GI and GIV A. majus exposed to CO$_2$ and O$_2$ treatments in Table 3.6.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>7.79</td>
<td>4.94</td>
<td>0.0008</td>
<td>0.5271</td>
<td>36.71</td>
</tr>
<tr>
<td>Error</td>
<td>31</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>38</td>
<td>14.78</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>0.09</td>
<td>0.42</td>
<td>0.5217</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO$_2$:O$_2$</td>
<td>3</td>
<td>7.29</td>
<td>10.70</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*CO$_2$:O$_2$</td>
<td>3</td>
<td>0.27</td>
<td>0.40</td>
<td>0.7553</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)

Table A.12.1B. Numerical difference and standard error of the estimate $^{14}$C-sucrose: starch retained in source leaves of GI and GIV A. majus exposed to CO$_2$ and O$_2$ treatments in Table 3.6.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>1$^{14}$C-sucrose: starch</td>
<td>40 Pa CO$_2$; 21 kPa O$_2$</td>
<td>0.07</td>
<td>0.27</td>
<td>0.27</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>1$^{14}$C-sucrose: starch</td>
<td>40 Pa CO$_2$; 2 kPa O$_2$</td>
<td>0.37</td>
<td>0.36</td>
<td>1.03</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>1$^{14}$C-sucrose: starch</td>
<td>91 Pa CO$_2$; 21 kPa O$_2$</td>
<td>0.13</td>
<td>0.29</td>
<td>0.44</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>1$^{14}$C-sucrose: starch</td>
<td>91 Pa CO$_2$; 2 kPa O$_2$</td>
<td>0.16</td>
<td>0.34</td>
<td>0.48</td>
</tr>
</tbody>
</table>

Table A.12.1C. Multiple mean comparisons for $^{14}$C-sucrose: starch retained in source leaves of GI and GIV A. majus exposed to CO$_2$ and O$_2$ treatments in Table 3.6.

<table>
<thead>
<tr>
<th>CV</th>
<th>CO2</th>
<th>SucStarch LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td>40;21</td>
<td>1.87093621</td>
<td>0.16786630</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>40;2</td>
<td>0.94564848</td>
<td>0.27412452</td>
<td>0.0016</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>91;21</td>
<td>0.84554887</td>
<td>0.19383531</td>
<td>0.0001</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>91;2</td>
<td>1.04532101</td>
<td>0.23739880</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>40;21</td>
<td>1.94383353</td>
<td>0.21233594</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>40;2</td>
<td>1.31848965</td>
<td>0.23739880</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>91;21</td>
<td>0.97229643</td>
<td>0.21233594</td>
<td>&lt;.0001</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>91;2</td>
<td>0.88275274</td>
<td>0.23739880</td>
<td>0.0008</td>
<td>8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Least Squares Means for effect CV*CO2  
| Pr > |t| for H0: LSMean(i)=LSMean(j)  
<p>| Dependent Variable: SucStarch |</p>
<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0072</td>
<td>0.0004</td>
<td>0.0079</td>
<td>0.7895</td>
<td>0.0668</td>
<td>0.0023</td>
<td>0.0019</td>
<td></td>
</tr>
</tbody>
</table>
Table A.12.2A. Two-way analysis of variance for $^{14}$C-sucrose: antirrhinoside retained in source leaves of GI and GIV A. majus exposed to CO$_2$ and O$_2$ treatments in Table 3.6.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>27.99</td>
<td>11.56</td>
<td>&lt;.0001</td>
<td>0.7103</td>
<td>21.76</td>
</tr>
<tr>
<td>Error</td>
<td>33</td>
<td>11.41</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>40</td>
<td>39.40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>1.70</td>
<td>4.92</td>
<td>0.0335</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO$_2$:O$_2$</td>
<td>3</td>
<td>24.59</td>
<td>23.70</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*CO$_2$:O$_2$</td>
<td>3</td>
<td>2.00</td>
<td>1.93</td>
<td>0.1444</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.12.2B. Numerical difference and standard error of the estimate $^{14}$C-sucrose: antirrhinoside retained in source leaves of GI and GIV A. majus exposed to CO$_2$ and O$_2$ treatments in Table 3.6.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>40 Pa CO$_2$; 2 kPa O$_2$</td>
<td>0.22</td>
<td>0.32</td>
<td>0.71</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>91 Pa CO$_2$; 21 kPa O$_2$</td>
<td>0.61</td>
<td>0.36</td>
<td>1.72</td>
</tr>
<tr>
<td>GIV vs. GI</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>91 Pa CO$_2$; 2 kPa O$_2$</td>
<td>1.09</td>
<td>0.41</td>
<td>2.62</td>
</tr>
</tbody>
</table>

Table A.12.2C. Multiple mean comparisons for $^{14}$C-sucrose: antirrhinoside retained in source leaves of GI and GIV A. majus exposed to CO$_2$ and O$_2$ treatments in Table 3.6.

<table>
<thead>
<tr>
<th>CV</th>
<th>CO2</th>
<th>SucAnti LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td>40;21</td>
<td>2.18289710</td>
<td>0.20793386</td>
<td>&lt;.0001</td>
<td>1</td>
</tr>
<tr>
<td>GI</td>
<td>40;2</td>
<td>2.38036753</td>
<td>0.29406288</td>
<td>&lt;.0001</td>
<td>2</td>
</tr>
<tr>
<td>GI</td>
<td>91;21</td>
<td>2.80960200</td>
<td>0.24010134</td>
<td>&lt;.0001</td>
<td>3</td>
</tr>
<tr>
<td>GI</td>
<td>91;2</td>
<td>4.76134592</td>
<td>0.29406288</td>
<td>&lt;.0001</td>
<td>4</td>
</tr>
<tr>
<td>GIV</td>
<td>40;21</td>
<td>1.95842569</td>
<td>0.24010134</td>
<td>&lt;.0001</td>
<td>5</td>
</tr>
<tr>
<td>GIV</td>
<td>40;2</td>
<td>2.62353952</td>
<td>0.29406288</td>
<td>&lt;.0001</td>
<td>6</td>
</tr>
<tr>
<td>GIV</td>
<td>91;21</td>
<td>2.19839015</td>
<td>0.26301784</td>
<td>&lt;.0001</td>
<td>7</td>
</tr>
<tr>
<td>GIV</td>
<td>91;2</td>
<td>3.67380643</td>
<td>0.26301784</td>
<td>&lt;.0001</td>
<td>8</td>
</tr>
</tbody>
</table>

Least Squares Means for effect CV*CO2

Pr > |t| for H0: LSMean(i)=LSMean(j)

<table>
<thead>
<tr>
<th>Dependent Variable: SucStarch</th>
</tr>
</thead>
<tbody>
<tr>
<td>i/j</td>
</tr>
<tr>
<td>1</td>
</tr>
</tbody>
</table>
### Table A.12.3A. Two-way analysis of variance for $^{14}$C-antirrhinoside: antirrhine retained in source leaves of GI and GIV *A. majus* exposed to CO$_2$ and O$_2$ treatments in Table 3.6.

**Two-way ANOVA**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS$^1$</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>31.91</td>
<td>8.49</td>
<td>&lt;.0001</td>
<td>0.6362</td>
<td>34.74</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>18.25</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>41</td>
<td>50.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>0.49</td>
<td>0.91</td>
<td>0.3456</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO$_2$:O$_2$</td>
<td>3</td>
<td>23.20</td>
<td>14.41</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*CO$_2$:O$_2$</td>
<td>3</td>
<td>4.72</td>
<td>2.93</td>
<td>0.0473</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

### Table A.12.3B. Numerical difference and standard error of the estimate $^{14}$C-sucrose: antirrhinoside retained in source leaves of GI and GIV *A. majus* exposed to CO$_2$ and O$_2$ treatments in Table 3.6.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV $^{14}$C-antirrhinoside: antirrhine</td>
<td>40 Pa CO$_2$; 21 kPa O$_2$</td>
<td>1.30</td>
<td>0.40</td>
<td>3.28</td>
<td>0.0024</td>
</tr>
<tr>
<td>GI vs. GIV $^{14}$C-antirrhinoside: antirrhine</td>
<td>40 Pa CO$_2$; 2 kPa O$_2$</td>
<td>0.31</td>
<td>0.52</td>
<td>0.60</td>
<td>0.5542</td>
</tr>
<tr>
<td>GI vs. GIV $^{14}$C-antirrhinoside: antirrhine</td>
<td>91 Pa CO$_2$; 21 kPa O$_2$</td>
<td>0.04</td>
<td>0.42</td>
<td>0.09</td>
<td>0.9284</td>
</tr>
<tr>
<td>GI vs. GIV $^{14}$C-antirrhinoside: antirrhine</td>
<td>91 Pa CO$_2$; 2 kPa O$_2$</td>
<td>0.13</td>
<td>0.52</td>
<td>0.26</td>
<td>0.7955</td>
</tr>
</tbody>
</table>

### Table A.12.3C. Multiple mean comparisons for $^{14}$C-antirrhinoside: antirrhine retained in source leaves of GI and GIV *A. majus* exposed to CO$_2$ and O$_2$ treatments in Table 3.6.

| CV | CO2 | Antirrhine LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|----|-----|-------------------|----------------|-------|---|----------------|
| GI | 40;21 | 3.63976356 | 0.25902301 | <.0001 | 1 |
| GI | 40;2 | 1.33947754 | 0.36631386 | 0.0009 | 2 |
| GI | 91;21 | 2.13055915 | 0.29909401 | <.0001 | 3 |
| GI | 91;2 | 0.94631152 | 0.36631386 | 0.0143 | 4 |
| GIV | 40;21 | 2.34005501 | 0.29909401 | <.0001 | 5 |
| GIV | 40;2 | 1.64897536 | 0.36631386 | <.0001 | 6 |
| GIV | 91;21 | 2.09225361 | 0.29909401 | <.0001 | 7 |
| GIV | 91;2 | 1.08162083 | 0.36631386 | 0.0057 | 8 |

### Least Squares Means for effect CV*CO2

Pr > |t| for H0: LSMean(i)=LSMean(j)

<table>
<thead>
<tr>
<th>Dependent Variable: Antirrhine</th>
</tr>
</thead>
<tbody>
<tr>
<td>i/j 1 2 3 4 5 6 7 8</td>
</tr>
</tbody>
</table>

---

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Table A.12.4A. Two-way analysis of variance % $^{14}$C-sucrose: antirrhinoside recovered in petiole of GI and GIV A. majus exposed to CO$_2$ and O$_2$ treatments in Table 3.6.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>56.55</td>
<td>1.41</td>
<td>0.2384</td>
<td>0.2309</td>
<td>41.80</td>
</tr>
<tr>
<td>Error</td>
<td>31</td>
<td>234.72</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>25.47</td>
<td>4.43</td>
<td>0.0435</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO$_2$:O$_2$</td>
<td>3</td>
<td>21.13</td>
<td>1.23</td>
<td>0.3170</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*CO$_2$:O$_2$</td>
<td>3</td>
<td>9.11</td>
<td>0.53</td>
<td>0.6661</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.12.4B. Numerical difference and standard error of the estimate % $^{14}$C-sucrose: antirrhinoside recovered in petiole of GI and GIV A. majus exposed to CO$_2$ and O$_2$ treatments in Table 3.6.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>% $^{14}$C-sucrose: antirrhinoside 40 Pa CO$_2$: 21 kPa O$_2$</td>
<td>3.11</td>
<td>1.45</td>
<td>2.14</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>% $^{14}$C-sucrose: antirrhinoside 40 Pa CO$_2$: 2 kPa O$_2$</td>
<td>0.87</td>
<td>1.69</td>
<td>0.52</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>% $^{14}$C-sucrose: antirrhinoside 91 Pa CO$_2$: 21 kPa O$_2$</td>
<td>0.82</td>
<td>1.38</td>
<td>0.59</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>% $^{14}$C-sucrose: antirrhinoside 91 Pa CO$_2$: 2 kPa O$_2$</td>
<td>1.78</td>
<td>1.69</td>
<td>1.05</td>
</tr>
</tbody>
</table>

Table A.12.4C. Multiple mean comparisons for % $^{14}$C-sucrose: antirrhinoside recovered in petiole of GI and GIV A. majus exposed to CO$_2$ and O$_2$ treatments in Table 3.6.

| CV CO2 Suc AntiP LSMEAN Standard Error Pr > |t| LSMEAN Number |
|-----|------|---------|----------|-------------|-------------|
| GI  | 40;21| 6.93729326 | 0.97872073 | <.0001 | 1 |
| GI  | 40;2 | 6.96842721  | 1.19868320 | <.0001 | 2 |
| GI  | 91;21| 5.26002959  | 0.97872073 | <.0001 | 3 |
| GI  | 91;2 | 7.44548387  | 1.19868320 | <.0001 | 4 |
| GIV | 40;21| 3.82879695  | 1.07213485 | 0.0012 | 5 |
| GIV | 40;2 | 6.09401642  | 1.19868320 | <.0001 | 6 |
| GIV | 91;21| 4.44187013  | 0.97872073 | <.0001 | 7 |
| GIV | 91;2 | 5.66616489  | 1.19868320 | <.0001 | 8 |
Table A.13.1A. Two-way analysis of variance for leaf photosynthesis (µmol C·m⁻²·s⁻¹) to compare GI exposed to three different short term temperatures at 21 and 2 kPa O₂ under 40 Pa CO₂ in Figure 3.6A.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>773.38</td>
<td>57.17</td>
<td>&lt;0.001</td>
<td>0.9108</td>
<td>8.06</td>
</tr>
<tr>
<td>Error</td>
<td>28</td>
<td>75.76</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>33</td>
<td>849.13</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>310.60</td>
<td>57.40</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O₂</td>
<td>1</td>
<td>358.85</td>
<td>132.64</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O₂</td>
<td>2</td>
<td>40.77</td>
<td>7.53</td>
<td>0.0024</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.13.1B. Numerical difference and standard error of the estimate for leaf photosynthesis (µmol C·m⁻²·s⁻¹) to compare GI A. majus exposed to short term 2 and 21 kPa O₂ to three different temperatures under 40 Pa CO₂ in Figure 3.6A.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Photosynthesis</td>
<td>15°C</td>
<td>9.95</td>
<td>1.06</td>
<td>9.38</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Photosynthesis</td>
<td>25°C</td>
<td>5.04</td>
<td>0.91</td>
<td>5.51</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

O₂ Temp NCER LSMEAN Standard Error Pr > |t| LSMEAN Number

<table>
<thead>
<tr>
<th>O₂</th>
<th>Temp</th>
<th>NCER</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>15</td>
<td>11.5009500</td>
<td>0.6715106</td>
<td>&lt;0.001</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>25</td>
<td>21.3967143</td>
<td>0.6216980</td>
<td>&lt;0.001</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>35</td>
<td>19.1159429</td>
<td>0.6216980</td>
<td>&lt;0.001</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>15</td>
<td>21.4493000</td>
<td>0.8224292</td>
<td>&lt;0.001</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>25</td>
<td>26.4346167</td>
<td>0.6715106</td>
<td>&lt;0.001</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>35</td>
<td>24.1690000</td>
<td>0.8224292</td>
<td>&lt;0.001</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table A.13.1B. Numerical difference and standard error of the estimate for leaf photosynthesis (µmol C·m⁻²·s⁻¹) to compare GI A. majus exposed to short term 2 and 21 kPa O₂ to three different temperatures under 40 Pa CO₂ in Figure 3.6A.

| Least Squares Means for effect O₂*Temp  
Pr > |t| for H₀: LSMEAN(i)=LSMEAN(j)  
Dependent Variable: NCER |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>i/j</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>1</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>2</td>
<td>&lt;.0001</td>
<td>0.0149</td>
<td>0.9597</td>
<td>&lt;.0001</td>
<td>0.0119</td>
<td></td>
</tr>
</tbody>
</table>
**Table A.13.2. Two-way analysis of variance for leaf export rate (mmol C·m\(^{-2}\)s\(^{-1}\)) to compare GI *A. majus* leaves exposed to three different short term temperatures at 21 and 2 kPa O\(_2\) under 40 Pa CO\(_2\) in Figure 3.6D.**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R(^2)</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>271.17</td>
<td>9.64</td>
<td>&lt;.0001</td>
<td>0.6325</td>
<td>17.32</td>
</tr>
<tr>
<td>Error</td>
<td>28</td>
<td>157.57</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>33</td>
<td>428.74</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>117.19</td>
<td>10.41</td>
<td>0.0004</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O(_2)</td>
<td>4</td>
<td>48.42</td>
<td>8.60</td>
<td>0.0066</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O(_2)</td>
<td>8</td>
<td>64.53</td>
<td>5.73</td>
<td>0.0082</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Sum of squares for model parameters are those of type III (SAS)

**Table A.13.2B. Numerical difference and standard error of the estimate for leaf export rate (mmol C·m\(^{-2}\)s\(^{-1}\)) to compare GI *A. majus* leaves exposed short term 2 and 21 kPa O\(_2\) to three different temperatures under 40 Pa CO\(_2\) in Figure 3.6D.**

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Export rate</td>
<td>15°C</td>
<td>6.06</td>
<td>1.53</td>
<td>3.95</td>
<td>0.0005</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Export rate</td>
<td>25°C</td>
<td>2.60</td>
<td>1.28</td>
<td>2.03</td>
<td>0.0523</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Export rate</td>
<td>35°C</td>
<td>1.27</td>
<td>1.53</td>
<td>0.83</td>
<td>0.4130</td>
</tr>
</tbody>
</table>

**Table A.13.2C. Multiple mean comparison for leaf export rate (mmol C·m\(^{-2}\)s\(^{-1}\)) to compare GI *A. majus* leaves exposed short term 2 and 21 kPa O\(_2\) to three different temperatures under 40 Pa CO\(_2\) in Figure 3.6D.**

| O\(_2\) Temp | Exp* LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|--------------|-------------|----------------|-------|---|----------------|
| a 15         | 7.9561167   | 0.9684654      | <.0001| 1 |
| a 25         | 13.8838125  | 0.8387156      | <.0001| 2 |
| a 35         | 15.7012667  | 0.9684654      | <.0001| 3 |
| l 15         | 14.0121500  | 1.1861230      | <.0001| 4 |
| l 25         | 16.4809500  | 0.9684654      | <.0001| 5 |
| l 35         | 14.4289000  | 1.1861230      | <.0001| 6 |

**Least Squares Means for effect O\(_2\)*Temp**

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
</table>
| Pr > |t| for H0: LSMean(i)=LSMean(j) | Dependent Variable: Exp

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
</table>
| Pr > |t| for H0: LSMean(i)=LSMean(j) | Dependent Variable: Exp

---

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Table A.13.3A Two-way analysis of variance for leaf relative export flux (% of photosynthesis) to compare GI A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O\textsubscript{2} under 40 Pa CO\textsubscript{2} in Figure 3.6G. Data expressed as percentage were arcsine square root transformed prior to analysis.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS\textsuperscript{1}</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R\textsuperscript{2}</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>0.15</td>
<td>2.82</td>
<td>0.0342</td>
<td>0.3268</td>
<td>10.68</td>
</tr>
<tr>
<td>Error</td>
<td>29</td>
<td>0.31</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>34</td>
<td>0.46</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>0.02</td>
<td>0.81</td>
<td>0.4550</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O\textsubscript{2}</td>
<td>1</td>
<td>0.07</td>
<td>6.93</td>
<td>0.0135</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O\textsubscript{2}</td>
<td>2</td>
<td>0.04</td>
<td>2.08</td>
<td>0.1429</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{1}Sum of squares for model parameters are those of type III (SAS)

Table A.13.3B. Numerical difference and standard error of the estimate for leaf relative export flux (% of photosynthesis) to compare GI A. majus leaves exposed to short term 2 and 21 kPa O\textsubscript{2} to three different temperatures under 40 Pa CO\textsubscript{2} in Figure 3.6G. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Relative export</td>
<td>15°C</td>
<td>0.04</td>
<td>0.07</td>
<td>0.65</td>
<td>0.5206</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Relative export</td>
<td>25°C</td>
<td>0.04</td>
<td>0.06</td>
<td>0.74</td>
<td>0.4641</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Relative export</td>
<td>35°C</td>
<td>0.2</td>
<td>0.06</td>
<td>3.10</td>
<td>0.0043</td>
</tr>
</tbody>
</table>

Table A.13.3C. Multiple mean comparison for leaf relative export flux (% of photosynthesis) to compare GI A. majus leaves exposed to short term 2 and 21 kPa O\textsubscript{2} to three different temperatures under 40 Pa CO\textsubscript{2} in Figure 3.6G. Data expressed as percentage were arcsine square root transformed prior to analysis.

| O\textsubscript{2} | Temp | Ratioi LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|---------------------|------|---------------|----------------|------|---|----------------|
| a                   | 15   | 0.98104370    | 0.04206573     | <.0001| <.0001| 1 |
| a                   | 25   | 0.94875245    | 0.03642999     | <.0001| <.0001| 2 |
| a                   | 35   | 1.08157547    | 0.03894530     | <.0001| <.0001| 3 |
| l                   | 15   | 0.93779035    | 0.05151978     | <.0001| <.0001| 4 |
| l                   | 25   | 0.90746420    | 0.04206573     | <.0001| <.0001| 5 |
| l                   | 35   | 0.88151533    | 0.05151978     | <.0001| <.0001| 6 |

Least Squares Means for effect O\textsubscript{2}*Temp
Pr > |t| for H0: LSMEAN(i)=LSMEAN(j)

<table>
<thead>
<tr>
<th>Dependent Variable: Ratioi</th>
</tr>
</thead>
<tbody>
<tr>
<td>i/j</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
</tbody>
</table>
Table A.13.4A. Two-way analysis of variance for leaf photosynthesis (µmol C·m$^{-2}$) to compare GI A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.6B.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>1691.28</td>
<td>33.34</td>
<td>&lt;.0001</td>
<td>0.8651</td>
<td>11.36</td>
</tr>
<tr>
<td>Error</td>
<td>26</td>
<td>263.77</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>31</td>
<td>1955.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>1076.64</td>
<td>53.06</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
<td>423.75</td>
<td>41.73</td>
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</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>67.98</td>
<td>3.35</td>
<td>0.0507</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^*$Sum of squares for model parameters are those of type III (SAS)

Table A.13.4B. Numerical difference and standard error of the estimate for leaf photosynthesis (µmol C·m$^{-2}$) to compare GI A. majus leaves exposed to short term 2 and 21 kPa O$_2$ to three different temperatures under 91 Pa CO$_2$ in Figure 3.6B.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Photosynthesis</td>
<td>15°C</td>
<td>10.07</td>
<td>2.06</td>
<td>5.24</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Photosynthesis</td>
<td>25°C</td>
<td>3.70</td>
<td>2.01</td>
<td>2.01</td>
<td>0.0546</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Photosynthesis</td>
<td>35°C</td>
<td>7.75</td>
<td>3.77</td>
<td>3.77</td>
<td>0.0008</td>
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</table>

Table A.13.4C. Multiple mean comparison for leaf photosynthesis (µmol C·m$^{-2}$) to compare GI A. majus leaves exposed to short term 2 and 21 kPa O$_2$ to three different temperatures under 91 Pa CO$_2$ in Figure 3.6B.

<table>
<thead>
<tr>
<th>O2</th>
<th>Temp</th>
<th>NCER</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>15</td>
<td>14.6129500</td>
<td>1.3003305</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>25</td>
<td>29.5007333</td>
<td>1.3003305</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>35</td>
<td>30.0790500</td>
<td>1.3003305</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>15</td>
<td>25.3815000</td>
<td>1.5925731</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>25</td>
<td>33.2017333</td>
<td>1.3003305</td>
<td>.0004</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>35</td>
<td>37.8339750</td>
<td>1.5925731</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>k/j</th>
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<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>&lt;.0001</td>
<td>0.7557</td>
<td>0.0556</td>
<td>0.0546</td>
<td>0.0004</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>&lt;.0001</td>
<td>0.7557</td>
<td>0.0037</td>
<td>0.1014</td>
<td>0.0008</td>
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</tr>
<tr>
<td>4</td>
<td></td>
<td>&lt;.0001</td>
<td>0.0556</td>
<td>0.0307</td>
<td>0.0008</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>&lt;.0001</td>
<td>0.0546</td>
<td>0.1014</td>
<td>0.0008</td>
<td>0.0329</td>
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</tr>
<tr>
<td>6</td>
<td></td>
<td>&lt;.0001</td>
<td>0.0004</td>
<td>0.0008</td>
<td>&lt;.0001</td>
<td>0.0329</td>
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</tr>
</tbody>
</table>

Table A.13.5A. Two-way analysis of variance for leaf export rate (mmol C·m$^{-2}$) to compare GI A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.6E.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>344.83</td>
<td>4.72</td>
<td>0.0041</td>
<td>0.5066</td>
<td>24.49</td>
</tr>
<tr>
<td>Error</td>
<td>23</td>
<td>355.82</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>28</td>
<td>680.66</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>318.78</td>
<td>10.92</td>
<td>0.0005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
<td>0.35</td>
<td>0.02</td>
<td>0.8774</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>3.04</td>
<td>0.10</td>
<td>0.9016</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^*$Sum of squares for model parameters are those of type III (SAS)
Table A.13.5B. Numerical difference and standard error of the estimate for leaf export rate (mmol C·m⁻²·s⁻¹) to compare GI A. majus leaves exposed to short term 2 and 21 kPa O₂ to three different temperatures under 91 Pa CO₂ in Figure 3.6E.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Export rate</td>
<td>15°C</td>
<td>0.85</td>
<td>2.47</td>
<td>0.34</td>
<td>0.7378</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Export rate</td>
<td>25°C</td>
<td>0.52</td>
<td>2.56</td>
<td>0.20</td>
<td>0.8420</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Export rate</td>
<td>35°C</td>
<td>0.68</td>
<td>2.47</td>
<td>0.27</td>
<td>0.7861</td>
</tr>
</tbody>
</table>

Table A.13.5C. Multiple mean comparison for leaf export rate (mmol C·m⁻²·s⁻¹) to compare GI A. majus leaves exposed to short term 2 and 21 kPa O₂ to three different temperatures under 91 Pa CO₂ in Figure 3.6E.

<table>
<thead>
<tr>
<th>O2</th>
<th>Temp</th>
<th>Expi</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>15</td>
<td>10.5593667</td>
<td>1.5599693</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>25</td>
<td>17.4553600</td>
<td>1.7088608</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>35</td>
<td>18.7141667</td>
<td>1.5599693</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>15</td>
<td>11.3951250</td>
<td>1.9105645</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>25</td>
<td>17.9722750</td>
<td>1.9105645</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>35</td>
<td>18.0368500</td>
<td>1.9105645</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Least Squares Means for effect O2*Temp
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: Expi

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0067</td>
<td>0.0012</td>
<td>0.7378</td>
<td>0.0063</td>
<td>0.0059</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.0067</td>
<td>0.5916</td>
<td>0.0269</td>
<td>0.8420</td>
<td>0.8225</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.0012</td>
<td>0.5916</td>
<td>0.0069</td>
<td>0.7663</td>
<td>0.7861</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.7378</td>
<td>0.0269</td>
<td>0.0069</td>
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<td>0.0219</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.0063</td>
<td>0.8420</td>
<td>0.7663</td>
<td>0.0231</td>
<td>0.9811</td>
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</tr>
<tr>
<td>6</td>
<td>0.0059</td>
<td>0.8225</td>
<td>0.7861</td>
<td>0.0219</td>
<td>0.9811</td>
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</tr>
</tbody>
</table>

Table A.13.6A. Two-way analysis of variance for leaf relative export flux (% of photosynthesis) to compare GI A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O₂ under 91 Pa CO₂ in Figure 3.6H. Data expressed as percentage were arcsine square root transformed prior to analysis.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>0.29</td>
<td>8.61</td>
<td>0.0001</td>
<td>0.6518</td>
<td>9.54</td>
</tr>
<tr>
<td>Error</td>
<td>23</td>
<td>0.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>28</td>
<td>0.45</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>0.01</td>
<td>0.65</td>
<td>0.5321</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O₂</td>
<td>1</td>
<td>0.23</td>
<td>34.31</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O₂</td>
<td>2</td>
<td>0.04</td>
<td>2.93</td>
<td>0.0733</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table A.13.6B. Numerical difference and standard error of the estimate for leaf relative export flux (% of photosynthesis) to compare GI A. majus leaves exposed to short term 2 and 21 kPa O₂ to three different temperatures under 91 Pa CO₂ in Figure 3.6H. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Relative export</td>
<td>15°C</td>
<td>0.28</td>
<td>0.05</td>
<td>5.33</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Relative export</td>
<td>25°C</td>
<td>0.11</td>
<td>0.05</td>
<td>1.92</td>
<td>0.0674</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Relative export</td>
<td>35°C</td>
<td>0.15</td>
<td>0.05</td>
<td>2.84</td>
<td>0.0092</td>
</tr>
</tbody>
</table>

Table A.13.6C. Multiple mean comparison for leaf relative export flux (% of photosynthesis) to compare GI A. majus leaves exposed to short term 2 and 21 kPa O₂ to three different temperatures under 91 Pa CO₂ in Figure 3.6H. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>O2</th>
<th>Temp</th>
<th>Ratioi</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>l</td>
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<tr>
<td>l</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

210
| O2 | Temp | Ratioi LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|----|------|---------------|----------------|------|---|-------------|
| a  | 15   | 1.01406461    | 0.03366937     | <.0001 | 1 |
| a  | 25   | 0.89217465    | 0.03688295     | <.0001 | 2 |
| a  | 35   | 0.90747950    | 0.03366937     | <.0001 | 3 |
| l  | 15   | 0.73025993    | 0.04123639     | <.0001 | 4 |
| l  | 25   | 0.78598646    | 0.04123639     | <.0001 | 5 |
| l  | 35   | 0.75618285    | 0.04123639     | <.0001 | 6 |

Table A.13.7A. Two-way analysis of variance for leaf photosynthesis (µmol C·m⁻²·s⁻¹) to compare GI A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O₂ under 182 Pa CO₂ in Figure 3.6C.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
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<td>5</td>
<td>1925.01</td>
<td>39.32</td>
<td>&lt;.0001</td>
<td>0.8994</td>
<td>10.13</td>
</tr>
<tr>
<td>Error</td>
<td>22</td>
<td>215.40</td>
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<tr>
<td>Corrected Total</td>
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<td>90.57</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>O₂</td>
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<td>5.36</td>
<td>0.23</td>
<td>0.6331</td>
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<td></td>
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<tr>
<td>Temp*O₂</td>
<td>2</td>
<td>149.13</td>
<td>7.62</td>
<td>0.0031</td>
<td></td>
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</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.13.7B. Numerical difference and standard error of the estimate for leaf photosynthesis (µmol C·m⁻²·s⁻¹) to compare GI A. majus leaves exposed to short term 2 and 21 kPa O₂ to three different temperatures under 182 Pa CO₂ in Figure 3.6C.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Photosynthesis</td>
<td>15°C</td>
<td>5.68</td>
<td>2.02</td>
<td>2.81</td>
<td>0.0102</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Photosynthesis</td>
<td>25°C</td>
<td>3.16</td>
<td>1.89</td>
<td>1.67</td>
<td>0.1093</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Photosynthesis</td>
<td>35°C</td>
<td>5.22</td>
<td>2.39</td>
<td>2.19</td>
<td>0.0398</td>
</tr>
</tbody>
</table>

Table A.13.7C. Multiple mean comparison for leaf photosynthesis (µmol C·m⁻²·s⁻¹) to compare GI A. majus leaves exposed to short term 2 and 21 kPa O₂ to three different temperatures under 182 Pa CO₂ in Figure 3.6C.

| O2 | Temp | NCER LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|----|------|-------------|----------------|------|---|-------------|
| a  | 15   | 17.9236833  | 1.2774214      | <.0001 | 1 |
| a  | 25   | 38.5331400  | 1.3993451      | <.0001 | 2 |
| a  | 35   | 39.7843000  | 1.8065467      | <.0001 | 3 |
| l  | 15   | 23.6018000  | 1.5645153      | <.0001 | 4 |
| l  | 25   | 35.3708167  | 1.2774214      | <.0001 | 5 |
| l  | 35   | 34.5614250  | 1.5645153      | <.0001 | 6 |
### Table A.13.8A. Two-way analysis of variance for leaf export rate (mmol C·m⁻²·s⁻¹) to compare GI *A. majus* leaves exposed to three different short term temperatures at 21 and 2 kPa O₂ under 182 Pa CO₂ in Figure 3.6F.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>516.53</td>
<td>9.55</td>
<td>&lt;.0001</td>
<td>0.6945</td>
<td>19.49</td>
</tr>
<tr>
<td>Error</td>
<td>21</td>
<td>227.19</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
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<td>743.72</td>
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<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>478.22</td>
<td>22.10</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O₂</td>
<td>1</td>
<td>2.42</td>
<td>0.22</td>
<td>0.6412</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O₂</td>
<td>2</td>
<td>35.90</td>
<td>1.66</td>
<td>0.2143</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† Sum of squares for model parameters are those of type III (SAS)

### Table A.13.8B. Numerical difference and standard error of the estimate for leaf export rate (mmol C·m⁻²·s⁻¹) to compare GI *A. majus* leaves exposed to short term 2 and 21 kPa O₂ to three different temperatures under 182 Pa CO₂ in Figure 3.6F.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Export rate</td>
<td>15°C</td>
<td>2.08</td>
<td>2.21</td>
<td>0.94</td>
<td>0.3558</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Export rate</td>
<td>25°C</td>
<td>2.67</td>
<td>2.21</td>
<td>1.21</td>
<td>0.2390</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Export rate</td>
<td>35°C</td>
<td>2.40</td>
<td>2.21</td>
<td>1.09</td>
<td>0.2894</td>
</tr>
</tbody>
</table>

### Table A.13.8C. Multiple mean comparison for leaf export rate (mmol C·m⁻²·s⁻¹) to compare GI *A. majus* leaves exposed to short term 2 and 21 kPa O₂ to three different temperatures under 182 Pa CO₂ in Figure 3.6F.

| O₂ | Temp | Expri LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|----|------|--------------|----------------|-------|---|----------------|
| a  | 15   | 12.0825600   | 1.4709640      | <.0001| 1 |
| a  | 25   | 17.1165200   | 1.4709640      | <.0001| 2 |
| a  | 35   | 22.2292200   | 1.4709640      | <.0001| 3 |
| l  | 15   | 9.9993250    | 1.6445878      | <.0001| 4 |
| l  | 25   | 19.7907750   | 1.6445878      | <.0001| 5 |
| l  | 35   | 19.8312250   | 1.6445878      | <.0001| 6 |

### Table A.13.8D. Least squares means for effect O₂*Temp

<table>
<thead>
<tr>
<th>Pr &gt;</th>
<th>t</th>
<th>for H₀: LSMean(i)=LSMean(j)</th>
<th>Dependent Variable: Expri</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0247</td>
<td>&lt;.0001</td>
<td>0.3558</td>
<td>0.0022</td>
</tr>
<tr>
<td>0.0247</td>
<td>0.0228</td>
<td>0.0041</td>
<td>0.2390</td>
</tr>
<tr>
<td>&lt;.0001</td>
<td>0.0228</td>
<td>&lt;.0001</td>
<td>0.2816</td>
</tr>
<tr>
<td>0.3558</td>
<td>0.0041</td>
<td>&lt;.0001</td>
<td>0.0004</td>
</tr>
</tbody>
</table>
Table A.13.9A. Two-way analysis of variance for leaf relative export flux (% of photosynthesis) to compare G. A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O\textsubscript{2} under 182 Pa CO\textsubscript{2} in Figure 3.6. Data expressed as percentage were arcsine square root transformed prior to analysis.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS\textsuperscript{1}</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R\textsuperscript{2}</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>0.20</td>
<td>6.96</td>
<td>0.0006</td>
<td>0.6202</td>
<td>9.37</td>
</tr>
<tr>
<td>Error</td>
<td>21</td>
<td>0.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>26</td>
<td>0.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>0.02</td>
<td>1.73</td>
<td>0.2020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O\textsubscript{2}</td>
<td>1</td>
<td>0.01</td>
<td>1.12</td>
<td>0.3022</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O\textsubscript{2}</td>
<td>2</td>
<td>0.19</td>
<td>16.13</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{1}Sum of squares for model parameters are those of type III (SAS)

Table A.13.9B. Numerical difference and standard error of the estimate for leaf relative export flux (% of photosynthesis) to compare G. A. majus leaves exposed to short term 2 and 21 kPa O\textsubscript{2} to three different temperatures under 182 Pa CO\textsubscript{2} in Figure 3.6. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Relative export</td>
<td>15°C</td>
<td>0.27</td>
<td>0.05</td>
<td>5.01</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Relative export</td>
<td>25°C</td>
<td>0.14</td>
<td>0.05</td>
<td>2.68</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Relative export</td>
<td>35°C</td>
<td>0.04</td>
<td>0.05</td>
<td>0.73</td>
</tr>
</tbody>
</table>

Table A.13.9C. Multiple mean comparison for leaf relative export flux (% of photosynthesis) to compare G. A. majus leaves exposed to short term 2 and 21 kPa O\textsubscript{2} to three different temperatures under 182 Pa CO\textsubscript{2} in Figure 3.6. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>O\textsubscript{2}</th>
<th>Temp</th>
<th>Ratioi</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>15</td>
<td>0.90414187</td>
<td>0.03145387</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>25</td>
<td>0.73026824</td>
<td>0.03445599</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>35</td>
<td>0.81825793</td>
<td>0.03445599</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>15</td>
<td>0.63107255</td>
<td>0.04448249</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>25</td>
<td>0.86903708</td>
<td>0.03852296</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>35</td>
<td>0.85612843</td>
<td>0.03852296</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Two-way analysis of variance for leaf photosynthesis (µmol C·m$^{-2}$·s$^{-1}$) to compare GIV A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.7.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>Value</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>683.35</td>
<td>23.85</td>
<td>&lt;.0001</td>
<td>0.8210</td>
<td>11.41</td>
</tr>
<tr>
<td>Error</td>
<td>26</td>
<td>148.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>31</td>
<td>832.34</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>286.45</td>
<td>24.99</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
<td>291.16</td>
<td>50.81</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>23.77</td>
<td>2.07</td>
<td>0.1460</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.14.1B. Numerical difference and standard error of the estimate for leaf photosynthesis (µmol C·m$^{-2}$·s$^{-1}$) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O$_2$ to three different temperatures under 40 Pa CO$_2$ in Figure 3.7.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Photosynthesis</td>
<td>15°C</td>
<td>7.74</td>
<td>1.54</td>
<td>5.01 &lt;.0001</td>
</tr>
<tr>
<td></td>
<td>Photosynthesis</td>
<td>25°C</td>
<td>7.06</td>
<td>1.38</td>
<td>5.11 &lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Photosynthesis</td>
<td>35°C</td>
<td>3.63</td>
<td>1.54</td>
<td>2.35 0.0267</td>
</tr>
</tbody>
</table>

Table A.14.1C. Multiple mean comparison for leaf photosynthesis (µmol C·m$^{-2}$·s$^{-1}$) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O$_2$ to three different temperatures under 40 Pa CO$_2$ in Figure 3.7.

<table>
<thead>
<tr>
<th>O$_2$ Temp</th>
<th>NCER LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>a 15</td>
<td>13.2042333</td>
<td>0.9772571</td>
<td>&lt;.0001</td>
<td>1</td>
</tr>
<tr>
<td>a 25</td>
<td>20.8028000</td>
<td>0.9772571</td>
<td>&lt;.0001</td>
<td>2</td>
</tr>
<tr>
<td>a 35</td>
<td>20.1779833</td>
<td>0.9772571</td>
<td>&lt;.0001</td>
<td>3</td>
</tr>
<tr>
<td>l 15</td>
<td>20.9417250</td>
<td>1.1968907</td>
<td>&lt;.0001</td>
<td>4</td>
</tr>
<tr>
<td>l 25</td>
<td>27.8666000</td>
<td>0.9772571</td>
<td>&lt;.0001</td>
<td>5</td>
</tr>
<tr>
<td>l 35</td>
<td>23.8072250</td>
<td>1.1968907</td>
<td>&lt;.0001</td>
<td>6</td>
</tr>
</tbody>
</table>

Table A.14.2A. Two-way analysis of variance for leaf export rate (mmol C·m$^{-2}$·s$^{-1}$) to compare GIV A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.7.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>Value</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>161.74</td>
<td>3.60</td>
<td>0.0131</td>
<td>0.4093</td>
<td>23.90</td>
</tr>
<tr>
<td>Error</td>
<td>26</td>
<td>233.42</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>31</td>
<td>395.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>114.97</td>
<td>7.21</td>
<td>0.0032</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
<td>26.68</td>
<td>2.97</td>
<td>0.0867</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>3.80</td>
<td>0.21</td>
<td>0.8104</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)
Table A.14.2B. Numerical difference and standard error of the estimate for leaf export rate (mmol C·m$^{-2}$s$^{-1}$) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O$_2$ to three different temperatures under 40 Pa CO$_2$ in Figure 3.7D.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Export rate</td>
<td>15°C</td>
<td>2.18</td>
<td>1.93</td>
<td>1.13</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Export rate</td>
<td>25°C</td>
<td>2.52</td>
<td>1.73</td>
<td>1.45</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Export rate</td>
<td>35°C</td>
<td>0.88</td>
<td>1.93</td>
<td>0.46</td>
</tr>
</tbody>
</table>

Table A.14.2C. Multiple mean comparison for leaf export rate (mmol C·m$^{-2}$s$^{-1}$) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O$_2$ to three different temperatures under 40 Pa CO$_2$ in Figure 3.7D.

| O2 Temp | ExpI LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|---------|-------------|----------------|------|---|----------------|
| a 15    | 8.735833    | 1.2232248      | <.0001 | 1  |
| a 25    | 13.0282667  | 1.2232248      | <.0001 | 2  |
| a 35    | 13.0992667  | 1.2232248      | <.0001 | 3  |
| I 15    | 10.9136750  | 1.4981383      | <.0001 | 4  |
| I 25    | 15.5442500  | 1.2232248      | <.0001 | 5  |
| I 35    | 13.8928000  | 1.4981383      | <.0001 | 6  |

Table A.14.3A. Two-way analysis of variance for leaf relative export flux (% of photosynthesis) to compare GIV A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.7G. Data expressed as percentage were arcsine square root transformed prior to analysis.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>0.11</td>
<td>1.82</td>
<td>0.1395</td>
<td>0.2700</td>
<td>12.41</td>
</tr>
<tr>
<td>Error</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>30</td>
<td>0.42</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>0.11</td>
<td>0.57</td>
<td>0.5743</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
<td>0.09</td>
<td>7.21</td>
<td>0.0127</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>0.01</td>
<td>0.45</td>
<td>0.6424</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table A.14.3B. Numerical difference and standard error of the estimate for leaf relative export flux (% of photosynthesis) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O$_2$ to three different temperatures under 40 Pa CO$_2$ in Figure 3.7G. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Relative export</td>
<td>15°C</td>
<td>0.16</td>
<td>0.07</td>
<td>2.23</td>
<td>0.0352</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Relative export</td>
<td>25°C</td>
<td>0.07</td>
<td>0.06</td>
<td>1.07</td>
<td>0.2959</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Relative export</td>
<td>35°C</td>
<td>0.10</td>
<td>0.07</td>
<td>1.42</td>
<td>0.1681</td>
</tr>
</tbody>
</table>

Table A.14.3C. Multiple mean comparison for leaf relative export flux (% of photosynthesis) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O$_2$ to three different temperatures under 40 Pa CO$_2$ in Figure 3.7G. Data expressed as percentage were arcsine square root transformed prior to analysis.
| O2 | Temp | Ratioi LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|----|------|---------------|----------------|-------|---|----------------|
| a  | 15   | 0.94289901    | 0.04522866     | <.0001|   | 1               |
| a  | 25   | 0.91373706    | 0.04522866     | <.0001|   | 2               |
| a  | 35   | 0.97297670    | 0.04954551     | <.0001|   | 3               |
| l  | 15   | 0.78362237    | 0.05539357     | <.0001|   | 4               |
| l  | 25   | 0.84545374    | 0.04522866     | <.0001|   | 5               |
| l  | 35   | 0.86748734    | 0.05539357     | <.0001|   | 6               |

Table A.14.4A. Two-way analysis of variance for leaf photosynthesis (µmol C·m⁻²·s⁻¹) to compare GIV A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O₂ under 91 Pa CO₂ in Figure 3.7B.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>Value</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>1212.71</td>
<td>26.31</td>
<td>&lt;.0001</td>
<td>0.8457</td>
<td>9.89</td>
</tr>
<tr>
<td>Error</td>
<td>24</td>
<td>221.27</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>29</td>
<td>1433.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
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<td>670.77</td>
<td>36.38</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O₂</td>
<td>1</td>
<td>495.25</td>
<td>53.72</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O₂</td>
<td>2</td>
<td>74.05</td>
<td>4.02</td>
<td>0.0313</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.14.4B. Numerical difference and standard error of the estimate for leaf photosynthesis (µmol C·m⁻²·s⁻¹) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O₂ to three different temperatures under 91 Pa CO₂ in Figure 3.7B.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Diffrences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Photosynthesis</td>
<td>15°C</td>
<td>6.19</td>
<td>2.15</td>
<td>2.88</td>
<td>0.0082</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Photosynthesis</td>
<td>25°C</td>
<td>5.91</td>
<td>1.75</td>
<td>3.37</td>
<td>0.0025</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Photosynthesis</td>
<td>35°C</td>
<td>12.78</td>
<td>1.96</td>
<td>6.52</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Table A.14.4C. Multiple mean comparison for leaf photosynthesis (µmol C·m⁻²·s⁻¹) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O₂ to three different temperatures under 91 Pa CO₂ in Figure 3.7B.

| O2 | Temp | NCER LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|----|------|-------------|----------------|-------|---|----------------|
| a  | 15   | 20.3249500  | 1.5181837      | <.0001|   | 1               |
| a  | 25   | 31.9031500  | 1.2395918      | <.0001|   | 2               |
| a  | 35   | 26.4503667  | 1.2395918      | <.0001|   | 3               |
| l  | 15   | 26.5126750  | 1.5181837      | <.0001|   | 4               |
| l  | 25   | 37.8185167  | 1.2395918      | <.0001|   | 5               |
| l  | 35   | 39.2283250  | 1.5181837      | <.0001|   | 6               |

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Table A.14.5A. Two-way analysis of variance for leaf export rate (mmol C·m$^{-2}$·s$^{-1}$) to compare GIV _A. majus_ leaves exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.7E.

**Table A.14.5A. Two-way ANOVA**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>319.78</td>
<td>10.64</td>
<td>&lt;.0001</td>
<td>0.7074</td>
<td>15.49</td>
</tr>
<tr>
<td>Error</td>
<td>22</td>
<td>132.28</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>27</td>
<td>452.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>203.82</td>
<td>16.95</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
<td>22.45</td>
<td>3.37</td>
<td>0.0663</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>107.24</td>
<td>8.92</td>
<td>0.0015</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)*

Table A.14.5B. Numerical difference and standard error of the estimate for leaf export rate (mmol C·m$^{-2}$·s$^{-1}$) to compare GIV _A. majus_ leaves exposed to short term 2 and 21 kPa O$_2$ to three different temperatures under 91 Pa CO$_2$ in Figure 3.7E.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Export rate</td>
<td>15°C</td>
<td>2.87</td>
<td>1.73</td>
<td>1.65</td>
<td>0.1124</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Export rate</td>
<td>25°C</td>
<td>1.35</td>
<td>1.55</td>
<td>0.87</td>
<td>0.3926</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Export rate</td>
<td>35°C</td>
<td>6.95</td>
<td>1.58</td>
<td>4.39</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

Table A.14.5C. Multiple mean comparison for leaf export rate (mmol C·m$^{-2}$·s$^{-1}$) to compare GIV _A. majus_ leaves exposed to short term 2 and 21 kPa O$_2$ to three different temperatures under 91 Pa CO$_2$ in Figure 3.7E.

| O$_2$ | Temp | ExpI LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|-------|------|-------------|----------------|------|---|----------------|
| a     | 15   | 13.2344500  | 1.2260571      | <.0001 |   | 1              |
| a     | 25   | 16.9884400  | 1.0966188      | <.0001 |   | 2              |
| a     | 35   | 14.4364000  | 1.0010714      | <.0001 |   | 3              |
| l     | 15   | 10.3669000  | 1.2260571      | <.0001 |   | 4              |
| l     | 25   | 18.3407400  | 1.0966188      | <.0001 |   | 5              |
| l     | 35   | 21.3881000  | 1.2260571      | <.0001 |   | 6              |

Table A.14.5D. Least squares means for effect O$_2$*Temp for H0: LSMean(i)=LSMean(j) for NCER.

**Table A.14.5D. Least Squares Means for effect O$_2$*Temp**

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.0325</td>
<td>0.4557</td>
<td>0.1124</td>
<td>.0052</td>
<td>.0001</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>.0325</td>
<td>0.0997</td>
<td>0.0006</td>
<td>.3926</td>
<td>.0138</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>.4557</td>
<td>0.0997</td>
<td>0.0174</td>
<td>.0153</td>
<td>.0002</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>.1124</td>
<td>.0006</td>
<td>.0174</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td></td>
</tr>
</tbody>
</table>
Table A.14.6A. Two-way analysis of variance for leaf relative export flux (% of photosynthesis) to compare GIV A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.7H. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>Value</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>0.18</td>
<td>6.69</td>
<td>0.0004</td>
<td>0.5724</td>
<td>9.14</td>
</tr>
<tr>
<td>Error</td>
<td>25</td>
<td>0.13</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>30</td>
<td>0.32</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Temp</td>
<td>2</td>
<td>0.02</td>
<td>1.71</td>
<td>0.2008</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>2</td>
<td>0.08</td>
<td>15.39</td>
<td>0.0006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>0.07</td>
<td>6.97</td>
<td>0.0039</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.14.6B. Numerical difference and standard error of the estimate for leaf relative export flux (% of photosynthesis) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O$_2$ to three different temperatures under 91 Pa CO$_2$ in Figure 3.7H. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Relative export</td>
<td>15°C</td>
<td>0.24</td>
<td>0.05</td>
<td>5.07</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Relative export</td>
<td>25°C</td>
<td>0.08</td>
<td>0.04</td>
<td>1.83</td>
<td>0.0792</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Relative export</td>
<td>35°C</td>
<td>0.01</td>
<td>0.05</td>
<td>0.13</td>
<td>0.8982</td>
</tr>
</tbody>
</table>

Table A.14.6C. Multiple mean comparison for leaf relative export flux (% of photosynthesis) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O$_2$ to three different temperatures under 91 Pa CO$_2$ in Figure 3.7H. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>O$_2$ Temp</th>
<th>Ratio</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>15</td>
<td>0.91512799</td>
<td>0.03002426</td>
<td>&lt;.0001</td>
<td>1</td>
</tr>
<tr>
<td>a</td>
<td>25</td>
<td>0.81254725</td>
<td>0.03288993</td>
<td>&lt;.0001</td>
<td>2</td>
</tr>
<tr>
<td>a</td>
<td>35</td>
<td>0.82874878</td>
<td>0.03002426</td>
<td>&lt;.0001</td>
<td>3</td>
</tr>
<tr>
<td>l</td>
<td>15</td>
<td>0.67431370</td>
<td>0.03677206</td>
<td>&lt;.0001</td>
<td>4</td>
</tr>
<tr>
<td>l</td>
<td>25</td>
<td>0.73117413</td>
<td>0.03002426</td>
<td>&lt;.0001</td>
<td>5</td>
</tr>
<tr>
<td>l</td>
<td>35</td>
<td>0.83488699</td>
<td>0.03677206</td>
<td>&lt;.0001</td>
<td>6</td>
</tr>
</tbody>
</table>

Table A.14.6D. Least squares means for effect O$_2$*Temp Pr > |t| for H0: LSMean(i)=LSMean(j) Dependent Variable: Expi

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0298</td>
<td>0.0527</td>
<td>&lt;.0001</td>
<td>0.0002</td>
<td>0.1034</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.0298</td>
<td>0.7191</td>
<td>0.0097</td>
<td>0.0796</td>
<td>0.6546</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.0527</td>
<td>0.7191</td>
<td>0.0033</td>
<td>0.0302</td>
<td>0.8982</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>&lt;.0001</td>
<td>0.0097</td>
<td>0.0033</td>
<td>0.2422</td>
<td>0.0049</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.0002</td>
<td>0.0796</td>
<td>0.0302</td>
<td>0.2422</td>
<td>0.0385</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.1034</td>
<td>0.6546</td>
<td>0.8982</td>
<td>0.0049</td>
<td>0.0385</td>
<td></td>
</tr>
</tbody>
</table>
Table A.14.7A. Two-way analysis of variance for leaf photosynthesis (µmol C·m$^{-2}$s$^{-1}$) to compare GIV A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.7C.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS$^1$</th>
<th>Value</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>1737.78</td>
<td>19.68</td>
<td>&lt;.0001</td>
<td>0.8173</td>
<td>13.03</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>22</td>
<td>388.44</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>27</td>
<td>2126.22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>1621.88</td>
<td>45.93</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>1</td>
<td>51.63</td>
<td>2.92</td>
<td>0.1013</td>
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<td></td>
<td></td>
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<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>4.18</td>
<td>0.12</td>
<td>0.8889</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.14.7B. Numerical difference and standard error of the estimate for leaf photosynthesis (µmol C·m$^{-2}$s$^{-1}$) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O$_2$ to three different temperatures under 182 Pa CO$_2$ in Figure 3.7C.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Photosynthesis</td>
<td>15°C</td>
<td>3.47</td>
<td>2.81</td>
<td>1.23</td>
</tr>
<tr>
<td></td>
<td>Photosynthesis</td>
<td>25°C</td>
<td>1.71</td>
<td>2.54</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>Photosynthesis</td>
<td>35°C</td>
<td>3.05</td>
<td>2.97</td>
<td>1.03</td>
</tr>
</tbody>
</table>

Table A.14.7C. Multiple mean comparison for leaf photosynthesis (µmol C·m$^{-2}$s$^{-1}$) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O$_2$ to three different temperatures under 182 Pa CO$_2$ in Figure 3.7C.

<table>
<thead>
<tr>
<th>O$_2$</th>
<th>Temp</th>
<th>NCER</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
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<td>19.4741800</td>
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<td>&lt;.0001</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>25</td>
<td>36.0626000</td>
<td>1.8791657</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>35</td>
<td>36.8492250</td>
<td>2.1009712</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>15</td>
<td>22.9444000</td>
<td>2.1009712</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>25</td>
<td>37.7822500</td>
<td>1.7154358</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>35</td>
<td>39.9045750</td>
<td>2.1009712</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

Table A.14.8A. Two-way analysis of variance for leaf export rate (mmol C·m$^{-2}$s$^{-1}$) to compare GIV A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.7F.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS$^1$</th>
<th>Value</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>398.30</td>
<td>6.83</td>
<td>0.0005</td>
<td>0.5975</td>
<td>21.97</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>23</td>
<td>268.35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>28</td>
<td>666.65</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>397.81</td>
<td>17.05</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
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<td>0.00</td>
<td>0.9811</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>8.03</td>
<td>0.34</td>
<td>0.7124</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)
Table A.14.8B. Numerical difference and standard error of the estimate for leaf export rate (mmol C·m⁻²s⁻¹) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O₂ to three different temperatures under 182 Pa CO₂ in Figure 3.7F.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Export rate</td>
<td>15°C</td>
<td>1.43</td>
<td>2.29</td>
<td>0.63</td>
<td>0.5380</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Export rate</td>
<td>25°C</td>
<td>0.09</td>
<td>2.07</td>
<td>0.05</td>
<td>0.9639</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Export rate</td>
<td>35°C</td>
<td>1.24</td>
<td>2.29</td>
<td>0.54</td>
<td>0.5919</td>
</tr>
</tbody>
</table>

Table A.14.8C. Multiple mean comparison for leaf export rate (mmol C·m⁻²s⁻¹) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O₂ to three different temperatures under 182 Pa CO₂ in Figure 3.7F.

<table>
<thead>
<tr>
<th>O2</th>
<th>Temp</th>
<th>Expi</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>15</td>
<td>11.2228600</td>
<td>1.5275691</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>25</td>
<td>16.0547000</td>
<td>1.5275691</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>35</td>
<td>19.2795600</td>
<td>1.5275691</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>15</td>
<td>9.7904250</td>
<td>1.7078742</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>25</td>
<td>16.1492833</td>
<td>1.3944734</td>
<td>0.0005</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>35</td>
<td>20.5253750</td>
<td>1.7078742</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table A.14.9A. Two way ANOVA for leaf relative export flux (% of photosynthesis) to compare GIV A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O₂ under 182 Pa CO₂ in Figure 3.7I. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>0.15</td>
<td>3.89</td>
<td>0.0092</td>
<td>0.4277</td>
<td>11.35</td>
</tr>
<tr>
<td>Error</td>
<td>26</td>
<td>0.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>31</td>
<td>0.35</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>287.38</td>
<td>1.96</td>
<td>0.1615</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O₂</td>
<td>1</td>
<td>286.11</td>
<td>3.90</td>
<td>0.0591</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O₂</td>
<td>2</td>
<td>694.23</td>
<td>4.73</td>
<td>0.0177</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table A.14.9B. Numerical difference and standard error of the estimate for leaf relative export flux (% of photosynthesis) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O₂ to three different temperatures under 182 Pa CO₂ in Figure 3.7I. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Relative export</td>
<td>15°C</td>
<td>0.20</td>
<td>0.06</td>
<td>3.49</td>
<td>0.0018</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Relative export</td>
<td>25°C</td>
<td>0.03</td>
<td>0.05</td>
<td>0.64</td>
<td>0.5302</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Relative export</td>
<td>35°C</td>
<td>0.04</td>
<td>0.06</td>
<td>0.73</td>
<td>0.4710</td>
</tr>
</tbody>
</table>

Table A.14.9C. Multiple mean comparison for leaf relative export flux (% of photosynthesis) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O₂ to three different temperatures under 182 Pa CO₂ in Figure 3.7I. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>O2</th>
<th>Temp</th>
<th>Ratioi</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th>LSMEAN Number</th>
</tr>
</thead>
</table>

220
**Least Squares Means for effect O2*Temp**

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.0045</td>
<td>0.0062</td>
<td>0.0018</td>
<td>0.0009</td>
<td>0.0641</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.0045</td>
<td>0.9013</td>
<td>0.4840</td>
<td>0.5302</td>
<td>0.4067</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.0062</td>
<td>0.9013</td>
<td>0.4186</td>
<td>0.4532</td>
<td>0.4710</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.0018</td>
<td>0.4840</td>
<td>0.4186</td>
<td>0.8890</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.0009</td>
<td>0.5302</td>
<td>0.4532</td>
<td>0.8890</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.0641</td>
<td>0.4067</td>
<td>0.4710</td>
<td>0.1680</td>
<td>0.1680</td>
<td>0.1697</td>
</tr>
</tbody>
</table>

Table A.15.1A. Two-way analysis of variance for leaf transpiration (mmol H\(_2\)O·m\(^{-2}\)s\(^{-1}\)) to compare GI A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O\(_2\) under 40 Pa CO\(_2\) in Figure 3.8A.

**Two-way ANOVA**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R(^2)</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>26.31</td>
<td>37.31</td>
<td>&lt;.0001</td>
<td>0.8695</td>
<td>13.92</td>
</tr>
<tr>
<td>Error</td>
<td>28</td>
<td>3.95</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>33</td>
<td>30.26</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>1</td>
<td>24.98</td>
<td>88.54</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O(_2)</td>
<td>1</td>
<td>0.50</td>
<td>3.52</td>
<td>0.0710</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O(_2)</td>
<td>2</td>
<td>0.11</td>
<td>0.41</td>
<td>0.6687</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{1}\)Sum of squares for model parameters are those of type III (SAS)

Table A.15.1B. Numerical difference and standard error of the estimate for leaf transpiration (mmol H\(_2\)O·m\(^{-2}\)s\(^{-1}\)) to compare GI A. majus leaves exposed to short term 2 and 21 kPa O\(_2\) to three different temperatures under 40 Pa CO\(_2\) in Figure 3.8A.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Transpiration</td>
<td>15°C</td>
<td>0.08</td>
<td>0.27</td>
<td>1.61</td>
<td>0.1185</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Transpiration</td>
<td>25°C</td>
<td>0.34</td>
<td>0.24</td>
<td>1.09</td>
<td>0.2840</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Transpiration</td>
<td>35°C</td>
<td>1.05</td>
<td>0.27</td>
<td>0.49</td>
<td>0.6297</td>
</tr>
</tbody>
</table>

Table A.15.1C. Multiple mean comparison for leaf transpiration (mmol H\(_2\)O·m\(^{-2}\)s\(^{-1}\)) to compare GI A. majus leaves exposed to short term 2 and 21 kPa O\(_2\) to three different temperatures under 40 Pa CO\(_2\) in Figure 3.8A.
Table A.15.2A. Two-way analysis of variance for leaf WUE (µmol C/ mmol H₂O) to compare GI *majus* leaves exposed to three different short term temperatures at 21 and 2 kPa O₂ under 40 Pa CO₂ in Figure 3.8D.

**Two-way ANOVA**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>Value</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>268.61</td>
<td>64.83</td>
<td>&lt;.0001</td>
<td>0.9205</td>
<td>10.72</td>
</tr>
<tr>
<td>Error</td>
<td>28</td>
<td>23.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>33</td>
<td>291.81</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>208.15</td>
<td>125.59</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O₂</td>
<td>1</td>
<td>31.82</td>
<td>38.40</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O₂</td>
<td>2</td>
<td>6.04</td>
<td>3.64</td>
<td>0.0392</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)*

Table A.15.2B. Numerical difference and standard error of the estimate for leaf WUE (µmol C/ mmol H₂O) to compare GI *majus* leaves exposed to short term 2 and 21 kPa O₂ to three different temperatures under 40 Pa CO₂ in Figure 3.8D.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>WUE</td>
<td>15°C</td>
<td>7.65</td>
<td>2.36</td>
<td>5.22</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>WUE</td>
<td>25°C</td>
<td>5.03</td>
<td>2.03</td>
<td>2.66</td>
<td>0.0129</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>WUE</td>
<td>35°C</td>
<td>4.44</td>
<td>2.49</td>
<td>2.56</td>
<td>0.0161</td>
</tr>
</tbody>
</table>

Table A.15.2C. Multiple mean comparison for leaf WUE (µmol C/ mmol H₂O) to compare GI *majus* leaves exposed to short term 2 and 21 kPa O₂ to three different temperatures under 40 Pa CO₂ in Figure 3.8D.

| O₂  | Temp | WUE LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|-----|------|-------------|----------------|------|---|---------------|
| a   | 15   | 10.9021000  | 0.4551599     | <.0001 | 1 |
| a   | 25   | 8.0795875   | 0.3218466     | <.0001 | 2 |
| a   | 35   | 5.1196000   | 0.3218466     | <.0001 | 3 |
| l   | 15   | 14.2607250  | 0.4551599     | <.0001 | 4 |
| l   | 25   | 9.3862000   | 0.3716365     | <.0001 | 5 |
| l   | 35   | 6.5476500   | 0.4551599     | <.0001 | 6 |

Least Squares Means for effect O₂*Temp

Pr > |t| for H₀: LSMean(i)=LSMean(j)
Dependent Variable: Trans

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0154</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0129</td>
<td>0.0104</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0015</td>
<td>0.0161</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td></td>
</tr>
</tbody>
</table>
Table A.15.3A. Two-way analysis of variance for leaf transpiration (mmol H\textsubscript{2}O·m\textsuperscript{-2}s\textsuperscript{-1}) to compare GI \textit{A. majus} leaves exposed to three different short term temperatures at 21 and 2 kPa O\textsubscript{2} under 91 Pa CO\textsubscript{2} in Figure 3.8B.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R\textsuperscript{2}</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>16.88</td>
<td>43.78</td>
<td>&lt;.0001</td>
<td>0.9049</td>
<td>13.66</td>
</tr>
<tr>
<td>Error</td>
<td>23</td>
<td>1.77</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>28</td>
<td>18.65</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>16.64</td>
<td>107.87</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O\textsubscript{2}</td>
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<td>0.22</td>
<td>2.76</td>
<td>0.1101</td>
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</tr>
<tr>
<td>Temp*O\textsubscript{2}</td>
<td>2</td>
<td>0.30</td>
<td>1.93</td>
<td>0.1677</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[\text{† Sum of squares for model parameters are those of type III (SAS)}\]

Table A.15.3B. Numerical difference and standard error of the estimate for leaf transpiration (mmol H\textsubscript{2}O·m\textsuperscript{-2}s\textsuperscript{-1}) to compare GI \textit{A. majus} leaves exposed to short term 2 and 21 kPa O\textsubscript{2} to three different temperatures under 91 Pa CO\textsubscript{2} in Figure 3.8B.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Transpiration</td>
<td>15°C</td>
<td>0.10</td>
<td>0.20</td>
<td>0.53</td>
<td>0.6017</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Transpiration</td>
<td>25°C</td>
<td>0.20</td>
<td>0.16</td>
<td>1.24</td>
<td>0.2260</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Transpiration</td>
<td>35°C</td>
<td>0.43</td>
<td>0.19</td>
<td>2.29</td>
<td>0.0313</td>
</tr>
</tbody>
</table>

Table A.15.3C. Multiple mean comparison for leaf transpiration (mmol H\textsubscript{2}O·m\textsuperscript{-2}s\textsuperscript{-1}) to compare GI \textit{A. majus} leaves exposed to short term 2 and 21 kPa O\textsubscript{2} to three different temperatures under 91 Pa CO\textsubscript{2} in Figure 3.7B.

<table>
<thead>
<tr>
<th>O2</th>
<th>Temp</th>
<th>Trans LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>15</td>
<td>1.04899750</td>
<td>0.13884687</td>
<td>&lt;.0001</td>
<td>1</td>
</tr>
<tr>
<td>a</td>
<td>25</td>
<td>1.92608500</td>
<td>0.11336800</td>
<td>&lt;.0001</td>
<td>2</td>
</tr>
<tr>
<td>a</td>
<td>35</td>
<td>2.77103200</td>
<td>0.12418842</td>
<td>&lt;.0001</td>
<td>3</td>
</tr>
<tr>
<td>l</td>
<td>15</td>
<td>0.94508750</td>
<td>0.13884687</td>
<td>&lt;.0001</td>
<td>4</td>
</tr>
<tr>
<td>l</td>
<td>25</td>
<td>2.12554167</td>
<td>0.11336800</td>
<td>&lt;.0001</td>
<td>5</td>
</tr>
<tr>
<td>l</td>
<td>35</td>
<td>3.19824500</td>
<td>0.13884687</td>
<td>&lt;.0001</td>
<td>6</td>
</tr>
</tbody>
</table>

Table A.15.3D. Least Squares Means for effect O2*Temp Pr > |t| for H0: LSMean(i)=LSMean(j) Dependent Variable: Trans

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.6017</td>
<td>&lt;.0001</td>
<td>0.6017</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>6</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0313</td>
<td>&lt;.0001</td>
<td>0.0313</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>
Table A.15.4A. Two-way analysis of variance for leaf WUE (µmol C/ mmol H₂O) to compare GI A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O₂ under 91 Pa CO₂ in Figure 3.8E.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>Value</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>763.31</td>
<td>44.54</td>
<td>&lt;.0001</td>
<td>0.8991</td>
<td>11.56</td>
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</tr>
<tr>
<td>Error</td>
<td>25</td>
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</tr>
<tr>
<td>Corrected Total</td>
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<tr>
<td>Temp</td>
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<td>572.48</td>
<td>83.51</td>
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<td>O₂</td>
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<td>145.46</td>
<td>42.44</td>
<td>&lt;.0001</td>
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<tr>
<td>Temp*O₂</td>
<td>2</td>
<td>119.33</td>
<td>17.41</td>
<td>&lt;.0001</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.15.4B. Numerical difference and standard error of the estimate for leaf WUE (µmol C/ mmol H₂O) to compare GI A. majus leaves exposed to short term 2 and 21 kPa O₂ to three different temperatures under 91 Pa CO₂ in Figure 3.8E.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>Pr &gt;</th>
<th>t</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>WUE</td>
<td>15°C</td>
<td>10.10</td>
<td>8.45</td>
<td>8.45</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>WUE</td>
<td>25°C</td>
<td>1.59</td>
<td>1.42</td>
<td>1.42</td>
<td>0.1691</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>WUE</td>
<td>35°C</td>
<td>1.52</td>
<td>1.27</td>
<td>1.27</td>
<td>0.2146</td>
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</table>

Table A.15.4C. Multiple mean comparison for leaf WUE (µmol C/ mmol H₂O) to compare GI A. majus leaves exposed to short term 2 and 21 kPa O₂ to three different temperatures under 91 Pa CO₂ in Figure 3.8E.

<table>
<thead>
<tr>
<th>O₂</th>
<th>Temp</th>
<th>WUE LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>15</td>
<td>16.9258167</td>
<td>0.7558044</td>
<td>&lt;.0001</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>a</td>
<td>25</td>
<td>15.4170667</td>
<td>0.7558044</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>35</td>
<td>10.3001833</td>
<td>0.7558044</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>15</td>
<td>27.0269000</td>
<td>0.9256676</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>25</td>
<td>17.0047000</td>
<td>0.827942</td>
<td>0.1691</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>35</td>
<td>11.8232250</td>
<td>0.9256676</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Least Squares Means for effect O₂*Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pr &gt;</td>
</tr>
<tr>
<td>i/j</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>1</td>
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<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
</tbody>
</table>

Table A.15.5A. Two-way analysis of variance for leaf transpiration (mmol H₂O·m⁻²·s⁻¹) to compare GI A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O₂ under 182 Pa CO₂ in Figure 3.8C.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>Value</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>24.82</td>
<td>35.99</td>
<td>&lt;.0001</td>
<td>0.8737</td>
<td>19.08</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>26</td>
<td>3.59</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>31</td>
<td>28.40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>21.66</td>
<td>10.83</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O₂</td>
<td>1</td>
<td>0.54</td>
<td>0.54</td>
<td>0.0580</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O₂</td>
<td>2</td>
<td>0.49</td>
<td>0.25</td>
<td>0.1868</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)
Table A.15.5B. Numerical difference and standard error of the estimate for leaf transpiration (mmol H\textsubscript{2}O·m\textsuperscript{-2}·s\textsuperscript{-1}) to compare GI A. \textit{majus} leaves exposed to short term 2 and 21 kPa O\textsubscript{2} to three different temperatures under 182 Pa CO\textsubscript{2} in Figure 3.8C.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Transpiration</td>
<td>15°C</td>
<td>0.09</td>
<td>0.24</td>
<td>0.40</td>
<td>0.6950</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Transpiration</td>
<td>25°C</td>
<td>0.47</td>
<td>0.21</td>
<td>2.20</td>
<td>0.0370</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Transpiration</td>
<td>35°C</td>
<td>0.42</td>
<td>0.24</td>
<td>1.75</td>
<td>0.0921</td>
</tr>
</tbody>
</table>

Table A.15.5C. Multiple mean comparison for leaf transpiration (mmol H\textsubscript{2}O·m\textsuperscript{-2}·s\textsuperscript{-1}) to compare GI A. \textit{majus} leaves exposed to short term 2 and 21 kPa O\textsubscript{2} to three different temperatures under 182 Pa CO\textsubscript{2} in Figure 3.8C.

| O2 Temp Trans LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|----------------------|---------------|------|--|----------------|
| a 15                 | 1.00096000    | 0.15161160 | <.0001 | 1             |
| a 25                 | 1.92655833    | 0.15161160 | <.0001 | 2             |
| a 35                 | 3.32603500    | 0.15161160 | <.0001 | 3             |
| l 15                 | 1.09600000    | 0.15161160 | <.0001 | 4             |
| l 25                 | 1.45514833    | 0.15161160 | <.0001 | 5             |
| l 35                 | 2.90677500    | 0.15161160 | <.0001 | 6             |

Least Squares Means for effect O2*Temp
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: Trans

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0002</td>
<td>&lt;.0001</td>
<td>0.6950</td>
<td>0.0439</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.0002</td>
<td>&lt;.0001</td>
<td>0.0019</td>
<td>0.0370</td>
<td>0.0004</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0921</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.6950</td>
<td>0.0019</td>
<td>&lt;.0001</td>
<td>0.1461</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.0439</td>
<td>0.0370</td>
<td>&lt;.0001</td>
<td>0.1461</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>&lt;.0001</td>
<td>0.0004</td>
<td>0.0921</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td></td>
</tr>
</tbody>
</table>

Table A.15.6A. Two-way analysis of variance for leaf WUE (µmol C/ mmol H\textsubscript{2}O) to compare GI A. \textit{majus} leaves exposed to three different short term temperatures at 21 and 2 kPa O\textsubscript{2} under 182 Pa CO\textsubscript{2} in Figure 3.8F.

**Two-way ANOVA**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS\textsuperscript{1}</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R\textsuperscript{2}</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>602.84</td>
<td>11.95</td>
<td>&lt;.0001</td>
<td>0.7135</td>
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</tr>
<tr>
<td>Error</td>
<td>24</td>
<td>242.05</td>
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</tr>
<tr>
<td>Corrected Total</td>
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<td>844.89</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>524.36</td>
<td>25.63</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O\textsubscript{2}</td>
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<td>55.45</td>
<td>6.67</td>
<td>0.0163</td>
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<td></td>
</tr>
<tr>
<td>Temp*O\textsubscript{2}</td>
<td>2</td>
<td>18.49</td>
<td>0.92</td>
<td>0.4134</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{1}Sum of squares for model parameters are those of type III (SAS)

Table A.15.6B. Numerical difference and standard error of the estimate for leaf WUE (µmol C/ mmol H\textsubscript{2}O) to compare GI A. \textit{majus} leaves exposed to short term 2 and 21 kPa O\textsubscript{2} to three different temperatures under 182 Pa CO\textsubscript{2} in Figure 3.8F.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>WUE</td>
<td>15°C</td>
<td>3.71</td>
<td>2.05</td>
<td>1.81</td>
<td>0.0829</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>WUE</td>
<td>25°C</td>
<td>4.18</td>
<td>1.83</td>
<td>2.28</td>
<td>0.0319</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>WUE</td>
<td>35°C</td>
<td>0.44</td>
<td>2.24</td>
<td>0.20</td>
<td>0.8468</td>
</tr>
</tbody>
</table>

Table A.15.6C. Multiple mean comparison for leaf WUE (µmol C/ mmol H\textsubscript{2}O) to compare GI A. \textit{majus} leaves exposed to short term 2 and 21 kPa O\textsubscript{2} to three different temperatures under 182 Pa CO\textsubscript{2} in Figure 3.8F.

| O2 Temp WUE LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|--------------------|---------------|------|--|----------------|
| a 15               | 18.0704500    | 1.2964939 | <.0001 | 1             |
| a 25               | 20.1590333    | 1.2964939 | <.0001 | 2             |
### Table A.16.1A

Two-way analysis of variance for leaf transpiration (mmol H$_2$O·m$^{-2}$·s$^{-1}$) to compare GIV *A. majus* leaves exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.9A.

**Two-way ANOVA**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>28.40</td>
<td>31.73</td>
<td>&lt;.0001</td>
<td>0.8592</td>
<td>22.34</td>
</tr>
<tr>
<td>Error</td>
<td>26</td>
<td>4.65</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Corrected Total</td>
<td>31</td>
<td>33.06</td>
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</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>26.99</td>
<td>75.36</td>
<td>&lt;.0001</td>
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<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
<td>1.47</td>
<td>8.19</td>
<td>0.0082</td>
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<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>1.57</td>
<td>4.38</td>
<td>0.0229</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)*

### Table A.16.1B

Numerical difference and standard error of the estimate for leaf transpiration (mmol H$_2$O·m$^{-2}$·s$^{-1}$) to compare GIV *A. majus* leaves exposed to short term 2 and 21 kPa O$_2$ to three different temperatures under 40 Pa CO$_2$ in Figure 3.9A.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Transpiration</td>
<td>15°C</td>
<td>0.13</td>
<td>0.20</td>
<td>0.65</td>
<td>0.5214</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Transpiration</td>
<td>25°C</td>
<td>0.10</td>
<td>0.16</td>
<td>0.64</td>
<td>0.5314</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Transpiration</td>
<td>35°C</td>
<td>0.33</td>
<td>0.18</td>
<td>1.81</td>
<td>0.0830</td>
</tr>
</tbody>
</table>

### Table A.16.1C

Multiple mean comparison for leaf transpiration (mmol H$_2$O·m$^{-2}$·s$^{-1}$) to compare GIV *A. majus* leaves exposed to short term 2 and 21 kPa O$_2$ to three different temperatures under 40 Pa CO$_2$ in Figure 3.9A.

| O$_2$ Temp | Trans LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|------------|--------------|----------------|-------|---|----------------|
| a 15       | 1.20512250   | 0.14089515     | <.0001| 1 |
| a 25       | 2.73933000   | 0.11504041     | <.0001| 2 |
| a 35       | 4.07442333   | 0.11504041     | <.0001| 3 |
| l 15       | 1.33479500   | 0.14089515     | <.0001| 4 |
| l 25       | 2.84264833   | 0.11504041     | <.0001| 5 |
| l 35       | 3.74541500   | 0.14089515     | <.0001| 6 |

**Least Squares Means for effect O$_2$*Temp**

Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: Trans
Table A.16.2A. Two-way analysis of variance for leaf WUE (µmol C/ mmol H₂O) to compare GIV A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O₂ under 40 Pa CO₂ in Figure 3.9D.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>1012.19</td>
<td>16.28</td>
<td>&lt;.0001</td>
<td>0.7797</td>
<td>16.95</td>
</tr>
<tr>
<td>Error</td>
<td>23</td>
<td>285.93</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Corrected Total</td>
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<td></td>
<td></td>
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<td></td>
</tr>
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<td>Temp</td>
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<td>806.38</td>
<td>32.43</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O₂</td>
<td>1</td>
<td>2.58</td>
<td>0.21</td>
<td>0.6531</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O₂</td>
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<td>238.66</td>
<td>9.60</td>
<td>0.0009</td>
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<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.16.2B. Numerical difference and standard error of the estimate for leaf WUE (µmol C/ mmol H₂O) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O₂ to three different temperatures under 40 Pa CO₂ in Figure 3.8D.

| Contrast | Variable | Treatment | Differences | SE | Pr>|t| | P |
|----------|----------|-----------|-------------|----|-----|----|
| 21 vs. 2 | WUE      | 15°C      | 3.88        | 0.27 | 14.11 | <.0001 |
| 21 vs. 2 | WUE      | 25°C      | 2.22        | 0.22 | 9.89  | <.0001 |
| 21 vs. 2 | WUE      | 35°C      | 1.41        | 0.25 | 5.62  | <.0001 |

Table A.16.2C. Multiple mean comparison for leaf WUE (µmol C/ mmol H₂O) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O₂ to three different temperatures under 40 Pa CO₂ in Figure 3.9D.

| O₂ Temp | WUE LSMEAN | Standard Error | Pr>|t| | LSMEAN Number |
|---------|------------|----------------|-----|----------------|
| a 15    | 11.8535250 | 0.1945989      | <.0001 | 1               |
| a 25    | 7.5911833  | 0.1588993      | <.0001 | 2               |
| a 35    | 4.9499833  | 0.1588993      | <.0001 | 3               |
| l 15    | 15.7360000 | 0.1945989      | <.0001 | 4               |
| l 25    | 9.8123833  | 0.1588993      | <.0001 | 5               |
| l 35    | 6.3619750  | 0.1945989      | <.0001 | 6               |

Least Squares Means for effect O₂*Temp
Pr>|t| for H₀: LSMean(i)=LSMean(j)
Dependent Variable: WUE

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
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<td>&lt;.0001</td>
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</table>
Table A.16.3A. Two-way analysis of variance for leaf transpiration (mmol H$_2$O·m$^{-2}$s$^{-1}$) to compare GIV A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.9B.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>17.91</td>
<td>47.23</td>
<td>&lt;.0001</td>
<td>0.9043</td>
<td>14.59</td>
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<td>Error</td>
<td>25</td>
<td>1.90</td>
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<td></td>
<td></td>
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<tr>
<td>Corrected Total</td>
<td>30</td>
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</tr>
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<td>Temp</td>
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<td>17.32</td>
<td>114.24</td>
<td>&lt;.0001</td>
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</tr>
<tr>
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<td>0.23</td>
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<td>0.0910</td>
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<td>Temp*O$_2$</td>
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<td>0.44</td>
<td>2.93</td>
<td>0.0721</td>
<td></td>
<td></td>
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</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.16.3B. Numerical difference and standard error of the estimate for leaf transpiration (mmol H$_2$O·m$^{-2}$s$^{-1}$) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O$_2$ to three different temperatures under 91 Pa CO$_2$ in Figure 3.9B.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Transpiration</td>
<td>15°C</td>
<td>0.04</td>
<td>0.18</td>
<td>0.25</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Transpiration</td>
<td>25°C</td>
<td>0.04</td>
<td>0.16</td>
<td>0.28</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Transpiration</td>
<td>35°C</td>
<td>0.53</td>
<td>0.18</td>
<td>2.87</td>
</tr>
</tbody>
</table>

Table A.16.3C. Multiple mean comparison for leaf transpiration (mmol H$_2$O·m$^{-2}$s$^{-1}$) to compare GIV leaves exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.9B.

| O$_2$ | Temp | Trans LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|------|------|--------------|----------------|------|---|----------------|
| a    | 15   | 0.90242167   | 0.11242160     | <.0001 | 1 |
| a    | 25   | 2.04911500   | 0.11242160     | <.0001 | 2 |
| a    | 35   | 2.52204200   | 0.12315169     | <.0001 | 3 |
| l    | 15   | 0.85824500   | 0.13768778     | <.0001 | 4 |
| l    | 25   | 2.09378667   | 0.11242160     | <.0001 | 5 |
| l    | 35   | 3.05180500   | 0.13768778     | <.0001 | 6 |

Least Squares Means for effect O$_2$*Temp
Pr > |t| for H0: LSMean(i)=LSMean(j)

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
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<td>1</td>
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<td>&lt;.0001</td>
<td>0.8058</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>&lt;.0001</td>
<td>0.0089</td>
<td>&lt;.0001</td>
<td>0.7810</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>&lt;.0001</td>
<td>0.0089</td>
<td>&lt;.0001</td>
<td>0.0166</td>
<td>0.0083</td>
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</tr>
<tr>
<td>4</td>
<td>0.8058</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
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</tr>
<tr>
<td>5</td>
<td>&lt;.0001</td>
<td>0.7810</td>
<td>0.0166</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
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</tr>
<tr>
<td>6</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0083</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td></td>
</tr>
</tbody>
</table>

Table A.16.4A. Two-way analysis of variance for leaf WUE (µmol C/ mmol H$_2$O) to compare GIV A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.9E.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>1912.19</td>
<td>16.28</td>
<td>&lt;.0001</td>
<td>0.7797</td>
<td>16.95</td>
</tr>
<tr>
<td>Error</td>
<td>23</td>
<td>285.93</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>28</td>
<td>1298.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
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<td>806.38</td>
<td>32.43</td>
<td>&lt;.0001</td>
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<td></td>
</tr>
<tr>
<td>O$_2$</td>
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<td>2.58</td>
<td>0.21</td>
<td>0.6531</td>
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<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>238.66</td>
<td>9.60</td>
<td>0.0009</td>
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<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)
Table A.16.4B. Numerical difference and standard error of the estimate for leaf WUE (\(\mu\)mol C/ mmol H\(_2\)O) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O\(_2\) to three different temperatures under 91 Pa CO\(_2\) in Figure 3.9E.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>WUE</td>
<td>15°C</td>
<td>11.25</td>
<td>1.45</td>
<td>7.76</td>
<td>&lt;.0001</td>
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<tr>
<td>21 vs. 2</td>
<td>WUE</td>
<td>25°C</td>
<td>2.41</td>
<td>1.30</td>
<td>1.86</td>
<td>0.0742</td>
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<td>21 vs. 2</td>
<td>WUE</td>
<td>35°C</td>
<td>2.79</td>
<td>1.45</td>
<td>1.92</td>
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Table A.16.4C. Multiple mean comparison for leaf WUE (\(\mu\)mol C/ mmol H\(_2\)O) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O\(_2\) to three different temperatures under 91 Pa CO\(_2\) in Figure 3.9E.

<table>
<thead>
<tr>
<th>O(_2)</th>
<th>Temp</th>
<th>WUE LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
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<th>LSMEAN Number</th>
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<tr>
<td>a</td>
<td>25</td>
<td>15.7781500</td>
<td>0.9164141</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
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<tr>
<td>a</td>
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<td>0.9164141</td>
<td>&lt;.0001</td>
<td>3</td>
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<tr>
<td>l</td>
<td>15</td>
<td>31.0840500</td>
<td>1.1223735</td>
<td>&lt;.0001</td>
<td>4</td>
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<tr>
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<tr>
<td>l</td>
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Least Squares Means for effect O\(_2\)*Temp

Pr > |t| for H\(_0\): LSMean(i)=LSMean(j)

<table>
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<tr>
<th>i/j</th>
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<td>&lt;.0001</td>
<td>0.0742</td>
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<td>0.0002</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0654</td>
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<td>0.0654</td>
<td>&lt;.0001</td>
<td>0.0011</td>
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Table A.16.5A. Two-way analysis of variance for leaf transpiration (mmol H\(_2\)O·m\(^{-2}\)s\(^{-1}\)) to compare GIV A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O\(_2\) under 182 Pa CO\(_2\) in Figure 3.9C.

Two-way ANOVA

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<th>CV</th>
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<td>4.38</td>
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</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.16.5B. Numerical difference and standard error of the estimate for leaf transpiration (mmol H\(_2\)O·m\(^{-2}\)s\(^{-1}\)) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O\(_2\) to three different temperatures under 182 Pa CO\(_2\) in Figure 3.9C.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>Transpiration</td>
<td>15°C</td>
<td>0.08</td>
<td>0.27</td>
<td>0.29</td>
<td>0.7737</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Transpiration</td>
<td>25°C</td>
<td>0.34</td>
<td>0.24</td>
<td>1.38</td>
<td>0.1787</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>Transpiration</td>
<td>35°C</td>
<td>1.05</td>
<td>0.27</td>
<td>3.84</td>
<td>0.0007</td>
</tr>
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</table>

Table A.16.5C. Multiple mean comparison for leaf transpiration (mmol H\(_2\)O·m\(^{-2}\)s\(^{-1}\)) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O\(_2\) to three different temperatures under 182 Pa CO\(_2\) in Figure 3.9C.
### Table A.16.6A. Two-way analysis of variance for leaf WUE (µmol C/ mmol H₂O) to compare GIV A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O₂ under 182 Pa CO₂ in Figure 3.9F.

| O₂ | Temp | WUE LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|----|------|------------|---------------|-------|-----|----------------|
| a  | 15   | 0.84301000 | 0.17274685    | <.0001| <   | 1              |
| a  | 25   | 1.65578333 | 0.17274685    | <.0001| <   | 2              |
| a  | 35   | 2.64126000 | 0.17274685    | <.0001| <   | 3              |
| l  | 15   | 0.76365500 | 0.21157082    | 0.0013|     | 4              |
| l  | 25   | 1.99340167 | 0.17274685    | <.0001| <   | 5              |
| l  | 35   | 3.69102500 | 0.21157082    | <.0001| <   | 6              |

### Least Squares Means for effect O₂*Temp

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
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<td>1</td>
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<td>0.7737</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>2</td>
<td>0.0026</td>
<td>0.0004</td>
<td>0.0031</td>
<td>0.1787</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>3</td>
<td>&lt;.0001</td>
<td>0.0004</td>
<td>&lt;.0001</td>
<td>0.0135</td>
<td>0.0007</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>4</td>
<td>0.7737</td>
<td>0.0031</td>
<td>&lt;.0001</td>
<td>0.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
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<td>0.1787</td>
<td>0.0135</td>
<td>0.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
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<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Table A.16.6A. Two-way analysis of variance for leaf WUE (µmol C/ mmol H₂O) to compare GIV A. majus leaves exposed to three different short term temperatures at 21 and 2 kPa O₂ under 182 Pa CO₂ in Figure 3.9F.

#### Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>Value</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
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<tr>
<td>Model</td>
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<td>1012.19</td>
<td>16.28</td>
<td>&lt;.0001</td>
<td>0.7797</td>
<td>16.95</td>
</tr>
<tr>
<td>Error</td>
<td>23</td>
<td>285.93</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>28</td>
<td>1298.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>806.38</td>
<td>32.43</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O₂</td>
<td>1</td>
<td>2.58</td>
<td>0.21</td>
<td></td>
<td>0.6531</td>
<td></td>
</tr>
<tr>
<td>Temp*O₂</td>
<td>2</td>
<td>238.66</td>
<td>9.60</td>
<td>&lt;.0001</td>
<td></td>
<td>0.0009</td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.16.6B. Numerical difference and standard error of the estimate for leaf WUE (µmol C/ mmol H₂O) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O₂ to three different temperatures under 182 Pa CO₂ in Figure 3.9F.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>WUE</td>
<td>15°C</td>
<td>7.65</td>
<td>2.36</td>
<td>3.23</td>
<td>0.0037</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>WUE</td>
<td>25°C</td>
<td>5.03</td>
<td>2.04</td>
<td>2.47</td>
<td>0.0213</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>WUE</td>
<td>35°C</td>
<td>4.44</td>
<td>2.49</td>
<td>1.78</td>
<td>0.0882</td>
</tr>
</tbody>
</table>

Table A.16.6C. Multiple mean comparison for leaf WUE (µmol C/ mmol H₂O) to compare GIV A. majus leaves exposed to short term 2 and 21 kPa O₂ to three different temperatures under 182 Pa CO₂ in Figure 3.9F.

| O₂ | Temp | WUE LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|----|------|------------|---------------|-------|-----|----------------|
| a  | 15   | 22.9166000 | 1.5768257     | <.0001| <   | 1              |
| a  | 25   | 24.3394500 | 1.4394384     | <.0001| <   | 2              |
| a  | 35   | 15.2715250 | 1.7629448     | <.0001| <   | 3              |
| l  | 15   | 30.5670250 | 1.7629448     | <.0001| <   | 4              |
| l  | 25   | 19.3098167 | 1.4394384     | <.0001| <   | 5              |
| l  | 35   | 10.8317750 | 1.7629448     | <.0001| <   | 6              |
### Table A.17.1A. Two-way and one-way analysis of variance for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.10A.

<table>
<thead>
<tr>
<th>Source</th>
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<th>F</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>3940.89</td>
<td>33.47</td>
<td>&lt;.0001</td>
<td>0.8611</td>
<td>22.58</td>
</tr>
<tr>
<td>Error</td>
<td>27</td>
<td>632.74</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>32</td>
<td>4576.63</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>1055.22</td>
<td>22.41</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
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<td>2881.56</td>
<td>122.38</td>
<td>&lt;.0001</td>
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<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>266.42</td>
<td>5.66</td>
<td>0.0089</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 $^*$Sum of squares for model parameters are those of type III (SAS)

### Table A.17.1B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.10A.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose</td>
<td>15°C</td>
<td>11.01</td>
<td>3.13</td>
<td>3.52</td>
<td>0.0016</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose</td>
<td>25°C</td>
<td>23.05</td>
<td>2.97</td>
<td>7.76</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose</td>
<td>35°C</td>
<td>24.36</td>
<td>3.04</td>
<td>8.01</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

### Table A.17.1C. Multiple mean comparison for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.10A.

| O$_2$ Temp | Suc LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|------------|------------|----------------|------|---|----------------|
| a 15       | 9.9928333  | 1.9809918      | <.0001 | 1 |
| a 25       | 16.7816250| 1.7155892      | <.0001 | 2 |
| a 35       | 15.8372857| 1.8340420      | <.0001 | 3 |
| l 15       | 21.0040000| 2.4262095      | <.0001 | 4 |
| l 25       | 39.8360000| 2.4262095      | <.0001 | 5 |
| l 35       | 40.1950000| 2.4262095      | <.0001 | 6 |

### Table A.17.2A. Two-way ANOVA

#### Least Squares Means for effect O$_2$*Temp

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.5118</td>
<td>0.0037</td>
<td>0.0037</td>
<td>0.1047</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.5118</td>
<td>0.0006</td>
<td>0.0118</td>
<td>0.0213</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.0037</td>
<td>0.0006</td>
<td>&lt;.0001</td>
<td>0.0892</td>
<td>0.0882</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.0037</td>
<td>0.0118</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.1047</td>
<td>0.0213</td>
<td>0.0892</td>
<td>&lt;.0001</td>
<td>0.0011</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0882</td>
<td>&lt;.0001</td>
<td>0.0011</td>
<td></td>
</tr>
</tbody>
</table>

Pr > |t| for H0: LSMean(i)=LSMean(j)
Table A.17.2A. Two-way analysis of variance for $^{14}$C-starch (mmol C·m$^{-2}$) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.10D.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
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<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>5546.12</td>
<td>28.03</td>
<td>&lt;.0001</td>
<td>0.8335</td>
<td>23.06</td>
</tr>
<tr>
<td>Error</td>
<td>25</td>
<td>1108.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>30</td>
<td>6654.32</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>345.86</td>
<td>4.37</td>
<td>0.0223</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
<td>4197.89</td>
<td>106.06</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>584.45</td>
<td>7.38</td>
<td>0.0027</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^*$Sum of squares for model parameters are those of type III (SAS)

Table A.17.2B. Numerical difference and standard error of the estimate for $^{14}$C-starch (mmol C·m$^{-2}$) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.10D.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>$t$-value</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-starch</td>
<td>15°C</td>
<td>24.34</td>
<td>3.38</td>
<td>5.99</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-starch</td>
<td>25°C</td>
<td>12.74</td>
<td>3.56</td>
<td>3.55</td>
<td>0.0014</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-starch</td>
<td>35°C</td>
<td>33.90</td>
<td>3.56</td>
<td>7.96</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Table A.17.2C. Multiple mean comparison for $^{14}$C-starch (mmol C·m$^{-2}$) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.10D.

<table>
<thead>
<tr>
<th>O$_2$</th>
<th>Temp</th>
<th>Insol LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>15</td>
<td>16.9150333</td>
<td>2.5683518</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>25</td>
<td>28.9095125</td>
<td>2.2242579</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>35</td>
<td>10.9008500</td>
<td>2.2242579</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>15</td>
<td>41.2521250</td>
<td>3.1455757</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>25</td>
<td>41.6506600</td>
<td>2.8134884</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>35</td>
<td>44.7977333</td>
<td>3.6321979</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

Table A.17.3A. Two-way analysis of variance for $^{14}$C-sucrose to starch ratio retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.10G.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>$F$</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>5546.12</td>
<td>28.03</td>
<td>&lt;.0001</td>
<td>0.8335</td>
<td>23.06</td>
</tr>
<tr>
<td>Error</td>
<td>25</td>
<td>1108.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>30</td>
<td>6654.32</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>345.86</td>
<td>4.37</td>
<td>0.0223</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
<td>4197.89</td>
<td>106.06</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
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<td>584.45</td>
<td>7.38</td>
<td>0.0027</td>
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<td></td>
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</tbody>
</table>

$^*$Sum of squares for model parameters are those of type III (SAS)
### Table A.17.3B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose to starch ratio retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.10G.

<table>
<thead>
<tr>
<th>Contrast</th>
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<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: starch</td>
<td>15°C</td>
<td>0.13</td>
<td>0.28</td>
<td>0.45</td>
<td>0.6565</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: starch</td>
<td>25°C</td>
<td>0.18</td>
<td>0.30</td>
<td>0.61</td>
<td>0.5451</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: starch</td>
<td>35°C</td>
<td>0.92</td>
<td>0.30</td>
<td>3.11</td>
<td>0.0045</td>
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</table>

### Table A.17.3C. Multiple mean comparison estimate for $^{14}$C-sucrose to starch ratio retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.10G.

<table>
<thead>
<tr>
<th>O$_2$</th>
<th>Temp</th>
<th>SucStarch LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th>LSMEAN Number</th>
</tr>
</thead>
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<tr>
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<tr>
<td>a</td>
<td>25</td>
<td>0.60263330</td>
<td>0.15525179</td>
<td>0.0006</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>35</td>
<td>1.87093621</td>
<td>0.15525179</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>l</td>
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<td>0.50969733</td>
<td>0.21955919</td>
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<tr>
<td>l</td>
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<tr>
<td>l</td>
<td>35</td>
<td>0.94564848</td>
<td>0.25352512</td>
<td>0.0009</td>
<td>6</td>
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</tr>
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</table>

### Least Squares Means for effect O$_2$*Temp

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.8852</td>
<td>&lt;.0001</td>
<td>0.6565</td>
<td>0.6383</td>
<td>0.3297</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.8852</td>
<td>&lt;.0001</td>
<td>0.7324</td>
<td>0.5451</td>
<td>0.2591</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0011</td>
<td>0.0045</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.6565</td>
<td>0.7324</td>
<td>&lt;.0001</td>
<td>0.4193</td>
<td>0.2051</td>
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</tr>
<tr>
<td>5</td>
<td>0.6383</td>
<td>0.5451</td>
<td>0.0011</td>
<td>0.4193</td>
<td>0.6577</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.3297</td>
<td>0.2591</td>
<td>0.0045</td>
<td>0.2051</td>
<td>0.6577</td>
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</table>

### Table A.17.4A. Two-way and one-way analysis of variance for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.10B.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
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<td>&lt;.0001</td>
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<td>Error</td>
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<tr>
<td>Corrected Total</td>
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<td></td>
<td></td>
</tr>
<tr>
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<td>0.0011</td>
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<td>2.01</td>
<td>0.1563</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)
Table A.17.4B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 2B.9.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose</td>
<td>15°C</td>
<td>45.97</td>
<td>11.54</td>
<td>3.98</td>
<td>0.0006</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose</td>
<td>25°C</td>
<td>13.52</td>
<td>11.54</td>
<td>1.71</td>
<td>0.2529</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose</td>
<td>35°C</td>
<td>33.26</td>
<td>11.54</td>
<td>2.88</td>
<td>0.0082</td>
</tr>
</tbody>
</table>

Table A.17.4C. Multiple mean comparison estimate for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 2B.9.

| O2 Temp | Suc LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|---------|------------|----------------|------|------|----------------|
| a 15    | 8.9945000  | 7.2996294      | 0.2298 |     | 1              |
| a 25    | 40.6237500 | 8.9401837      | 0.0001 |     | 2              |
| a 35    | 50.1763333 | 7.2996294      | <.0001 |     | 3              |
| l 15    | 54.9635000 | 8.9401837      | <.0001 |     | 4              |
| l 25    | 54.1443333 | 7.2996294      | <.0001 |     | 5              |
| l 35    | 83.4410000 | 8.9401837      | <.0001 |     | 6              |

Table A.17.5A. Two-way analysis of variance for $^{14}$C-starch (mmol C·m$^{-2}$) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.10E.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>9959.93</td>
<td>25.32</td>
<td>&lt;.0001</td>
<td>0.8462</td>
<td>16.57</td>
</tr>
<tr>
<td>Error</td>
<td>23</td>
<td>1809.60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>28</td>
<td>11769.53</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>8747.61</td>
<td>55.59</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
<td>1981.98</td>
<td>25.19</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp$^*$O$_2$</td>
<td>2</td>
<td>381.83</td>
<td>2.43</td>
<td>0.1106</td>
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<td></td>
</tr>
</tbody>
</table>

Table A.17.5B. Numerical difference and standard error of the estimate for $^{14}$C-starch (mmol C·m$^{-2}$) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.10E.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-starch</td>
<td>15°C</td>
<td>10.69</td>
<td>6.27</td>
<td>1.71</td>
<td>0.1017</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-starch</td>
<td>25°C</td>
<td>12.61</td>
<td>5.12</td>
<td>2.46</td>
<td>0.0217</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-starch</td>
<td>35°C</td>
<td>28.10</td>
<td>6.27</td>
<td>4.48</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

Table A.17.5C. Multiple mean comparison for $^{14}$C-starch (mmol C·m$^{-2}$) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.10E.

| O2 Temp | Insol LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|---------|--------------|----------------|------|------|----------------|
| a 15    | 22.7161250  | 4.4350420      | <.0001 |     | 1              |
### Table A.17.6A
Two-way analysis of variance for $^{14}$C-sucrose to starch ratio retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.10H.

**Two-way ANOVA**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>$F$</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>3.98</td>
<td>5.58</td>
<td>0.0017</td>
<td>0.5481</td>
<td>40.74</td>
</tr>
<tr>
<td>Error</td>
<td>23</td>
<td>3.28</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>28</td>
<td>7.26</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>0.08</td>
<td>0.29</td>
<td>0.7484</td>
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<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
<td>1.83</td>
<td>12.82</td>
<td>0.0016</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>2.54</td>
<td>8.89</td>
<td>0.0014</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^*$Sum of squares for model parameters are those of type III (SAS)

### Table A.17.6B
Numerical difference and standard error of the estimate for $^{14}$C-sucrose to starch ratio retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.10H.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: starch</td>
<td>15°C</td>
<td>1.37</td>
<td>0.27</td>
<td>5.16</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: starch</td>
<td>25°C</td>
<td>0.04</td>
<td>0.23</td>
<td>0.20</td>
<td>0.8464</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: starch</td>
<td>35°C</td>
<td>0.20</td>
<td>0.24</td>
<td>0.81</td>
<td>0.4211</td>
</tr>
</tbody>
</table>

### Table A.17.6C
Multiple mean comparison for $^{14}$C-sucrose to starch ratio retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.10H.

<table>
<thead>
<tr>
<th>O$_2$ Temp SucStarch LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>a 15</td>
<td>0.31787044</td>
<td>0.18898681</td>
<td>0.1059</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>a 25</td>
<td>0.89653109</td>
<td>0.16895444</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>a 35</td>
<td>0.84554887</td>
<td>0.15423360</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>l 15</td>
<td>1.69545805</td>
<td>0.18898681</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>l 25</td>
<td>0.85081439</td>
<td>0.15423360</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>l 35</td>
<td>1.04532101</td>
<td>0.18898681</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>
Table A.17.7A. Two-way analysis of variance for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa $O_2$ under 182 Pa CO$_2$ in Figure 3.10C.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>13678.40</td>
<td>12.41</td>
<td>&lt;.0001</td>
<td>0.7382</td>
<td>29.23</td>
</tr>
<tr>
<td>Error</td>
<td>22</td>
<td>4851.11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>27</td>
<td>18529.50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>4122.52</td>
<td>6.01</td>
<td>0.0076</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$O_2$</td>
<td>1</td>
<td>222.37</td>
<td>0.65</td>
<td>0.4285</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*$O_2$</td>
<td>2</td>
<td>10051.18</td>
<td>14.66</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)

Table A.17.7B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa $O_2$ under 182 Pa CO$_2$ in Figure 3.10C.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose</td>
<td>15°C</td>
<td>44.54</td>
<td>9.96</td>
<td>4.47</td>
<td>0.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose</td>
<td>25°C</td>
<td>11.64</td>
<td>9.96</td>
<td>1.17</td>
<td>0.2549</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose</td>
<td>35°C</td>
<td>40.11</td>
<td>9.58</td>
<td>4.18</td>
<td>0.0004</td>
</tr>
</tbody>
</table>

Table A.17.7C. Multiple mean comparison for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa $O_2$ under 182 Pa CO$_2$ in Figure 3.10C.

| $O_2$ | Temp | Suc LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|-------|------|------------|----------------|------|--------|----------------|
| a     | 15   | 11.7064000 | 6.6408566      | 0.0918 | 1      |
| a     | 25   | 62.0018000 | 6.6408566      | <.0001 | 2      |
| a     | 35   | 78.7985000 | 6.0622449      | <.0001 | 3      |
| l     | 15   | 56.2425000 | 7.4247033      | <.0001 | 4      |
| l     | 25   | 50.3565000 | 7.4247033      | <.0001 | 5      |
| l     | 35   | 38.6892500 | 7.4247033      | <.0001 | 6      |

Least Squares Means for effect $O_2$*Temp

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0002</td>
<td>0.0008</td>
<td>0.0128</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>&lt;.0001</td>
<td>0.0751</td>
<td>0.5690</td>
<td>0.2549</td>
<td>0.0287</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>&lt;.0001</td>
<td>0.0751</td>
<td>0.0280</td>
<td>0.0071</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.0002</td>
<td>0.5690</td>
<td>0.0280</td>
<td>0.5808</td>
<td>0.1087</td>
<td></td>
</tr>
</tbody>
</table>

---

Least Squares Mean

Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: Suc

Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: SucStarch

i/j | 1 | 2 | 3 | 4 | 5 | 6
---|---|---|---|---|---|---
1   | <.0001 | <.0001 | 0.0002 | 0.0008 | 0.0128 |
2   | <.0001 | 0.0751 | 0.5690 | 0.2549 | 0.0287 |
3   | <.0001 | 0.0751 | 0.0280 | 0.0071 | 0.004 |
4   | 0.0002 | 0.5690 | 0.0280 | 0.5808 | 0.1087 |
### Table A.17.8A. Two-way analysis of variance for $^{14}$C-starch (mmol C·m$^{-2}$) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.10F.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>8386.49</td>
<td>11.71</td>
<td>&lt;.0001</td>
<td>0.7179</td>
<td>20.53</td>
</tr>
<tr>
<td>Error</td>
<td>23</td>
<td>3295.62</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>28</td>
<td>11682.11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>6253.71</td>
<td>21.82</td>
<td>&lt;.0001</td>
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<td></td>
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<tr>
<td>O$_2$</td>
<td>1</td>
<td>9.49</td>
<td>0.07</td>
<td>0.7992</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>515.81</td>
<td>1.80</td>
<td>0.1878</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)

### Table A.17.8B. Numerical difference and standard error of the estimate for $^{14}$C-starch (mmol C·m$^{-2}$) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.10F.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-starch</td>
<td>15°C</td>
<td>15.74</td>
<td>8.46</td>
<td>1.62</td>
<td>0.1180</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-starch</td>
<td>25°C</td>
<td>6.84</td>
<td>7.73</td>
<td>0.89</td>
<td>0.3847</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-starch</td>
<td>35°C</td>
<td>3.34</td>
<td>7.73</td>
<td>0.43</td>
<td>0.6694</td>
</tr>
</tbody>
</table>

### Table A.17.8C. Multiple mean comparison for $^{14}$C-starch (mmol C·m$^{-2}$) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.10F.

<table>
<thead>
<tr>
<th>O$_2$</th>
<th>Temp</th>
<th>Insol LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th>LSMEAN Number</th>
</tr>
</thead>
</table>
Table A.17.9A. Two-way and one-way analysis of variance for \(^{14}\text{C}\)-sucrose to starch ratio retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O\(_2\) under 182 Pa CO\(_2\) in Figure 3.10I.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS†</th>
<th>F</th>
<th>Value</th>
<th>Pr&gt;F</th>
<th>R(^2)</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>2.65</td>
<td>8.74</td>
<td>&lt;.0001</td>
<td>0.6551</td>
<td>28.52</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>23</td>
<td>1.40</td>
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<td></td>
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<td></td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
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<td>0.12</td>
<td>0.98</td>
<td>0.3915</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O(_2)</td>
<td>1</td>
<td>0.08</td>
<td>1.35</td>
<td>0.2579</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O(_2)</td>
<td>2</td>
<td>2.47</td>
<td>20.36</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{†}\)Sum of squares for model parameters are those of type III (SAS)

Table A.17.9B. Numerical difference and standard error of the estimate for \(^{14}\text{C}\)-sucrose to starch ratio retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O\(_2\) under 182 Pa CO\(_2\) in Figure 3.10I.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>(^{14}\text{C})-sucrose: starch</td>
<td>15°C</td>
<td>0.89</td>
<td>0.16</td>
<td>5.61</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>(^{14}\text{C})-sucrose: starch</td>
<td>25°C</td>
<td>0.05</td>
<td>0.16</td>
<td>0.32</td>
<td>0.7526</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>(^{14}\text{C})-sucrose: starch</td>
<td>35°C</td>
<td>0.52</td>
<td>0.16</td>
<td>3.25</td>
<td>0.0036</td>
</tr>
</tbody>
</table>

Table A.17.9C. Multiple mean comparison for \(^{14}\text{C}\)-sucrose to starch ratio retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O\(_2\) under 182 Pa CO\(_2\) in Figure 3.10I.

| O\(_2\) Temp | SucStarch | LSMEAN     | Standard Error | Pr > |t| | LSMEAN Number |
|--------------|----------|------------|----------------|------|---|----------------|
| a 15         | 0.45533683 | 0.10060976 | 0.0002         | 1    |   | 1               |
| a 25         | 0.97005677 | 0.11021247 | <.0001         | 2    |   | 2               |
| a 35         | 1.04791893 | 0.10060976 | <.0001         | 3    |   | 3               |
| l 15         | 1.34845316 | 0.12322129 | <.0001         | 4    |   | 4               |
| l 25         | 0.91731289 | 0.12322129 | <.0001         | 5    |   | 5               |
| l 35         | 0.53142925 | 0.12322129 | 0.0003         | 6    |   | 6               |

Table A.18.1A. Two-way and one-way analysis of variance for \(^{14}\text{C}\)-sucrose (mmol C·m\(^{-2}\)) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O\(_2\) under 40 Pa CO\(_2\) in Figure 3.11A.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS†</th>
<th>F</th>
<th>Value</th>
<th>Pr&gt;F</th>
<th>R(^2)</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>3114.52</td>
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<td>0.6282</td>
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<tr>
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<td>1843.02</td>
<td>0.00</td>
<td></td>
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<tr>
<td>Corrected Total</td>
<td>28</td>
<td>4957.55</td>
<td>0.00</td>
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<tr>
<td>Temp</td>
<td>2</td>
<td>156.37</td>
<td>3.45</td>
<td>0.0488</td>
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</tr>
<tr>
<td>O(_2)</td>
<td>1</td>
<td>2190.46</td>
<td>27.34</td>
<td>&lt;.0001</td>
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<td></td>
</tr>
<tr>
<td>Temp*O(_2)</td>
<td>2</td>
<td>109.97</td>
<td>0.69</td>
<td>0.5135</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{†}\)Sum of squares for model parameters are those of type III (SAS)
Table A.18.1B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.11A.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose</td>
<td>15°C</td>
<td>19.63</td>
<td>3.40</td>
<td>3.40</td>
<td>0.0025</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose</td>
<td>25°C</td>
<td>12.30</td>
<td>2.27</td>
<td>2.27</td>
<td>0.0330</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose</td>
<td>35°C</td>
<td>21.09</td>
<td>3.33</td>
<td>3.33</td>
<td>0.0029</td>
</tr>
</tbody>
</table>

Table A.18.1a. Multiple mean comparison for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.11C.

| O2 Temp | Suc LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|---------|------------|----------------|-------|---|----------------|
| a 15    | 13.0160000 | 3.6544824      | <.0001| 1 |
| a 25    | 27.0024000 | 4.0032849      | <.0001| 2 |
| a 35    | 19.0825000 | 4.4758086      | <.0001| 3 |
| l 15    | 32.6515000 | 4.4758086      | <.0001| 4 |
| l 25    | 39.3003333 | 3.6544824      | <.0001| 5 |
| l 35    | 40.1687500 | 4.4758086      | <.0001| 6 |

Table A.18.2A. Two-way and one-way analysis of variance for $^{14}$C-starch (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.11D.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>3473.43</td>
<td>31.99</td>
<td>&lt;.0001</td>
<td>0.8743</td>
<td>17.50</td>
</tr>
<tr>
<td>Error</td>
<td>23</td>
<td>499.39</td>
<td></td>
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</tr>
<tr>
<td>Corrected Total</td>
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<td></td>
</tr>
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<td>Temp</td>
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<td>1102.29</td>
<td>25.34</td>
<td>&lt;.0001</td>
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</tr>
<tr>
<td>O$_2$</td>
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<td>2063.09</td>
<td>95.02</td>
<td>&lt;.0001</td>
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<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
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<td>7.57</td>
<td>0.17</td>
<td>0.8412</td>
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</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.18.2B. Numerical difference and standard error of the estimate for $^{14}$C-starch (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.11D.

<table>
<thead>
<tr>
<th>Contrast</th>
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<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
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<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-starch</td>
<td>15°C</td>
<td>16.63</td>
<td>3.01</td>
<td>5.53</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-starch</td>
<td>25°C</td>
<td>18.84</td>
<td>2.69</td>
<td>7.01</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-starch</td>
<td>35°C</td>
<td>16.97</td>
<td>3.56</td>
<td>4.77</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Table A.18.2C. Multiple mean comparison for $^{14}$C-starch (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.11D.

| O2 Temp | Insol LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|---------|--------------|----------------|-------|---|----------------|
| a 15    | 13.1372333   | 1.9023121      | <.0001| 1 |
| O2 | Temp | Insol LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|----|------|--------------|----------------|-------|---|----------------|
| a  | 25   | 24.8603667   | 1.9023121      | <.0001|   | 2              |
| a  | 35   | 13.5590667   | 2.6902756      | <.0001|   | 3              |
| l  | 15   | 29.7694000   | 2.3298470      | <.0001|   | 4              |
| l  | 25   | 43.7059500   | 1.9023121      | <.0001|   | 5              |
| l  | 35   | 30.5292750   | 2.3298470      | <.0001|   | 6              |

<table>
<thead>
<tr>
<th>Least Squares Means for effect O2*Temp</th>
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<tbody>
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<td>Pr &gt;</td>
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</tbody>
</table>

<table>
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<th>Dependent Variable: Insol</th>
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<tr>
<td>4</td>
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<tr>
<td>5</td>
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<tr>
<td>6</td>
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</table>

Table A.18.3A. Two-way analysis of variance for 14C-sucrose to starch ratio retained in leaves to compare GIV plants exposed to three short term temperatures at 21 and 2 kPa O2 under 40 Pa CO2 in Figure 3.11G.

<table>
<thead>
<tr>
<th>Source</th>
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<th>SS†</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>3.63</td>
<td>4.47</td>
<td>0.0051</td>
<td>0.4822</td>
<td>33.29</td>
</tr>
<tr>
<td>Error</td>
<td>24</td>
<td>3.90</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>29</td>
<td>7.54</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>2.27</td>
<td>7.01</td>
<td>0.0040</td>
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</tr>
<tr>
<td>O2</td>
<td>1</td>
<td>0.39</td>
<td>2.44</td>
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</tr>
<tr>
<td>Temp*O2</td>
<td>2</td>
<td>0.61</td>
<td>1.89</td>
<td>0.1722</td>
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<td></td>
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</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.18.3B. Numerical difference and standard error of the estimate for 14C-sucrose to starch ratio retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O2 under 40 Pa CO2 in Figure 3.11G.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
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<th>t-value</th>
<th>P</th>
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<td>21 vs. 2</td>
<td>14C-sucrose: starch</td>
<td>15°C</td>
<td>0.10</td>
<td>0.26</td>
<td>0.38</td>
<td>0.7047</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>14C-sucrose: starch</td>
<td>25°C</td>
<td>0.17</td>
<td>0.24</td>
<td>0.72</td>
<td>0.4810</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>14C-sucrose: starch</td>
<td>35°C</td>
<td>0.62</td>
<td>0.27</td>
<td>2.31</td>
<td>0.0297</td>
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</table>

Table A.18.3C. Multiple mean comparison estimate for 14C-sucrose to starch ratio retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O2 under 40 Pa CO2 in Figure 3.11G.
Table A.18.4A. Two-way analysis of variance for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa $O_2$ under 91 Pa CO$_2$ in Figure 3.11B.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
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<th>F Value</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
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<tbody>
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<td>0.7489</td>
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<tr>
<td>Error</td>
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<tr>
<td>Corrected Total</td>
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<td>23.04</td>
<td>&lt;.0001</td>
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<td></td>
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</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.18.4B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa $O_2$ under 91 Pa CO$_2$ in Figure 3.11B.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose</td>
<td>15°C</td>
<td>59.11</td>
<td>8.16</td>
<td>7.24</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose</td>
<td>25°C</td>
<td>23.62</td>
<td>9.23</td>
<td>2.56</td>
<td>0.0179</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose</td>
<td>35°C</td>
<td>12.53</td>
<td>8.16</td>
<td>1.54</td>
<td>0.1388</td>
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</table>

Table A.18.4C. Multiple mean comparison for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa $O_2$ under 91 Pa CO$_2$ in Figure 3.11B.

| O2 Temp Suc LSMEAN Standard Error Pr > |t| LSMEAN Number |
|----|-----------------|-----------------|-----------------|-----------------|-----------------|
| a 15 | 16.4839500 | 5.1620702 | 0.0042 | 1 |
| a 25 | 61.3602000 | 5.6547646 | <.0001 | 2 |
| a 35 | 39.8466667 | 5.1620702 | <.0001 | 3 |
| l 15 | 75.5942500 | 6.3222190 | <.0001 | 4 |
| l 25 | 37.7426667 | 7.3002697 | <.0001 | 5 |
| l 35 | 52.3817500 | 6.3222190 | <.0001 | 6 |

Least Squares Means for effect $O_2$*Temp

<table>
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<th>1</th>
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<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<tbody>
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<td>&lt;.0001</td>
<td>0.0265</td>
<td>0.0002</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>&lt;.0001</td>
<td>0.0102</td>
<td>0.1075</td>
<td>0.0179</td>
<td>0.3013</td>
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</tr>
<tr>
<td>3</td>
<td>0.0041</td>
<td>0.0102</td>
<td>0.0002</td>
<td>0.8161</td>
<td>0.1388</td>
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</tr>
<tr>
<td>4</td>
<td>&lt;.0001</td>
<td>0.1075</td>
<td>0.0002</td>
<td>0.0007</td>
<td>0.0165</td>
<td></td>
</tr>
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</table>
Table A.18.5A. Two-way analysis of variance for $^{14}$C-starch (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.11E.

Two-way ANOVA

<table>
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<th>Source</th>
<th>DF</th>
<th>SS†</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
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</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>7596.58</td>
<td>34.52</td>
<td>&lt;.0001</td>
<td>0.8779</td>
<td>14.36</td>
</tr>
<tr>
<td>Error</td>
<td>24</td>
<td>1056.26</td>
<td></td>
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</tr>
<tr>
<td>Corrected Total</td>
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<td></td>
</tr>
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<td>Temp</td>
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<td>5789.79</td>
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</tr>
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<td>24.44</td>
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<td>0.7599</td>
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</table>

† Sum of squares for model parameters are those of type III (SAS)

Table A.18.5B. Numerical difference and standard error of the estimate for $^{14}$C-starch (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.11E.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2 $^{14}$C-starch</td>
<td>15°C</td>
<td>11.02</td>
<td>2.37</td>
<td>3.67</td>
<td>0.0012</td>
</tr>
<tr>
<td>21 vs. 2 $^{14}$C-starch</td>
<td>25°C</td>
<td>11.82</td>
<td>2.55</td>
<td>2.76</td>
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<tr>
<td>21 vs. 2 $^{14}$C-starch</td>
<td>35°C</td>
<td>15.76</td>
<td>3.39</td>
<td>3.68</td>
<td>0.0012</td>
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</table>

Table A.18.5C. Multiple mean comparison for $^{14}$C-starch (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.11E.

| O$_2$ Temp | Insol LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|------------|--------------|----------------|-------|---|----------------|
| a          | 15           | 20.3611500     | 2.7083423     | <.0001 | 1              |
| a          | 25           | 47.1983333     | 2.7083423     | <.0001 | 2              |
| a          | 35           | 53.7546833     | 2.7083423     | <.0001 | 3              |
| l          | 15           | 36.0678750     | 3.3170283     | <.0001 | 4              |
| l          | 25           | 59.0224500     | 3.3170283     | <.0001 | 5              |
| l          | 35           | 69.5130000     | 3.3170283     | <.0001 | 6              |

Least Squares Means for effect O2*Temp
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: Suc

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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<tbody>
<tr>
<td>5</td>
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<td>0.0179</td>
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<td>0.0007</td>
<td>0.1438</td>
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<tr>
<td>6</td>
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<td>0.3013</td>
<td>0.1388</td>
<td>0.0165</td>
<td>0.1438</td>
<td></td>
</tr>
</tbody>
</table>

Least Squares Means for effect O2*Temp
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: Insol

<table>
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<th>6</th>
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<tr>
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<td>0.2306</td>
<td>&lt;.0001</td>
<td>0.0349</td>
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</tr>
<tr>
<td>6</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0012</td>
<td>&lt;.0001</td>
<td>0.0349</td>
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Table A.18.6A. Two-way analysis of variance for $^{14}$C-sucrose to starch ratio retained in leaves to compare GIV plants exposed to three short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.11H.

Two-way ANOVA

<table>
<thead>
<tr>
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<th>Value</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
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<tbody>
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<td>35.29</td>
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<td>0.8936</td>
<td>13.09</td>
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<tr>
<td>Error</td>
<td>21</td>
<td>1.07</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>26</td>
<td>10.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>1.03</td>
<td>10.23</td>
<td>0.0008</td>
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<td></td>
</tr>
<tr>
<td>O$_2$</td>
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<td>1.17</td>
<td>22.84</td>
<td>0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>7.76</td>
<td>75.97</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.18.6B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose to starch ratio retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.11H.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: starch</td>
<td>15°C</td>
<td>2.00</td>
<td>0.16</td>
<td>12.54</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: starch</td>
<td>25°C</td>
<td>0.68</td>
<td>0.16</td>
<td>4.12</td>
<td>0.0005</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: starch</td>
<td>35°C</td>
<td>0.02</td>
<td>0.15</td>
<td>0.16</td>
<td>0.8753</td>
</tr>
</tbody>
</table>

Table A.18.6C. Multiple mean comparison for $^{14}$C-sucrose to starch ratio retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.11H.

<table>
<thead>
<tr>
<th>O$_2$</th>
<th>Temp</th>
<th>SucStarch LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>15</td>
<td>0.35195830</td>
<td>0.09229201</td>
<td>0.0010</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>25</td>
<td>1.29145678</td>
<td>0.10110083</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>35</td>
<td>0.90592540</td>
<td>0.09229201</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>15</td>
<td>2.35674685</td>
<td>0.13052061</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>l</td>
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<td>0.61086421</td>
<td>0.13052061</td>
<td>0.0001</td>
<td>5</td>
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</tr>
<tr>
<td>l</td>
<td>35</td>
<td>0.88275274</td>
<td>0.11303417</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

Table A.18.7A. Two-way analysis of variance for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 2B.10.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS $^1$</th>
<th>Value</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>10639.61</td>
<td>9.69</td>
<td>&lt;.0001</td>
<td>0.7077</td>
<td>30.43</td>
</tr>
<tr>
<td>Error</td>
<td>20</td>
<td>4394.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>25</td>
<td>14784.68</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>3831.90</td>
<td>8.72</td>
<td>0.0019</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
<td>270.51</td>
<td>1.23</td>
<td>0.2803</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>5686.73</td>
<td>12.49</td>
<td>0.0002</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)
Table A.18.7B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 2B.10.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose</td>
<td>15°C</td>
<td>48.13</td>
<td>9.94</td>
<td>4.84</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose</td>
<td>25°C</td>
<td>13.91</td>
<td>10.48</td>
<td>1.33</td>
<td>0.1994</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose</td>
<td>35°C</td>
<td>14.76</td>
<td>9.94</td>
<td>1.48</td>
<td>0.1532</td>
</tr>
</tbody>
</table>

Table A.18.7C. Multiple mean comparison for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 2B.10.

<table>
<thead>
<tr>
<th>O2</th>
<th>Temp</th>
<th>Suc</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>15</td>
<td>10.8112000</td>
<td>6.6288787</td>
<td>0.1186</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>25</td>
<td>71.9885000</td>
<td>7.4113117</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>35</td>
<td>57.2728000</td>
<td>6.6288787</td>
<td>&lt;.0001</td>
<td>3</td>
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<td></td>
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</tr>
<tr>
<td>l</td>
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<td>58.9450000</td>
<td>7.4113117</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>25</td>
<td>58.0782500</td>
<td>7.4113117</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>35</td>
<td>42.5097500</td>
<td>7.4113117</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
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</tr>
</tbody>
</table>

Table A.18.8A. Two-way analysis of variance for $^{14}$C-starch (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 2B.10.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS$^1$</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>23.96</td>
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<td>18.19</td>
</tr>
<tr>
<td>Error</td>
<td>24</td>
<td>2005.18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Temp</td>
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<td>9145.99</td>
<td>54.73</td>
<td>&lt;.0001</td>
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<td></td>
</tr>
<tr>
<td>O$_2$</td>
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<td>77.60</td>
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<td>0.3448</td>
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<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
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<td>0.87</td>
<td>0.4302</td>
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<td></td>
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</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.18.8B. Numerical difference and standard error of the estimate for $^{14}$C-starch (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 2B.10.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-starch</td>
<td>15°C</td>
<td>8.54</td>
<td>5.90</td>
<td>1.45</td>
<td>0.1607</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-starch</td>
<td>25°C</td>
<td>2.46</td>
<td>5.90</td>
<td>0.42</td>
<td>0.6806</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-starch</td>
<td>35°C</td>
<td>3.77</td>
<td>5.90</td>
<td>0.64</td>
<td>0.5293</td>
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</table>

Table A.18.8C. Multiple mean comparison for $^{14}$C-starch (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 2B.10.

<table>
<thead>
<tr>
<th>O2</th>
<th>Temp</th>
<th>Insol</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
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<td>23.3440500</td>
<td>3.7316039</td>
<td>&lt;.0001</td>
<td>1</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>O2</td>
<td>Temp</td>
<td>Insol LSMEAN</td>
<td>Standard Error</td>
<td>Pr &gt;</td>
<td>t</td>
<td></td>
<td>LSMEAN Number</td>
<td></td>
</tr>
<tr>
<td>----</td>
<td>------</td>
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<td>----------------</td>
<td>-------</td>
<td>---</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>25</td>
<td>54.3025500</td>
<td>3.7316039</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>a</td>
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<td>&lt;.0001</td>
<td>3</td>
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<td></td>
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<tr>
<td>l</td>
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<td>4.5702627</td>
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<td>4</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>l</td>
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<td>5</td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td>4.5702627</td>
<td>&lt;.0001</td>
<td>6</td>
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</tr>
</tbody>
</table>

Table A.18.9A. Two-way analysis of variance for $^{14}$C-sucrose to starch ratio retained in leaves to compare GIV plants exposed to three short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 2B.10.

### Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS $^\dagger$</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>0.5603</td>
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<td>Error</td>
<td>22</td>
<td>3.76</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
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<td>8.55</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
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<td>1.83</td>
<td>5.36</td>
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<td></td>
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</tr>
<tr>
<td>Temp*O$_2$</td>
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<td>3.26</td>
<td>9.55</td>
<td>0.0010</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^\dagger$Sum of squares for model parameters are those of type III (SAS)

Table A.18.9B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose to starch ratio retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 2B.10.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable Treatment</th>
<th>Source</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: starch</td>
<td>15°C</td>
<td>1.10</td>
<td>0.27</td>
<td>4.12</td>
<td>0.0005</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: starch</td>
<td>25°C</td>
<td>0.37</td>
<td>0.29</td>
<td>1.28</td>
<td>0.2149</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: starch</td>
<td>35°C</td>
<td>0.33</td>
<td>0.27</td>
<td>1.24</td>
<td>0.2273</td>
</tr>
</tbody>
</table>

Table A.18.9C. Multiple mean comparison for $^{14}$C-sucrose to starch ratio retained in source leaves to compare GIV A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 2B.10.
### Table A.19.1A

#### Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
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<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>698.35</td>
<td></td>
<td>&lt;.0001</td>
<td>0.6932</td>
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<tr>
<td>Error</td>
<td>26</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
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<td></td>
</tr>
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<td>0.2273</td>
<td></td>
</tr>
<tr>
<td>Temp*O₂</td>
<td>2</td>
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<td>3.30</td>
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<td>0.0878</td>
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</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)*

### Table A.19.1B

#### Contrast Variable

<table>
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<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>¹⁴C-antirrhinoside</td>
<td>15°C</td>
<td>1.88</td>
<td>2.22</td>
<td>0.84</td>
<td>0.4063</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>¹⁴C-antirrhinoside</td>
<td>25°C</td>
<td>1.48</td>
<td>2.11</td>
<td>0.70</td>
<td>0.4880</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>¹⁴C-antirrhinoside</td>
<td>35°C</td>
<td>8.60</td>
<td>2.22</td>
<td>3.87</td>
<td>0.0007</td>
</tr>
</tbody>
</table>

### Table A.19.1C

#### Multiple mean comparison

<table>
<thead>
<tr>
<th>O₂</th>
<th>Temp</th>
<th>Antirrhinoside LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>15</td>
<td>1.9651000</td>
<td>1.4075883</td>
<td>0.1745</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>25</td>
<td>10.1707125</td>
<td>1.2190073</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>35</td>
<td>8.4578167</td>
<td>1.2190073</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>15</td>
<td>3.8437500</td>
<td>1.7239366</td>
<td>0.0346</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>25</td>
<td>11.6560250</td>
<td>1.7239366</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>35</td>
<td>17.0639000</td>
<td>1.7239366</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

### Least Squares Means for effect O₂*Temp

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0002</td>
<td>0.0031</td>
<td>0.4063</td>
<td>0.0002</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.0002</td>
<td>0.3661</td>
<td>0.0059</td>
<td>0.4880</td>
<td>0.0031</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.0031</td>
<td>0.3661</td>
<td>0.0482</td>
<td>0.1626</td>
<td>0.0007</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.4063</td>
<td>0.0059</td>
<td>0.0482</td>
<td>0.0036</td>
<td>&lt;.0001</td>
<td></td>
</tr>
</tbody>
</table>
### Table A.19.2A

Two-way analysis of variance for $^{14}$C-antirrhine (mmol C·m$^{-2}$) retained in source leaves to compare GI A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.12D.

#### Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>$F$</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>566.89</td>
<td>26.30</td>
<td>&lt;.0001</td>
<td>0.8296</td>
<td>41.52</td>
</tr>
<tr>
<td>Error</td>
<td>27</td>
<td>116.40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>32</td>
<td>683.29</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>239.21</td>
<td>27.74</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$O_2$</td>
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<td>266.18</td>
<td>62.21</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*$O_2$</td>
<td>2</td>
<td>122.38</td>
<td>14.19</td>
<td>&lt;.0001</td>
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<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)*

### Table A.19.2B

Numerical difference and standard error of the estimate for $^{14}$C-antirrhine (mmol C·m$^{-2}$) retained in source leaves to compare GI A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.12D.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhine</td>
<td>15°C</td>
<td>0.77</td>
<td>1.34</td>
<td>0.58</td>
<td>0.5684</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhine</td>
<td>25°C</td>
<td>6.33</td>
<td>1.27</td>
<td>4.98</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhine</td>
<td>35°C</td>
<td>10.71</td>
<td>1.30</td>
<td>8.23</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

### Table A.19.2C

Multiple mean comparison for $^{14}$C-antirrhine (mmol C·m$^{-2}$) retained in source leaves to compare GI A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.12D.

<table>
<thead>
<tr>
<th>O2</th>
<th>Temp</th>
<th>Antirrhine</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>15</td>
<td>1.3033500</td>
<td>0.8476619</td>
<td>0.1358</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>25</td>
<td>4.6131500</td>
<td>0.7340967</td>
<td>&lt;.0001</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>35</td>
<td>2.3034143</td>
<td>0.7847824</td>
<td>0.0067</td>
<td></td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>15</td>
<td>2.0773750</td>
<td>1.0381696</td>
<td>0.0555</td>
<td></td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>25</td>
<td>10.9486500</td>
<td>1.0381696</td>
<td>&lt;.0001</td>
<td></td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>35</td>
<td>13.0170250</td>
<td>1.0381696</td>
<td>&lt;.0001</td>
<td></td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Least Squares Means for effect O2*Temp

Pr > |t| for H0: LSMean(i)=LSMean(j)

<table>
<thead>
<tr>
<th>Source</th>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Least Squares Means for effect O2*Temp</td>
<td>i/j</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Least Squares Means for effect O2*Temp</td>
<td>Pr &gt;</td>
<td>t</td>
<td>for H0: LSMean(i)=LSMean(j)</td>
<td>Dependent Variable: Antirrhine</td>
<td>i/j</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Least Squares Means for effect O2*Temp</td>
<td>Pr &gt;</td>
<td>t</td>
<td>for H0: LSMean(i)=LSMean(j)</td>
<td>Dependent Variable: Antirrhine</td>
<td>2</td>
<td>0.0065</td>
<td>0.0407</td>
</tr>
<tr>
<td>Least Squares Means for effect O2*Temp</td>
<td>Pr &gt;</td>
<td>t</td>
<td>for H0: LSMean(i)=LSMean(j)</td>
<td>Dependent Variable: Antirrhine</td>
<td>3</td>
<td>0.3943</td>
<td>0.0407</td>
</tr>
<tr>
<td>Least Squares Means for effect O2*Temp</td>
<td>Pr &gt;</td>
<td>t</td>
<td>for H0: LSMean(i)=LSMean(j)</td>
<td>Dependent Variable: Antirrhine</td>
<td>4</td>
<td>0.5684</td>
<td>0.0563</td>
</tr>
<tr>
<td>Least Squares Means for effect O2*Temp</td>
<td>Pr &gt;</td>
<td>t</td>
<td>for H0: LSMean(i)=LSMean(j)</td>
<td>Dependent Variable: Antirrhine</td>
<td>5</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Least Squares Means for effect O2*Temp</td>
<td>Pr &gt;</td>
<td>t</td>
<td>for H0: LSMean(i)=LSMean(j)</td>
<td>Dependent Variable: Antirrhine</td>
<td>6</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>
Table A.19.3A. Two-way analysis of variance for \(^{14}\text{C}-\)antirrhinoside to antirrhide ratio retained in source leaves to compare \textit{GI A. majus} plants exposed to three different short term temperatures at 21 and 2 kPa \(\text{O}_2\) under 40 Pa \(\text{CO}_2\) in Figure 3.12G.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS†</th>
<th>(F) Value</th>
<th>(\text{Pr}&gt;F)</th>
<th>(R^2)</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>27.36</td>
<td>8.51</td>
<td>&lt;.0001</td>
<td>0.6121</td>
<td>37.76</td>
</tr>
<tr>
<td>Error</td>
<td>27</td>
<td>17.34</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>32</td>
<td>44.69</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Temp</td>
<td>2</td>
<td>5.17</td>
<td>4.03</td>
<td>0.0294</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\text{O}_2)</td>
<td>1</td>
<td>6.80</td>
<td>10.59</td>
<td>0.0031</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*(\text{O}_2)</td>
<td>2</td>
<td>9.19</td>
<td>7.16</td>
<td>0.0032</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{1}\text{Sum of squares for model parameters are those of type III (SAS)}\

Table A.19.3B. Numerical difference and standard error of the estimate for \(^{14}\text{C}-\)antirrhinoside to antirrhide ratio retained in source leaves to compare \textit{GI A. majus} plants exposed to three different short term temperatures at 21 and 2 kPa \(\text{O}_2\) under 40 Pa \(\text{CO}_2\) in Figure 3.12G.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>(t)-value</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2 (^{14}\text{C}-\text{antirrhinoside:antirrhide})</td>
<td>15°C</td>
<td>0.39</td>
<td>0.52</td>
<td>0.76</td>
<td>0.4513</td>
</tr>
<tr>
<td>21 vs. 2 (^{14}\text{C}-\text{antirrhinoside:antirrhide})</td>
<td>25°C</td>
<td>0.93</td>
<td>0.50</td>
<td>1.86</td>
<td>0.0740</td>
</tr>
<tr>
<td>21 vs. 2 (^{14}\text{C}-\text{antirrhinoside:antirrhide})</td>
<td>35°C</td>
<td>2.30</td>
<td>0.49</td>
<td>4.69</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Table A.19.3C. Multiple mean comparison for \(^{14}\text{C}-\)antirrhinoside to antirrhide ratio retained in source leaves to compare \textit{GI A. majus} plants exposed to three different short term temperatures at 21 and 2 kPa \(\text{O}_2\) under 40 Pa \(\text{CO}_2\) in Figure 3.12G.

| \(\text{O}_2\) | \(\text{Temp}\) | \(\text{AntiAntirrhide LSMEAN}\) | \(\text{Standard Error}\) | \(\text{Pr} > |t|\) | \(\text{LSMEAN Number}\) |
|---------------|-----------------|-------------------------------|---------------------------|-----------------|-----------------------------|
| A             | 15              | 1.56691234                    | 0.32715721                | <.0001          | 1                           |
| A             | 25              | 2.00335759                    | 0.30288872                | <.0001          | 2                           |
| A             | 35              | 3.63976356                    | 0.28332645                | <.0001          | 3                           |
| L             | 15              | 1.96226701                    | 0.40068411                | <.0001          | 4                           |
| L             | 25              | 1.06977403                    | 0.40068411                | 0.1272          | 5                           |
| L             | 35              | 1.33947754                    | 0.40068411                | 0.0024          | 6                           |

Table A.19.4A. Two-way analysis of variance for \(^{14}\text{C}-\)antirrhinoside (mmol C·m\(^{-2}\)) retained in source leaves to compare \textit{GI A. majus} plants exposed to three different short term temperatures at 21 and 2 kPa \(\text{O}_2\) under 91 Pa \(\text{CO}_2\) in Figure 3.12B.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS†</th>
<th>(F) Value</th>
<th>(\text{Pr}&gt;F)</th>
<th>(R^2)</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>1062.48</td>
<td>14.68</td>
<td>&lt;.0001</td>
<td>0.7614</td>
<td>36.11</td>
</tr>
<tr>
<td>Error</td>
<td>23</td>
<td>332.94</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>28</td>
<td>1395.42</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>842.37</td>
<td>29.10</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\text{O}_2)</td>
<td>1</td>
<td>81.61</td>
<td>5.64</td>
<td>0.0263</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*(\text{O}_2)</td>
<td>2</td>
<td>46.02</td>
<td>1.59</td>
<td>0.2256</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table A.19.4B. Least Squares Means for effect \(\text{O}_2*\text{Temp}\) for \textit{GI A. majus} plants exposed to three different short term temperatures at 21 and 2 kPa \(\text{O}_2\) under 91 Pa \(\text{CO}_2\) in Figure 3.12B.

\text{\textit{Dependent Variable: AntiAntirrhide}}

\| i/j | 1  | 2  | 3  | 4  | 5  | 6  |
\|-----|----|----|----|----|----|----|
\| 1   | 0.3363 | <.0001 | 0.4513 | 0.3451 | 0.6637 |
\| 2   | 0.3363 | 0.0005 | 0.9354 | 0.0740 | 0.1974 |
\| 3   | <.0001 | 0.0005 | 0.0020 | <.0001 | <.0001 |
\| 4   | 0.4513 | 0.9354 | 0.0020 | 0.1269 | 0.2814 |
\| 5   | 0.3451 | 0.0740 | <.0001 | 0.1269 | 0.6379 |
\| 6   | 0.6637 | 0.1974 | <.0001 | 0.2814 | 0.6379 |

Table A.19.4A. Two-way analysis of variance for \(^{14}\text{C}-\)antirrhinoside (mmol C·m\(^{-2}\)) retained in source leaves to compare \textit{GI A. majus} plants exposed to three different short term temperatures at 21 and 2 kPa \(\text{O}_2\) under 91 Pa \(\text{CO}_2\) in Figure 3.12B.
Sum of squares for model parameters are those of type III (SAS)

Table A.19.4B. Numerical difference and standard error of the estimate for $^{14}$C-antirrhidoside (mmol C·m$^{-2}$) retained in source leaves to compare GI A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.12B.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhidoside</td>
<td>15°C</td>
<td>5.37</td>
<td>2.45</td>
<td>2.19</td>
<td>0.0391</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhidoside</td>
<td>25°C</td>
<td>5.20</td>
<td>2.69</td>
<td>1.39</td>
<td>0.0654</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhidoside</td>
<td>35°C</td>
<td>0.14</td>
<td>2.45</td>
<td>0.06</td>
<td>0.9532</td>
</tr>
</tbody>
</table>

Table A.19.4C. Multiple mean comparison for $^{14}$C-antirrhidoside (mmol C·m$^{-2}$) retained in source leaves to compare GI A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.12B.

| O2 | Temp | Antirrhidoside LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|----|------|-----------------------|----------------|------|-------|---------------|
| A  | 15   | 1.6572167             | 1.5532666      | 0.2971 | 1     |
| A  | 25   | 6.7998000             | 2.1966507      | 0.0051 | 2     |
| A  | 35   | 17.5615333            | <.0001         | <.0001 | <.0001 |
| L  | 15   | 7.0295250             | 1.9023554      | 0.0012 | 4     |
| L  | 25   | 12.0050000            | <.0001         | <.0001 | <.0001 |
| L  | 35   | 17.4158000            | <.0001         | <.0001 | <.0001 |

Least Squares Means for effect O2*Temp
Pr>|t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: Antirrhidoside

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0685</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
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<tr>
<td>2</td>
<td>0.0685</td>
<td>0.0006</td>
<td>0.9377</td>
<td>0.0654</td>
<td>0.0013</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>3</td>
<td>&lt;.0001</td>
<td>0.0006</td>
<td>0.0003</td>
<td>0.0187</td>
<td>0.9532</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>4</td>
<td>0.0391</td>
<td>0.9377</td>
<td>0.0003</td>
<td>0.0545</td>
<td>0.0008</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>5</td>
<td>&lt;.0001</td>
<td>0.0654</td>
<td>0.0187</td>
<td>0.0545</td>
<td>0.0379</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>6</td>
<td>&lt;.0001</td>
<td>0.0013</td>
<td>0.9532</td>
<td>0.0008</td>
<td>0.0379</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Table A.19.5A. Two-way analysis of variance for $^{14}$C-antirrhidoside (mmol C·m$^{-2}$) retained in source leaves to compare GI A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.12E.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS$^1$</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>810.03</td>
<td>13.59</td>
<td>&lt;.0001</td>
<td>0.7390</td>
<td>46.93</td>
</tr>
<tr>
<td>Error</td>
<td>24</td>
<td>286.14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>29</td>
<td>1096.17</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>588.32</td>
<td>23.41</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
<td>218.32</td>
<td>18.31</td>
<td>0.0002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>96.90</td>
<td>4.06</td>
<td>0.0302</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.19.5B. Numerical difference and standard error of the estimate for $^{14}$C-antirrhidoside(mmol C·m$^{-2}$) retained in source leaves to compare GI A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.12E.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhidoside</td>
<td>15°C</td>
<td>3.67</td>
<td>2.23</td>
<td>1.62</td>
<td>0.1122</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhidoside</td>
<td>25°C</td>
<td>2.21</td>
<td>2.23</td>
<td>1.00</td>
<td>0.3296</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhidoside</td>
<td>35°C</td>
<td>10.63</td>
<td>2.23</td>
<td>4.77</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>
Table A.19.5C. Multiple mean comparison for $^{14}$C-antirhine (mmol C·m$^{-2}$) retained in source leaves to compare GI *A. majus* plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.12E.

| O2 | Temp | Antirrhide LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|----|------|------------------|----------------|-------|---|----------------|
| a  | 15   | 1.1898000        | 1.4096346      | 0.4070 | 1 |
| a  | 25   | 5.5115750        | 1.7264428      | 0.0039 | 2 |
| a  | 35   | 8.3176167        | 1.4096346      | <.0001 | 3 |
| l  | 15   | 4.8653000        | 1.7264428      | 0.0095 | 4 |
| l  | 25   | 7.7296833        | 1.4096346      | <.0001 | 5 |
| l  | 35   | 18.9436500       | 1.7264428      | <.0001 | 6 |

Table A.19.6A. Two-way analysis of variance for $^{14}$C-antirrhinoside to antirrhine ratio retained in source leaves to compare GI *A. majus* plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.12H.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS$^1$</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>4.06</td>
<td>3.10</td>
<td>0.0261</td>
<td>0.3823</td>
<td>31.12</td>
</tr>
<tr>
<td>Corrected Total</td>
<td>25</td>
<td>6.56</td>
<td>10.61</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>0.58</td>
<td>1.11</td>
<td>0.3443</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
<td>1.94</td>
<td>7.42</td>
<td>0.0116</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>1.71</td>
<td>3.28</td>
<td>0.0545</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.19.6B. Numerical difference and standard error of the estimate for $^{14}$C-antirrhinoside to antirrhine ratio retained in source leaves to compare GI *A. majus* plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.12H.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhinoside:antirrhine</td>
<td>15°C</td>
<td>0.06</td>
<td>0.33</td>
<td>0.28</td>
<td>0.7820</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhinoside:antirrhine</td>
<td>25°C</td>
<td>0.29</td>
<td>0.31</td>
<td>4.46</td>
<td>0.0002</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhinoside:antirrhine</td>
<td>35°C</td>
<td>1.18</td>
<td>0.33</td>
<td>5.17</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Table A.19.6C. Multiple mean comparison estimate for $^{14}$C-antirrhinoside to antirrhine ratio retained in source leaves to compare GI *A. majus* plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.12H.
### Table A.19.7A
Two-way analysis of variance for \(^{14}\)C-antirrhinoside (mmol C·m\(^{-2}\)) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O\(_2\) under 182 Pa CO\(_2\) in Figure 3.12C.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R(^2)</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>2005.88</td>
<td>22.13</td>
<td>&lt;.0001</td>
<td>0.8342</td>
<td>32.42</td>
</tr>
<tr>
<td>Error</td>
<td>22</td>
<td>398.76</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>27</td>
<td>2404.64</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>738.28</td>
<td>20.37</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O(_2)</td>
<td>1</td>
<td>515.13</td>
<td>28.42</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O(_2)</td>
<td>2</td>
<td>585.07</td>
<td>16.14</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)*

### Table A.19.7B
Numerical difference and standard error of the estimate for \(^{14}\)C-antirrhinoside (mmol C·m\(^{-2}\)) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O\(_2\) under 182 Pa CO\(_2\) in Figure 3.12C.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>(^{14})C-antirrhinoside</td>
<td>15°C</td>
<td>3.75</td>
<td>2.75</td>
<td>1.37</td>
<td>0.1860</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>(^{14})C-antirrhinoside</td>
<td>25°C</td>
<td>11.78</td>
<td>2.85</td>
<td>4.13</td>
<td>0.0004</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>(^{14})C-antirrhinoside</td>
<td>35°C</td>
<td>18.01</td>
<td>2.85</td>
<td>6.31</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

### Table A.19.7C
Multiple mean comparison for \(^{14}\)C-antirrhinoside (mmol C·m\(^{-2}\)) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O\(_2\) under 182 Pa CO\(_2\) in Figure 3.12C.

<table>
<thead>
<tr>
<th>O(_2)</th>
<th>Temp</th>
<th>Antirrhinoside LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>15</td>
<td>3.9026167</td>
<td>1.7380837</td>
<td>0.0351</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>25</td>
<td>21.7970800</td>
<td>1.9039753</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>35</td>
<td>26.2964000</td>
<td>1.9039753</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>15</td>
<td>7.6544500</td>
<td>2.1287091</td>
<td>0.0016</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>25</td>
<td>10.0116250</td>
<td>2.1287091</td>
<td>0.0001</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>35</td>
<td>8.2868000</td>
<td>2.1287091</td>
<td>0.0008</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

### Least Squares Means for effect O\(_2\)*Temp
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: Antirrhinoside

<table>
<thead>
<tr>
<th>i</th>
<th>j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.1860</td>
<td>0.0368</td>
<td>0.1249</td>
<td></td>
</tr>
</tbody>
</table>
**Table A.19.8A.** Two-way analysis of variance for $^{14}$C-antirrhine (mmol C·m$^{-2}$) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.12F.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>$F$ Value</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>409.36</td>
<td>11.85</td>
<td>&lt;.0001</td>
<td>0.7204</td>
<td>34.08</td>
</tr>
<tr>
<td>Error</td>
<td>23</td>
<td>158.89</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>28</td>
<td>568.25</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>239.71</td>
<td>17.35</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
<td>27.67</td>
<td>4.00</td>
<td>0.0573</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>78.83</td>
<td>5.71</td>
<td>0.0097</td>
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<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)*

**Table A.19.8B.** Numerical difference and standard error of the estimate for $^{14}$C-antirrhine (mmol C·m$^{-2}$) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.12F.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhine</td>
<td>15°C</td>
<td>2.72</td>
<td>1.70</td>
<td>1.60</td>
<td>0.1231</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhine</td>
<td>25°C</td>
<td>4.18</td>
<td>1.76</td>
<td>2.37</td>
<td>0.0265</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhine</td>
<td>35°C</td>
<td>4.49</td>
<td>1.70</td>
<td>2.61</td>
<td>0.0143</td>
</tr>
</tbody>
</table>

**Table A.19.8C.** Multiple mean comparison for $^{14}$C-antirrhine (mmol C·m$^{-2}$) retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.12F.

| O$_2$ | Temp | Antirrhine LSMEAN | Standard Error | Pr>|t| | LSMEAN Number |
|-------|------|-------------------|----------------|------|---------------|
| a     | 15   | 2.4466833         | 1.0730292     | 0.0322 | 1             |
| a     | 25   | 10.2840800        | 1.1754446     | <.0001 | 2             |
| a     | 35   | 13.0471667        | 1.0730292     | <.0001 | 3             |
| b     | 15   | 5.1623000         | 1.3141871     | 0.0007 | 4             |
| b     | 25   | 6.1050500         | 1.3141871     | 0.0001 | 5             |
| b     | 35   | 8.5518500         | 1.3141871     | <.0001 | 6             |
Least Squares Means for effect O2*Temp
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: Antirrhide

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0.0015</td>
<td>0.3361</td>
<td>0.0143</td>
<td>0.0812</td>
<td>0.2010</td>
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</tbody>
</table>

Table A.19.9A. Two-way analysis of variance for $^{14}$C-antirrhinoside to antirrhide ratio retained in source leaves to compare Gl plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.12I.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>3.28</td>
<td>5.58</td>
<td>0.0018</td>
<td>0.5593</td>
<td>20.61</td>
</tr>
<tr>
<td>Error</td>
<td>22</td>
<td>2.59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>27</td>
<td>5.87</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>0.96</td>
<td>4.07</td>
<td>0.0312</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$O_2$</td>
<td>1</td>
<td>1.72</td>
<td>14.66</td>
<td>0.0009</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*$O_2$</td>
<td>2</td>
<td>0.71</td>
<td>3.02</td>
<td>0.0693</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)

Table A.19.9B. Numerical difference and standard error of the estimate for $^{14}$C-antirrhinoside to antirrhide ratio retained in source leaves to compare Gl plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.12I.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2 $^{14}$C-antirrhinoside: antirrhide</td>
<td>15°C</td>
<td>0.11</td>
<td>0.22</td>
<td>0.51</td>
<td>0.6184</td>
</tr>
<tr>
<td>21 vs. 2 $^{14}$C-antirrhinoside: antirrhide</td>
<td>25°C</td>
<td>0.50</td>
<td>0.23</td>
<td>2.17</td>
<td>0.0415</td>
</tr>
<tr>
<td>21 vs. 2 $^{14}$C-antirrhinoside: antirrhide</td>
<td>35°C</td>
<td>0.90</td>
<td>0.23</td>
<td>3.90</td>
<td>0.0008</td>
</tr>
</tbody>
</table>

Table A.19.9C. Multiple mean comparison for $^{14}$C-antirrhinoside to antirrhide ratio retained in source leaves to compare Gl plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.12I.

<table>
<thead>
<tr>
<th>O2</th>
<th>Temp</th>
<th>Anti</th>
<th>Antirrhide</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>25</td>
<td>0.0250</td>
<td>0.0250</td>
<td>1.63923342</td>
<td>0.14002110</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>35</td>
<td>0.0247</td>
<td>0.0247</td>
<td>2.13979128</td>
<td>0.15338543</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>15</td>
<td>0.0250</td>
<td>0.0250</td>
<td>1.88432476</td>
<td>0.15338543</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>25</td>
<td>0.0247</td>
<td>0.0247</td>
<td>1.52736103</td>
<td>0.17149012</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>35</td>
<td>0.0247</td>
<td>0.0247</td>
<td>1.64152750</td>
<td>0.17149012</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>35</td>
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Least Squares Means for effect O2*Temp
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: AntiAntirrhide

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253
Table A.20.1A. Two-way analysis of variance for $^{14}$C-antirrhinoside (mmol C·m$^{-2}$) retained in source leaves to compare GIV A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.13A.

Two-way ANOVA

<table>
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<th>Source</th>
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<th>Pr&gt;F</th>
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<td>622.95</td>
<td>23.24</td>
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</tr>
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<td>Error</td>
<td>20</td>
<td>107.24</td>
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<td>Corrected Total</td>
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<td>Temp</td>
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<td>O$_2$</td>
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<td>5.28</td>
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<td>5.24</td>
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†Sum of squares for model parameters are those of type III (SAS)

Table A.20.1B. Numerical difference and standard error of the estimate for $^{14}$C-antirrhinoside (mmol C·m$^{-2}$) retained in source leaves to compare GIV A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.13A.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhinoside</td>
<td>15°C</td>
<td>0.86</td>
<td>1.49</td>
<td>0.58</td>
<td>0.5703</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhinoside</td>
<td>25°C</td>
<td>0.83</td>
<td>1.64</td>
<td>0.51</td>
<td>0.6171</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhinoside</td>
<td>35°C</td>
<td>6.30</td>
<td>1.64</td>
<td>3.85</td>
<td>0.0010</td>
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</table>

Table A.20.1C. Multiple mean comparison for $^{14}$C-antirrhinoside (mmol C·m$^{-2}$) retained in source leaves to compare GIV A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.13A.

| O2 | Temp | Antirrhinoside LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|----|------|-----------------------|----------------|-------| | |
| A  | 15   | 3.0561333             | 0.9453455      | 0.0042 | 1 |
| A  | 25   | 13.6635000            | 1.1578070      | <.0001 | 2 |
| A  | 35   | 9.0696750             | 1.1578070      | <.0001 | 3 |
| L  | 15   | 3.9188250             | 1.1578070      | 0.0029 | 4 |
| L  | 25   | 12.8319500            | 1.1578070      | <.0001 | 5 |
| L  | 35   | 15.3737750            | 1.1578070      | <.0001 | 6 |

Least Squares Means for effect O2*Temp
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: Antirrhinoside

<table>
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<tr>
<th>i/j</th>
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<th>4</th>
<th>5</th>
<th>6</th>
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<tbody>
<tr>
<td>1</td>
<td>&lt;.0001</td>
<td>0.0007</td>
<td>0.5703</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>&lt;.0001</td>
<td>0.0109</td>
<td>&lt;.0001</td>
<td>0.6171</td>
<td>0.3087</td>
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<tr>
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<td>0.0007</td>
<td>0.0109</td>
<td>0.0051</td>
<td>0.0325</td>
<td>0.0010</td>
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<tr>
<td>4</td>
<td>0.5703</td>
<td>&lt;.0001</td>
<td>0.0051</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>&lt;.0001</td>
<td>0.6171</td>
<td>0.0325</td>
<td>&lt;.0001</td>
<td>0.1363</td>
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</tr>
<tr>
<td>6</td>
<td>&lt;.0001</td>
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<td>0.0010</td>
<td>&lt;.0001</td>
<td>0.1363</td>
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Table A.20.2A. Two-way analysis of variance for $^{14}$C-antirrhide (mmol C·m$^{-2}$) retained in source leaves to compare GIV A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.13D.

Two-way ANOVA

<table>
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<tr>
<th>Source</th>
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<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
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<tbody>
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<td>232.36</td>
<td>10.54</td>
<td>&lt;.0001</td>
<td>0.6961</td>
<td>41.27</td>
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<td>Error</td>
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<td>101.42</td>
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<tr>
<td>Corrected Total</td>
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<td>333.79</td>
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<td>Temp</td>
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<td>118.38</td>
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<td>O$_2$</td>
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<td>74.56</td>
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<td>0.0004</td>
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<td>Temp*O$_2$</td>
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<td>35.93</td>
<td>4.07</td>
<td>0.0306</td>
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</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)
**Table A.20.2B.** Numerical difference and standard error of the estimate for $^{14}$C-antirrhine (mmol C·m$^{-2}$) retained in source leaves to compare GIV A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.13D.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
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</thead>
<tbody>
<tr>
<td>21 vs. 2 $^{14}$C-antirrhine</td>
<td>15°C</td>
<td>0.63</td>
<td>1.35</td>
<td>0.46</td>
<td>0.6464</td>
</tr>
<tr>
<td>21 vs. 2 $^{14}$C-antirrhine</td>
<td>25°C</td>
<td>2.81</td>
<td>1.27</td>
<td>2.21</td>
<td>0.0375</td>
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<tr>
<td>21 vs. 2 $^{14}$C-antirrhine</td>
<td>35°C</td>
<td>6.34</td>
<td>1.48</td>
<td>4.27</td>
<td>0.0003</td>
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</table>

**Table A.20.2C.** Multiple mean comparison for $^{14}$C-antirrhine (mmol C·m$^{-2}$) retained in source leaves to compare GIV A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.13D.

| O$_2$ Temp | Antirrhine LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|------------|-------------------|----------------|------|---|----------------|
| a 15       | 1.92590000        | 0.85730190     | 0.0346 | 1  |
| a 25       | 5.00764000        | 0.93912717     | <.0001 | 2  |
| a 35       | 3.55752500        | 1.04997610     | 0.0025 | 3  |
| l 15       | 2.55600000        | 1.04997610     | 0.0231 | 4  |
| l 25       | 7.81438333        | 0.85730190     | <.0001 | 5  |
| l 35       | 9.90265000        | 1.04997610     | <.0001 | 6  |

**Table A.20.3A.** Two-way analysis of variance for $^{14}$C-antirrhinoside to antirrhide ratio retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.13G.

<table>
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<tr>
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<th>Value</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
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<tbody>
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<td>9.87</td>
<td>16.83</td>
<td>&lt;.0001</td>
<td>0.7928</td>
<td>16.94</td>
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<tr>
<td>Error</td>
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<td>2.58</td>
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<td></td>
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<td>Corrected Total</td>
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<td></td>
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<td>Temp</td>
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<td>2.34</td>
<td>9.99</td>
<td>0.0008</td>
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<td>O$_2$</td>
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<td>3.76</td>
<td>32.01</td>
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<td>Temp*O$_2$</td>
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<td>3.09</td>
<td>13.16</td>
<td>0.0002</td>
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**Table A.20.3B.** Numerical difference and standard error of the estimate for $^{14}$C-antirrhinoside to antirrhide ratio retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.13G.

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<th>Contrast Variable</th>
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<th>P</th>
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<tr>
<td>21 vs. 2 $^{14}$C-antirrhinoside:antirrhide</td>
<td>15°C</td>
<td>0.63</td>
<td>0.22</td>
<td>0.29</td>
<td>0.7734</td>
</tr>
<tr>
<td>21 vs. 2 $^{14}$C-antirrhinoside:antirrhide</td>
<td>25°C</td>
<td>1.67</td>
<td>0.23</td>
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<td>&lt;.0001</td>
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<tr>
<td>21 vs. 2 $^{14}$C-antirrhinoside:antirrhide</td>
<td>35°C</td>
<td>0.53</td>
<td>0.24</td>
<td>2.21</td>
<td>0.0381</td>
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**Table A.20.3C.** Multiple mean comparison for $^{14}$C-antirrhinoside to antirrhide ratio retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.13G.
| O2 | Temp | AntiAntirrhide LSMEAN | Standard Error | Pr > | t| | LSMEAN Number |
|----|------|-----------------------|----------------|-------|------|----------------|
| A  | 15   | 1.61336381            | 0.13983975     | <.0001|      | 1              |
| A  | 25   | 3.10535034            | 0.15318677     | <.0001|      | 2              |
| A  | 35   | 2.34005501            | 0.13983975     | <.0001|      | 3              |
| L  | 15   | 1.54891298            | 0.17126801     | <.0001|      | 4              |
| L  | 25   | 1.43856864            | 0.17126801     | <.0001|      | 5              |
| L  | 35   | 1.80572697            | 0.19776327     | <.0001|      | 6              |

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<td>0.4356</td>
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</tr>
<tr>
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<td>0.0013</td>
<td>&lt;.0001</td>
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</tr>
<tr>
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<td>0.0013</td>
<td>0.0017</td>
<td>0.0005</td>
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<td>0.3369</td>
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</tr>
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<td>&lt;.0001</td>
<td>0.0005</td>
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<td>0.1744</td>
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<tr>
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Table A.20.4A. Two-way analysis of variance for $^{14}$C-antirrhinoside (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.13B.

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</tr>
<tr>
<td>Corrected Total</td>
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<td>29.78</td>
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<td>7.39</td>
<td>0.0033</td>
<td>20.86</td>
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Table A.20.4B. Numerical difference and standard error of the estimate for $^{14}$C-antirrhinoside (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.13B.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhinoside</td>
<td>15°C</td>
<td>1.96</td>
<td>2.77</td>
<td>0.71</td>
<td>0.4873</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhinoside</td>
<td>25°C</td>
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<td>2.88</td>
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<td>0.0052</td>
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<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhinoside</td>
<td>35°C</td>
<td>6.05</td>
<td>2.77</td>
<td>2.18</td>
<td>0.0394</td>
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Table A.20.4C. Multiple mean comparison for $^{14}$C-antirrhinoside (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ in Figure 3.13B.
Table A.20.5A. Two-way analysis of variance for $^{14}$C-antirhide (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.13E.

Two-way ANOVA

<table>
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<tr>
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<th>Pr&gt;F</th>
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<td>0.6081</td>
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<td></td>
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<td>0.6753</td>
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</tbody>
</table>

1Sum of squares for model parameters are those of type III (SAS).

Table A.20.5B. Numerical difference and standard error of the estimate for $^{14}$C-antirhide (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.13E.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirhide</td>
<td>15°C</td>
<td>0.98</td>
<td>1.67</td>
<td>0.59</td>
<td>0.5613</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirhide</td>
<td>25°C</td>
<td>1.16</td>
<td>1.73</td>
<td>0.67</td>
<td>0.5101</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirhide</td>
<td>35°C</td>
<td>0.20</td>
<td>1.67</td>
<td>0.12</td>
<td>0.9072</td>
</tr>
</tbody>
</table>

Table A.20.5C. Multiple mean comparison for $^{14}$C-antirhide (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.13E.

<table>
<thead>
<tr>
<th>O2 Temp</th>
<th>Antirrhine LS MEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LS MEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>a 15</td>
<td>2.9270717</td>
<td>1.0560582</td>
<td>0.0109</td>
<td>1</td>
</tr>
<tr>
<td>a 25</td>
<td>8.7066000</td>
<td>1.1568538</td>
<td>&lt;.0001</td>
<td>2</td>
</tr>
<tr>
<td>a 35</td>
<td>10.0042500</td>
<td>1.0560582</td>
<td>&lt;.0001</td>
<td>3</td>
</tr>
<tr>
<td>l 15</td>
<td>3.9114000</td>
<td>1.2934019</td>
<td>0.0060</td>
<td>4</td>
</tr>
<tr>
<td>l 25</td>
<td>7.5456000</td>
<td>1.2934019</td>
<td>&lt;.0001</td>
<td>5</td>
</tr>
<tr>
<td>l 35</td>
<td>9.8075250</td>
<td>1.2934019</td>
<td>&lt;.0001</td>
<td>6</td>
</tr>
</tbody>
</table>

Least Squares Means for effect O2*Temp
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: Antirrhine

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0012</td>
<td>&lt;.0001</td>
<td>0.5613</td>
<td>0.0110</td>
<td>0.0004</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.0012</td>
<td>0.4159</td>
<td>0.0111</td>
<td>0.5101</td>
<td>0.5321</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>&lt;.0001</td>
<td>0.4159</td>
<td>0.0013</td>
<td>0.1545</td>
<td>0.9072</td>
<td></td>
</tr>
</tbody>
</table>
Table A.20.6A. Two-way analysis of variance for $^{14}$C-antirrhinoside to antirhlide ratio retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.13H.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
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<th>F Value</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>6.02</td>
<td>18.42</td>
<td>&lt;.0001</td>
<td>0.8001</td>
<td>13.05</td>
</tr>
<tr>
<td>Error</td>
<td>23</td>
<td>1.50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>28</td>
<td>7.52</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>2.37</td>
<td>18.11</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
<td>3.08</td>
<td>47.14</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>1.08</td>
<td>8.29</td>
<td>0.0019</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)

Table A.20.6B. Numerical difference and standard error of the estimate for $^{14}$C-antirrhinoside to antirhlide ratio retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.13H.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhinoside:antirhlide</td>
<td>15°C</td>
<td>0.12</td>
<td>0.16</td>
<td>0.72</td>
<td>0.4768</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhinoside:antirhlide</td>
<td>25°C</td>
<td>0.86</td>
<td>0.17</td>
<td>5.01</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-antirrhinoside:antirhlide</td>
<td>35°C</td>
<td>1.01</td>
<td>0.16</td>
<td>6.12</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Table A.20.6C. Multiple mean comparison estimate for $^{14}$C-antirrhinoside to antirhlide ratio retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.13H.

| O$_2$ | Temp | AntiAntirhlide LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|-------|------|-----------------------|----------------|------|---|----------------|
| A     | 15   | 2.34127093            | 0.10438969     | <.0001 | 1 |
| A     | 25   | 2.27165554            | 0.11435318     | <.0001 | 2 |
| A     | 35   | 2.09225361            | 0.10438969     | <.0001 | 3 |
| L     | 15   | 2.22189891            | 0.12785074     | <.0001 | 4 |
| L     | 25   | 1.41289783            | 0.12785074     | <.0001 | 5 |
| L     | 35   | 1.08162083            | 0.12785074     | <.0001 | 6 |

Least Squares Means for effect O$_2$*Temp

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.6572</td>
<td>0.1052</td>
<td>0.4768</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.6572</td>
<td>0.2585</td>
<td>0.7744</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.1052</td>
<td>0.2585</td>
<td>0.4402</td>
<td>0.0004</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.4768</td>
<td>0.7744</td>
<td>0.4402</td>
<td>0.0002</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0004</td>
<td>0.0002</td>
<td>0.0799</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0799</td>
<td></td>
</tr>
</tbody>
</table>
Table A.20.7A. Two-way and one-way analysis of variance for $^{14}$C-antirrhinoside (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.13C.

### Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>1003.65</td>
<td>13.49</td>
<td>&lt;.0001</td>
<td>0.7540</td>
<td>32.30</td>
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<tr>
<td>Error</td>
<td>22</td>
<td>327.36</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>27</td>
<td>1331.02</td>
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<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>508.45</td>
<td>17.08</td>
<td>&lt;.0001</td>
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<td></td>
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<tr>
<td>O$_2$</td>
<td>1</td>
<td>132.98</td>
<td>8.94</td>
<td>0.0068</td>
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<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>291.84</td>
<td>9.81</td>
<td>0.0009</td>
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</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)

Table A.20.7B. Numerical difference and standard error of the estimate for $^{14}$C-antirrhinoside (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.13C.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2 $^{14}$C-antirrhinoside</td>
<td>15°C</td>
<td>3.87</td>
<td>2.49</td>
<td>1.56</td>
<td>0.1341</td>
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<td></td>
</tr>
<tr>
<td>21 vs. 2 $^{14}$C-antirrhinoside</td>
<td>25°C</td>
<td>5.58</td>
<td>2.72</td>
<td>2.04</td>
<td>0.0531</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21 vs. 2 $^{14}$C-antirrhinoside</td>
<td>35°C</td>
<td>11.61</td>
<td>2.49</td>
<td>4.66</td>
<td>0.0001</td>
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<td></td>
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Table A.20.7C. Multiple mean comparison for $^{14}$C-antirrhinoside (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.13C.

<table>
<thead>
<tr>
<th>O$_2$</th>
<th>Temp</th>
<th>Antirrhinoside LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>15</td>
<td>4.6805167</td>
<td>1.5748124</td>
<td>0.0070</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>25</td>
<td>20.1734250</td>
<td>1.9287434</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>35</td>
<td>17.9480500</td>
<td>1.9287434</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>15</td>
<td>8.5533000</td>
<td>1.9287434</td>
<td>0.0002</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>25</td>
<td>14.5967250</td>
<td>1.9287434</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>35</td>
<td>6.3363500</td>
<td>1.9287434</td>
<td>0.0034</td>
<td>6</td>
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</table>

<table>
<thead>
<tr>
<th>Least Squares Means for effect O$_2$*Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pr &gt;</td>
</tr>
<tr>
<td>Dependent Variable: Antirrhinoside</td>
</tr>
<tr>
<td>i/j</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
</tbody>
</table>

Table A.20.8A. Two-way analysis of variance for $^{14}$C-antirrhide (mmol C·m$^{-2}$) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.13F.

### Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>194.40</td>
<td>9.89</td>
<td>&lt;.0001</td>
<td>0.7121</td>
<td>29.45</td>
</tr>
<tr>
<td>Error</td>
<td>20</td>
<td>78.59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>25</td>
<td>273.00</td>
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<td></td>
<td></td>
<td></td>
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<td>Temp</td>
<td>2</td>
<td>152.49</td>
<td>19.40</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
<td>1.46</td>
<td>0.37</td>
<td>0.5485</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>29.12</td>
<td>3.70</td>
<td>0.0428</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)
Table A.20.8B. Numerical difference and standard error of the estimate for \(^{14}\text{C}\)-antirrhide (mmol C·m\(^{-2}\)) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O\(_2\) under 182 Pa CO\(_2\) in Figure 3.13F.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>(^{14}\text{C})-antirrhide</td>
<td>15°C</td>
<td>0.94</td>
<td>1.40</td>
<td>0.67</td>
<td>0.5090</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>(^{14}\text{C})-antirrhide</td>
<td>25°C</td>
<td>1.03</td>
<td>1.40</td>
<td>0.74</td>
<td>0.4693</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>(^{14}\text{C})-antirrhide</td>
<td>35°C</td>
<td>3.42</td>
<td>1.28</td>
<td>2.67</td>
<td>0.0147</td>
</tr>
</tbody>
</table>

Table A.20.8C. Multiple mean comparison for \(^{14}\text{C}\)-antirrhide (mmol C·m\(^{-2}\)) retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O\(_2\) under 182 Pa CO\(_2\) in Figure 3.13F.

| O\(_2\) Temp | Antirrhide LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|--------------|-------------------|----------------|------|---|----------------|
| a 15         | 2.51895000        | 0.99118085     | 0.99118085 | <.0001 | 1              |
| a 25         | 8.11547500        | 0.99118085     | <.0001 | 0.7473 | 4              |
| a 35         | 9.56745000        | 0.80929578     | <.0001 | 0.0147 | 6              |
| l 15         | 3.46162500        | 0.99118085     | <.0001 | 0.0175 | 1              |
| l 25         | 9.14950000        | 0.99118085     | <.0001 | 0.0006 | 2              |
| l 35         | 6.15065000        | 0.99118085     | <.0001 | 0.0449 | 6              |

Table A.20.9A. Two-way analysis of variance for \(^{14}\text{C}\)-antirrhinoside to antirrhide ratio retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O\(_2\) under 182 Pa CO\(_2\) in Figure 3.13I.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS(^1)</th>
<th>(F) Value</th>
<th>Pr&gt;F</th>
<th>(R^2)</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>8.10</td>
<td>027.73</td>
<td>13.62</td>
<td>0.863</td>
<td>14.81</td>
</tr>
<tr>
<td>Error</td>
<td>22</td>
<td>1.28</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>27</td>
<td>9.38</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>1.51</td>
<td>12.96</td>
<td>0.0002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O(_2)</td>
<td>1</td>
<td>0.21</td>
<td>3.63</td>
<td>0.0698</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O(_2)</td>
<td>2</td>
<td>7.00</td>
<td>59.95</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\text{Sum of squares for model parameters are those of type III (SAS)}\)

Table A.20.9B. Numerical difference and standard error of the estimate for \(^{14}\text{C}\)-antirrhinoside to antirrhide ratio retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O\(_2\) under 182 Pa CO\(_2\) in Figure 3.13I.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>(^{14}\text{C})-antirrhinoside:antirrhide</td>
<td>15°C</td>
<td>1.24</td>
<td>0.17</td>
<td>7.91</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>(^{14}\text{C})-antirrhinoside:antirrhide</td>
<td>25°C</td>
<td>0.88</td>
<td>0.17</td>
<td>5.16</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>(^{14}\text{C})-antirrhinoside:antirrhide</td>
<td>35°C</td>
<td>0.89</td>
<td>0.16</td>
<td>5.70</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Table A.20.9C. Multiple mean comparisons for \(^{14}\text{C}\)-antirrhinoside to antirrhide ratio retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O\(_2\) under 182 Pa CO\(_2\) in Figure 3.13I.
Table A.21.1A. Two-way analysis of variance for $^{14}$C-sucrose to antirrhinoside ratio retained in source leaves to compare GI $A. majus$ plants exposed to three different short term temperatures at 21 and 2 kPa $O_2$ under 40 Pa $CO_2$ in Figure 3.14A.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>70.23</td>
<td>35.29</td>
<td>&lt;.0001</td>
<td>0.8673</td>
<td>19.75</td>
</tr>
<tr>
<td>Error</td>
<td>27</td>
<td>10.75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>32</td>
<td>80.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>55.11</td>
<td>69.23</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$O_2$</td>
<td>1</td>
<td>4.88</td>
<td>12.25</td>
<td>0.0016</td>
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<td></td>
</tr>
<tr>
<td>Temp*$O_2$</td>
<td>2</td>
<td>3.66</td>
<td>4.59</td>
<td>0.0182</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.21.1B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose to antirrhinoside ratio retained in source leaves to compare GI $A. majus$ plants exposed to three different short term temperatures at 21 and 2 kPa $O_2$ under 40 Pa $CO_2$ in Figure 3.14A.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose:antirrhinoside</td>
<td>15°C</td>
<td>0.44</td>
<td>0.41</td>
<td>1.08</td>
<td>0.2899</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose:antirrhinoside</td>
<td>25°C</td>
<td>1.77</td>
<td>0.39</td>
<td>4.49</td>
<td>0.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose:antirrhinoside</td>
<td>35°C</td>
<td>0.20</td>
<td>0.39</td>
<td>0.51</td>
<td>0.6134</td>
</tr>
</tbody>
</table>

Table A.21.1C. Multiple mean comparison for $^{14}$C-sucrose to antirrhinoside ratio retained in source leaves to compare GI $A. majus$ plants exposed to three different short term temperatures at 21 and 2 kPa $O_2$ under 40 Pa $CO_2$ in Figure 3.14A.
Table A.21.2A. Two-way analysis of variance for $^{14}$C-sucrose to antirrhinoside ratio recovered in petiole tissues to compare GI A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.14D.

**Two-way ANOVA**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>Value</th>
<th>$F$</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>107.60</td>
<td>4.17</td>
<td>0.0061</td>
<td>0.4359</td>
<td>52.94</td>
</tr>
<tr>
<td>Error</td>
<td>27</td>
<td>139.24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>32</td>
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<td></td>
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<td></td>
<td></td>
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<td>Temp</td>
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<td>101.40</td>
<td>9.83</td>
<td>0.0006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$O_2$</td>
<td>1</td>
<td>0.10</td>
<td>0.02</td>
<td>0.8913</td>
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<td></td>
</tr>
<tr>
<td>Temp*$O_2$</td>
<td>2</td>
<td>0.14</td>
<td>0.01</td>
<td>0.9863</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.21.2B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose to antirrhinoside ratio recovered in petiole tissues to compare GI A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.14D.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose:antirrhinoside</td>
<td>15°C</td>
<td>0.01</td>
<td>1.49</td>
<td>0.01</td>
<td>0.9944</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose:antirrhinoside</td>
<td>25°C</td>
<td>0.33</td>
<td>1.42</td>
<td>0.23</td>
<td>0.8212</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose:antirrhinoside</td>
<td>35°C</td>
<td>0.03</td>
<td>1.49</td>
<td>0.02</td>
<td>0.9832</td>
</tr>
</tbody>
</table>

Table A.21.2C. Multiple mean comparison for $^{14}$C-sucrose to antirrhinoside ratio recovered in petiole tissues to compare GI A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 40 Pa CO$_2$ in Figure 3.14D.

**O2 Temp SucAntiP LSMEAN Standard Error Pr > |t| LSMEAN Number**

<table>
<thead>
<tr>
<th>O2</th>
<th>Temp</th>
<th>SucAntiP</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>15</td>
<td>3.70239116</td>
<td>0.92709347</td>
<td>0.0005</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>25</td>
<td>2.57858333</td>
<td>0.80288649</td>
<td>0.0034</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>35</td>
<td>6.93729326</td>
<td>0.92709347</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>15</td>
<td>3.71281324</td>
<td>1.13545297</td>
<td>0.0029</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>25</td>
<td>2.87410025</td>
<td>1.01558001</td>
<td>0.0087</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>35</td>
<td>6.96842721</td>
<td>1.13545297</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Least Squares Means for effect O2*Temp
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: SucAntiP

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>2</td>
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<tr>
<td>3</td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
Table A.21.3A. Two-way analysis of variance for $^{14}$C-sucrose to antirrhinoside (mmol C·m$^{-2}$) retained in source leaves to compare GI A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.14B.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>$F$</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>65.34</td>
<td>8.59</td>
<td>&lt;.0001</td>
<td>0.632</td>
<td>25.36</td>
</tr>
<tr>
<td>Corrected Total</td>
<td>25</td>
<td>38.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>41.89</td>
<td>13.77</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
<td>20.04</td>
<td>13.17</td>
<td></td>
<td>0.5881</td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>6.28</td>
<td>2.07</td>
<td>0.1487</td>
<td></td>
<td></td>
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</tbody>
</table>

$^*$Sum of squares for model parameters are those of type III (SAS)

Table A.21.3B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose to antirrhinoside ratio retained in source leaves to compare GI A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.14B.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>15°C</td>
<td>2.54</td>
<td>0.80</td>
<td>3.19</td>
<td>0.0038</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>25°C</td>
<td>0.41</td>
<td>0.75</td>
<td>0.55</td>
<td>0.5881</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>35°C</td>
<td>1.95</td>
<td>0.80</td>
<td>2.35</td>
<td>0.0216</td>
</tr>
</tbody>
</table>

Table A.21.3C. Multiple mean comparison for $^{14}$C-sucrose to antirrhinoside ratio retained in source leaves to compare GI A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.14B.

<table>
<thead>
<tr>
<th>O$_2$ Temp</th>
<th>SucAnti LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>15</td>
<td>5.37705292</td>
<td>&lt;.0001</td>
<td>1</td>
</tr>
<tr>
<td>a</td>
<td>25</td>
<td>4.40546651</td>
<td>&lt;.0001</td>
<td>2</td>
</tr>
<tr>
<td>a</td>
<td>35</td>
<td>2.80960200</td>
<td>&lt;.0001</td>
<td>3</td>
</tr>
<tr>
<td>l</td>
<td>15</td>
<td>7.91907603</td>
<td>&lt;.0001</td>
<td>4</td>
</tr>
<tr>
<td>l</td>
<td>25</td>
<td>4.81523948</td>
<td>&lt;.0001</td>
<td>5</td>
</tr>
<tr>
<td>l</td>
<td>35</td>
<td>4.76134592</td>
<td>&lt;.0001</td>
<td>6</td>
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</tbody>
</table>

Table A.21.3D. Least squares means for effect O$_2$*Temp

Pr > |t| for H0: LSMean(i)=LSMean(j)

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<tr>
<th>i/j</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.2052</td>
<td>0.0014</td>
<td>0.0038</td>
<td>0.4376</td>
<td>0.4466</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.0014</td>
<td>0.0426</td>
<td>0.0003</td>
<td>0.5881</td>
<td>0.6708</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.0038</td>
<td>0.0003</td>
<td>&lt;.0001</td>
<td>0.0093</td>
<td>0.0216</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.4376</td>
<td>0.5881</td>
<td>0.0093</td>
<td>0.0006</td>
<td>0.0013</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.4466</td>
<td>0.6708</td>
<td>0.0216</td>
<td>0.0013</td>
<td>0.9466</td>
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</table>
Table A.21.4A. Two-way analysis of variance for $^{14}$C-sucrose to antirrhinoside ratio recovered in petiole tissues to compare GI *A. majus* plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.14E.

### Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>93.16</td>
<td>6.88</td>
<td>0.0004</td>
<td>0.5792</td>
<td>33.29</td>
</tr>
<tr>
<td>Error</td>
<td>25</td>
<td>67.67</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>30</td>
<td>160.82</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>77.92</td>
<td>14.39</td>
<td>&lt;.0001</td>
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<td></td>
</tr>
<tr>
<td>O$_2$</td>
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<td>5.81</td>
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<td>0.1552</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>18.14</td>
<td>3.35</td>
<td>0.0514</td>
<td></td>
<td></td>
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</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.21.4B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose to antirrhinoside ratio recovered in petiole tissues to compare GI *A. majus* plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.14E.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>15°C</td>
<td>1.65</td>
<td>1.10</td>
<td>1.50</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>25°C</td>
<td>1.20</td>
<td>0.95</td>
<td>1.26</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>35°C</td>
<td>2.18</td>
<td>1.06</td>
<td>2.06</td>
</tr>
</tbody>
</table>

Table A.21.4C. Multiple mean comparison for $^{14}$C-sucrose to antirrhinoside ratio recovered in petiole tissues to compare GI *A. majus* plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.14E.

| O$_2$ Temp | SucAntiP LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|------------|-----------------|----------------|-------|---|-----------------|
| A 15       | 5.42527624      | 0.73579550     | <.0001 | 1 |
| A 25       | 3.63280269      | 0.67165345     | <.0001 | 2 |
| A 35       | 5.26009259      | 0.67165345     | <.0001 | 3 |
| L 15       | 7.08012223      | 0.82260412     | <.0001 | 4 |
| L 25       | 2.43930360      | 0.67165345     | 0.0013 | 5 |
| L 35       | 7.44548387      | 0.82260412     | <.0001 | 6 |

Table A.21.5A. Two-way analysis of variance for $^{14}$C-sucrose to antirrhinoside ratio retained in source leaves to compare GI *A. majus* plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.14C.

### Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>59.69</td>
<td>10.90</td>
<td>&lt;.0001</td>
<td>0.7032</td>
<td>23.91</td>
</tr>
<tr>
<td>Error</td>
<td>23</td>
<td>25.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>28</td>
<td>84.88</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>11.24</td>
<td>5.13</td>
<td>0.0144</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
<td>43.83</td>
<td>40.01</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>8.11</td>
<td>3.70</td>
<td>0.0403</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Sum of squares for model parameters are those of type III (SAS)

Table A.21.5B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose to antirrhinoside ratio retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.14C.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>15°C</td>
<td>3.81</td>
<td>0.67</td>
<td>5.64</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>25°C</td>
<td>2.49</td>
<td>0.70</td>
<td>3.54</td>
<td>0.0017</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>35°C</td>
<td>1.21</td>
<td>0.67</td>
<td>1.79</td>
<td>0.0872</td>
</tr>
</tbody>
</table>

Table A.21.5C. Multiple mean comparison for $^{14}$C-sucrose to antirrhinoside ratio retained in source leaves to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.14C.

| O2 Temp | SucAnti LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|---------|----------------|----------------|-------|---|----------------|
| a 15 | 3.56378171 | 0.42727523 | <.0001 | 1 |
| a 25 | 2.91786353 | 0.468056 | <.0001 | 2 |
| a 35 | 3.50604711 | 0.42727523 | <.0001 | 3 |
| l 15 | 7.37075385 | 0.52330315 | <.0001 | 4 |
| l 25 | 5.40407825 | 0.52330315 | <.0001 | 5 |
| l 35 | 4.71285648 | 0.52330315 | <.0001 | 6 |

Table A.21.6A. Two-way analysis of variance for $^{14}$C-sucrose to antirrhinoside ratio recovered in petiole tissues to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.14F.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS$^1$</th>
<th>Value</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>77.23</td>
<td>15.33</td>
<td>&lt;.0001</td>
<td>0.7692</td>
<td>26.82</td>
</tr>
<tr>
<td>Error</td>
<td>23</td>
<td>23.18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>28</td>
<td>100.41</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>32.23</td>
<td>15.99</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
<td>29.10</td>
<td>28.88</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>9.81</td>
<td>4.87</td>
<td>0.0173</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table A.21.6B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose to antirrhinoside ratio recovered in petiole tissues to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.14F.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>15°C</td>
<td>3.21</td>
<td>0.67</td>
<td>4.77</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>25°C</td>
<td>0.42</td>
<td>0.65</td>
<td>0.65</td>
<td>0.5233</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>35°C</td>
<td>2.48</td>
<td>0.65</td>
<td>3.83</td>
<td>0.0009</td>
</tr>
</tbody>
</table>

Table A.21.6C. Multiple mean comparison for $^{14}$C-sucrose to antirrhinoside ratio recovered in petiole tissues to compare GI plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.14F.
Table A.22.1A. Two-way analysis of variance for \(^{14}\)C-sucrose to antirrhinoside ratio retained in source leaves to compare GIV A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O\(_2\) under 40 Pa CO\(_2\) in Figure 3.15A.

### Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R(^2)</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>122.99</td>
<td>31.01</td>
<td>&lt;.0001</td>
<td>0.8708</td>
<td>24.62</td>
</tr>
<tr>
<td>Error</td>
<td>23</td>
<td>18.24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>28</td>
<td>141.23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>95.17</td>
<td>60.00</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O(_2)</td>
<td>1</td>
<td>26.77</td>
<td>33.75</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O(_2)</td>
<td>2</td>
<td>11.35</td>
<td>7.15</td>
<td>0.0038</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)Sum of squares for model parameters are those of type III (SAS)

Table A.22.1B. Numerical difference and standard error of the estimate for \(^{14}\)C-sucrose to antirrhinoside ratio retained in source leaves to compare GIV A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O\(_2\) under 40 Pa CO\(_2\) in Figure 3.15A.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>(^{14})C-sucrose: antirrhinoside</td>
<td>15°C</td>
<td>3.66</td>
<td>0.57</td>
<td>6.36</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>(^{14})C-sucrose: antirrhinoside</td>
<td>25°C</td>
<td>1.54</td>
<td>0.60</td>
<td>2.57</td>
<td>0.0170</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>(^{14})C-sucrose: antirrhinoside</td>
<td>35°C</td>
<td>0.66</td>
<td>0.57</td>
<td>1.16</td>
<td>0.2592</td>
</tr>
</tbody>
</table>

Table A.22.1C. Multiple mean comparison for \(^{14}\)C-sucrose to antirrhinoside ratio retained in source leaves to compare GIV A. majus plants exposed to three different short term temperatures at 21 and 2 kPa O\(_2\) under 40 Pa CO\(_2\) in Figure 3.15A.

<table>
<thead>
<tr>
<th>O(_2)</th>
<th>Temp</th>
<th>SucAnti</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>15</td>
<td>4.50047230</td>
<td>0.36357763</td>
<td>&lt;.0001</td>
<td>1</td>
</tr>
<tr>
<td>a</td>
<td>25</td>
<td>1.87553648</td>
<td>0.39827934</td>
<td>&lt;.0001</td>
<td>2</td>
</tr>
<tr>
<td>a</td>
<td>35</td>
<td>1.95842569</td>
<td>0.36357763</td>
<td>&lt;.0001</td>
<td>3</td>
</tr>
<tr>
<td>I</td>
<td>15</td>
<td>8.15915425</td>
<td>0.44528984</td>
<td>&lt;.0001</td>
<td>4</td>
</tr>
<tr>
<td>I</td>
<td>25</td>
<td>3.41253520</td>
<td>0.44528984</td>
<td>&lt;.0001</td>
<td>5</td>
</tr>
<tr>
<td>I</td>
<td>35</td>
<td>2.62353952</td>
<td>0.44528984</td>
<td>&lt;.0001</td>
<td>6</td>
</tr>
</tbody>
</table>
### Table A.22.2A. Two-way analysis of variance for $^{14}$C-sucrose to antirrhinoside ratio recovered in petiole tissues to compare GIV A. majus plants exposed to three different short term temperatures at 21 and 2 kPa $O_2$ under 40 Pa $CO_2$ in Figure 3.15D.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>136.61</td>
<td>11.71</td>
<td>&lt;.0001</td>
<td>0.7093</td>
<td>35.84</td>
</tr>
<tr>
<td>Error</td>
<td>29</td>
<td>55.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>34</td>
<td>192.59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>113.06</td>
<td>24.24</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$O_2$</td>
<td>1</td>
<td>28.54</td>
<td>12.24</td>
<td>0.0019</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*$O_2$</td>
<td>2</td>
<td>2.38</td>
<td>0.51</td>
<td>0.6065</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS).

### Table A.22.2B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose to antirrhinoside ratio recovered in petiole tissues to compare GIV A. majus plants exposed to three different short term temperatures at 21 and 2 kPa $O_2$ under 40 Pa $CO_2$ in Figure 3.15D.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 21</td>
<td>$^{14}$C-sucrose:antirrhinoside</td>
<td>15°C</td>
<td>2.47</td>
<td>0.98</td>
<td>2.50</td>
<td>0.0196</td>
</tr>
<tr>
<td>21 vs. 21</td>
<td>$^{14}$C-sucrose:antirrhinoside</td>
<td>25°C</td>
<td>1.20</td>
<td>0.92</td>
<td>1.30</td>
<td>0.2059</td>
</tr>
<tr>
<td>21 vs. 21</td>
<td>$^{14}$C-sucrose:antirrhinoside</td>
<td>35°C</td>
<td>2.26</td>
<td>1.02</td>
<td>2.21</td>
<td>0.0368</td>
</tr>
</tbody>
</table>

### Table A.22.2C. Multiple mean comparison for $^{14}$C-sucrose to antirrhinoside ratio recovered in petiole tissues to compare GIV A. majus plants exposed to three different short term temperatures at 21 and 2 kPa $O_2$ under 40 Pa $CO_2$ in Figure 3.15D.

<table>
<thead>
<tr>
<th>O2</th>
<th>Temp</th>
<th>SuccAnti</th>
<th>LSMAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>15</td>
<td>5.34590100</td>
<td>0.62348236</td>
<td>&lt;.0001</td>
<td>1.0001</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>25</td>
<td>1.36332934</td>
<td>0.62348236</td>
<td>0.0388</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>35</td>
<td>3.82879695</td>
<td>0.68299070</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>15</td>
<td>7.81155315</td>
<td>0.76360682</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>25</td>
<td>2.56573963</td>
<td>0.68299070</td>
<td>0.0010</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>35</td>
<td>6.09401642</td>
<td>0.76360682</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Least Squares Means for effect $O_2$*Temp

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0001</td>
<td>0.1139</td>
<td>0.0196</td>
<td>0.0061</td>
<td>0.4553</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.0001</td>
<td>0.0135</td>
<td>&lt;.0001</td>
<td>0.2059</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.1139</td>
<td>0.0135</td>
<td>0.0007</td>
<td>0.2034</td>
<td>0.0368</td>
<td></td>
</tr>
</tbody>
</table>

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Table A.22.3A. Two-way analysis of variance for $^{14}$C-sucrose to antirrhinoside (mmol C·m$^{-2}$) retained in source leaves to compare *GIV A. majus* plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.15B.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>130.80</td>
<td>23.46</td>
<td>&lt;.0001</td>
<td>0.8543</td>
<td>26.59</td>
</tr>
<tr>
<td>Error</td>
<td>20</td>
<td>22.30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>25</td>
<td>153.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>23.00</td>
<td>10.31</td>
<td>0.0008</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$O_2$</td>
<td>1</td>
<td>67.03</td>
<td>60.12</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*$O_2$</td>
<td>2</td>
<td>40.62</td>
<td>18.21</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^*$Sum of squares for model parameters are those of type III (SAS)

Table A.22.3B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose to antirrhinoside ratio retained in source leaves to compare *GIV A. majus* plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.15B.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>15°C</td>
<td>6.91</td>
<td>0.75</td>
<td>9.26</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>25°C</td>
<td>1.60</td>
<td>0.77</td>
<td>2.08</td>
<td>0.0506</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>35°C</td>
<td>1.34</td>
<td>0.68</td>
<td>1.97</td>
<td>0.0629</td>
</tr>
</tbody>
</table>

Table A.22.3C. Multiple mean comparison for $^{14}$C-sucrose to antirrhinoside ratio retained in source leaves to compare *GIV A. majus* plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.15B.

| O2 Temp | SucAnti LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|---------|----------------|----------------|------|---|----------------|
| a 15    | 1.83299456     | 0.52797565     | 0.0024 | 1 |
| a 25    | 3.42835164     | 0.47223578     | <.0001 | 2 |
| a 35    | 2.33137419     | 0.43109031     | <.0001 | 3 |
| l 15    | 8.74535986     | 0.52797565     | <.0001 | 4 |
| l 25    | 5.03249517     | 0.60965376     | <.0001 | 5 |
| l 35    | 3.67380643     | 0.52797565     | <.0001 | 6 |
Table A.22.4A. Two-way analysis of variance for $^{14}$C-sucrose to antirrhinoside ratio recovered in petiole tissues to compare *GIV A. majus* plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.15E.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>Value</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>58.18</td>
<td>12.93</td>
<td>&lt;.0001</td>
<td>0.7462</td>
<td>22.81</td>
</tr>
<tr>
<td>Error</td>
<td>22</td>
<td>19.79</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>27</td>
<td>77.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>9.34</td>
<td>5.19</td>
<td>0.0142</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
<td>13.36</td>
<td>14.85</td>
<td>0.0009</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>27.64</td>
<td>15.26</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)*

Table A.22.4B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose to antirrhinoside ratio recovered in petiole tissues to compare *GIV A. majus* plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.15E.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>15°C</td>
<td>1.00</td>
<td>0.67</td>
<td>1.49</td>
<td>0.1500</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>25°C</td>
<td>4.00</td>
<td>0.61</td>
<td>6.53</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>35°C</td>
<td>1.22</td>
<td>0.61</td>
<td>2.00</td>
<td>0.0580</td>
</tr>
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</table>

Table A.22.4C. Multiple mean comparison for $^{14}$C-sucrose to antirrhinoside ratio recovered in petiole tissues to compare *GIV A. majus* plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 91 Pa CO$_2$ in Figure 3.15E.

<table>
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<th>O$_2$</th>
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<th>Standard Error</th>
<th>Pr &gt;</th>
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<tbody>
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<td>A</td>
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<td>4.81128419</td>
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<td>1</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>25</td>
<td></td>
<td>1.66092968</td>
<td>0.38722269</td>
<td>0.0003</td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>A</td>
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<td></td>
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<td>0.38722269</td>
<td>&lt;.0001</td>
<td></td>
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<tr>
<td>L</td>
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<td>3.81081234</td>
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<td>4</td>
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<tr>
<td>L</td>
<td>25</td>
<td></td>
<td>5.65812947</td>
<td>0.47424900</td>
<td>&lt;.0001</td>
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<td>5</td>
<td></td>
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<tr>
<td>L</td>
<td>35</td>
<td></td>
<td>5.66616489</td>
<td>0.47424900</td>
<td>&lt;.0001</td>
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Least Squares Means for effect O$_2$*Temp

<table>
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<th>6</th>
</tr>
</thead>
<tbody>
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<td>0.1500</td>
<td>0.2199</td>
<td>0.2157</td>
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</tr>
<tr>
<td>2</td>
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<td>&lt;.0001</td>
<td>0.0020</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.5524</td>
<td>&lt;.0001</td>
<td>0.3139</td>
<td>0.0596</td>
<td>0.0580</td>
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</tr>
<tr>
<td>4</td>
<td>0.1500</td>
<td>0.0020</td>
<td>0.3139</td>
<td>0.0116</td>
<td>0.0113</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.2199</td>
<td>&lt;.0001</td>
<td>0.0596</td>
<td>0.0116</td>
<td>0.9905</td>
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<td>0.2157</td>
<td>&lt;.0001</td>
<td>0.0580</td>
<td>0.0113</td>
<td>0.9905</td>
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</tr>
</tbody>
</table>
Two-way analysis of variance for $^{14}$C-sucrose to antirrhinoside ratio retained in source leaves to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.15C.

### Table A.22.5A

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>68.18</td>
<td>16.26</td>
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<td>0.7871</td>
<td>20.78</td>
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<tr>
<td>Error</td>
<td>22</td>
<td>18.44</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>27</td>
<td>86.62</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp</td>
<td>2</td>
<td>7.28</td>
<td>4.34</td>
<td>0.0257</td>
<td></td>
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</tr>
<tr>
<td>O$_2$</td>
<td>1</td>
<td>44.02</td>
<td>52.51</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>15.79</td>
<td>9.42</td>
<td>0.0011</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)*

### Table A.22.5B

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside 15°C</td>
<td>3.95</td>
<td>0.59</td>
<td>6.68</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside 25°C</td>
<td>0.35</td>
<td>0.55</td>
<td>0.55</td>
<td>0.5903</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside 35°C</td>
<td>3.36</td>
<td>0.59</td>
<td>5.68</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

### Table A.22.5C

| O$_2$ | Temp | SucAnti LSMEAN | Standard Error | Pr>|t| | LSMEAN Number |
|-------|------|----------------|----------------|-------|-----------------|
|      a | 15   | 2.99646843     | 0.37381658     | <.0001 | 1               |
|      a | 25   | 3.67930962     | 0.45782994     | <.0001 | 2               |
|      a | 35   | 3.33195125     | 0.37381658     | <.0001 | 3               |
|      l | 15   | 6.94397816     | 0.45782994     | <.0001 | 4               |
|      l | 25   | 4.03311614     | 0.45782994     | <.0001 | 5               |
|      l | 35   | 6.69204417     | 0.45782994     | <.0001 | 6               |

**Least Squares Means for effect O$_2$*Temp**

<table>
<thead>
<tr>
<th>l/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.2604</td>
<td>0.5322</td>
<td>&lt;.0001</td>
<td>0.0934</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.2604</td>
<td>0.5627</td>
<td>&lt;.0001</td>
<td>0.5903</td>
<td>0.0001</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.5322</td>
<td>0.5627</td>
<td>&lt;.0001</td>
<td>0.2482</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0002</td>
<td>0.7009</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.0934</td>
<td>0.5903</td>
<td>0.2482</td>
<td>0.0002</td>
<td>0.0005</td>
<td></td>
</tr>
<tr>
<td>6</td>
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<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.7009</td>
<td>0.0005</td>
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</tr>
</tbody>
</table>

Two-way analysis of variance for $^{14}$C-sucrose to antirrhinoside ratio recovered in petiole tissues to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.15F.

### Table A.22.6A

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>14.87</td>
<td>&lt;.0001</td>
<td>0.7560</td>
<td>29.08</td>
</tr>
<tr>
<td>Error</td>
<td>24</td>
<td>23.96</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>29</td>
<td>98.20</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Temp</td>
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<td>21.14</td>
<td>9.56</td>
<td>0.0005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_2$</td>
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<td>44.02</td>
<td>52.51</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp*O$_2$</td>
<td>2</td>
<td>15.79</td>
<td>9.42</td>
<td>0.0011</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table A.22.6B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose to antirrhinoside ratio recovered in petiole tissues to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.15F.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>15°C</td>
<td>4.29</td>
<td>0.64</td>
<td>6.66</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>25°C</td>
<td>2.12</td>
<td>0.64</td>
<td>3.29</td>
<td>0.0031</td>
</tr>
<tr>
<td>21 vs. 2</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>35°C</td>
<td>0.23</td>
<td>0.64</td>
<td>0.35</td>
<td>0.7258</td>
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</table>

Table A.22.6C. Multiple mean comparison for $^{14}$C-sucrose to antirrhinoside ratio recovered in petiole tissues to compare GIV plants exposed to three different short term temperatures at 21 and 2 kPa O$_2$ under 182 Pa CO$_2$ in Figure 3.15F.

<table>
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<tr>
<th>O2</th>
<th>Temp</th>
<th>SucAntiP</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
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<td>2.50007389</td>
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<td>&lt;.0001</td>
<td>1</td>
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<td></td>
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<tr>
<td>A</td>
<td>25</td>
<td>1.49280969</td>
<td>0.40793636</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>35</td>
<td>3.84202232</td>
<td>0.40793636</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>15</td>
<td>6.79319790</td>
<td>0.49961797</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
<td></td>
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<tr>
<td>L</td>
<td>25</td>
<td>3.61316252</td>
<td>0.49961797</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>35</td>
<td>3.61316252</td>
<td>0.49961797</td>
<td>&lt;.0001</td>
<td>6</td>
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Table A.23.1A. Two-way analysis of variance for whole plant mass (g) of two greenhouse cultivars grown at 40 and 91 Pa CO$_2$ in Table 4.1.

<table>
<thead>
<tr>
<th>Source</th>
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<th>Value</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
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<tbody>
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<td>2.87</td>
<td>7.34</td>
<td>0.0004</td>
<td>0.3386</td>
<td>13.99</td>
</tr>
<tr>
<td>Error</td>
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<td>5.69</td>
<td></td>
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</tr>
<tr>
<td>Corrected Total</td>
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</tr>
<tr>
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<td>0.7145</td>
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$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.23.1B. Numerical difference and standard error of the estimate for whole plant mass (g) to compare greenhouse cultivars grown at 40 and 91 Pa CO$_2$ in Table 4.1.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gl vs. GIV</td>
<td>Mass</td>
<td>40 Pa CO$_2$</td>
<td>0.14</td>
<td>0.15</td>
<td>0.92</td>
<td>0.3640</td>
</tr>
<tr>
<td>Gl vs. GIV</td>
<td>Mass</td>
<td>91 Pa CO$_2$</td>
<td>0.22</td>
<td>0.15</td>
<td>1.46</td>
<td>0.1502</td>
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</table>

$^1$Sum of squares for model parameters are those of type III (SAS)
Table A.23.1C. Numerical difference and standard error of the estimate for whole plant mass (g) of two greenhouse cultivars to compare growth at 40 and 91 Pa CO\textsubscript{2} in Table 4.1.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 vs. 91 Pa CO\textsubscript{2}</td>
<td>Mass</td>
<td>GI</td>
<td>0.49</td>
<td>0.15</td>
<td>3.29</td>
<td>0.0020</td>
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<tr>
<td>40 vs. 91 Pa CO\textsubscript{2}</td>
<td>Mass</td>
<td>GIV</td>
<td>0.42</td>
<td>0.15</td>
<td>2.83</td>
<td>0.0070</td>
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</tbody>
</table>

Table A.23.2A. Two-way analysis of variance for whole plant area (m\textsuperscript{2}) of two greenhouse cultivars grown at 40 and 91 Pa CO\textsubscript{2} in Table 4.1.

Two-way ANOVA

<table>
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<tr>
<th>Source</th>
<th>DF</th>
<th>SS\textsuperscript{1}</th>
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<th>Pr&gt;F</th>
<th>R\textsuperscript{2}</th>
<th>CV</th>
</tr>
</thead>
<tbody>
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<td>Model</td>
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<td>0.0004</td>
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<tr>
<td>Error</td>
<td>43</td>
<td>0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>46</td>
<td>0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
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<td>0.0003</td>
<td>14.62</td>
<td>0.0004</td>
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<td></td>
</tr>
<tr>
<td>CO\textsubscript{2}</td>
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<td>0.000005</td>
<td>2.16</td>
<td>0.1492</td>
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<td></td>
</tr>
<tr>
<td>CV*CO\textsubscript{2}</td>
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<td>0.000001</td>
<td>0.05</td>
<td>0.8209</td>
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</table>

\textsuperscript{1}Sum of squares for model parameters are those of type III (SAS)

Table A.23.2B. Numerical difference and standard error of the estimate for whole plant area (m\textsuperscript{2}) to compare greenhouse cultivars grown at 40 and 91 Pa CO\textsubscript{2} in Table 4.1.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>Area</td>
<td>40 Pa CO\textsubscript{2}</td>
<td>0.005</td>
<td>0.002</td>
<td>2.83</td>
<td>0.0070</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Area</td>
<td>91 Pa CO\textsubscript{2}</td>
<td>0.005</td>
<td>0.002</td>
<td>2.57</td>
<td>0.0137</td>
</tr>
</tbody>
</table>

Table A.23.2C. Numerical difference and standard error of the estimate for whole plant area (m\textsuperscript{2}) to compare growth at 40 and 91 Pa CO\textsubscript{2} in Table 4.1.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 vs. 91 Pa CO\textsubscript{2}</td>
<td>Area</td>
<td>GI</td>
<td>0.002</td>
<td>0.002</td>
<td>0.87</td>
<td>0.3903</td>
</tr>
<tr>
<td>40 vs. 91 Pa CO\textsubscript{2}</td>
<td>Area</td>
<td>GIV</td>
<td>0.002</td>
<td>0.002</td>
<td>1.21</td>
<td>0.2317</td>
</tr>
</tbody>
</table>

Table A.24.1A. Two-way analysis of variance for whole plant photosynthesis (µmol C·m\textsuperscript{-2}·s\textsuperscript{-1}) of two greenhouse cultivars grown at 40 and 91 Pa CO\textsubscript{2} in Table 4.2.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS\textsuperscript{1}</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R\textsuperscript{2}</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>831.87</td>
<td>115.15</td>
<td>&lt;.0001</td>
<td>0.9154</td>
<td>6.07</td>
</tr>
<tr>
<td>Error</td>
<td>43</td>
<td>76.85</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>46</td>
<td>908.72</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>87.47</td>
<td>48.94</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO\textsubscript{2}</td>
<td>1</td>
<td>751.34</td>
<td>420.38</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*CO\textsubscript{2}</td>
<td>1</td>
<td>3.08</td>
<td>1.72</td>
<td>0.1961</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{1}Sum of squares for model parameters are those of type III (SAS)

Table A.24.1B. Numerical difference and standard error of the estimate for whole plant photosynthesis (µmol C·m\textsuperscript{-2}·s\textsuperscript{-1}) to compare greenhouse A. majus cultivars grown at 40 and 91 Pa CO\textsubscript{2} in Table 4.2.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>Photosynthesis</td>
<td>40 Pa CO\textsubscript{2}</td>
<td>2.22</td>
<td>0.56</td>
<td>3.97</td>
<td>0.003</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Photosynthesis</td>
<td>91 Pa CO\textsubscript{2}</td>
<td>3.24</td>
<td>0.55</td>
<td>5.94</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Table A.24.1C. Numerical difference and standard error of the estimate for whole plant photosynthesis (µmol C·m\textsuperscript{-2}·s\textsuperscript{-1}) of two greenhouse cultivars to compare growth at 40 and 91 Pa CO\textsubscript{2} in Table 4.2.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 vs. 91 Pa CO\textsubscript{2}</td>
<td>Photosynthesis</td>
<td>GI</td>
<td>7.48</td>
<td>0.56</td>
<td>13.40</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>40 vs. 91 Pa CO\textsubscript{2}</td>
<td>Photosynthesis</td>
<td>GIV</td>
<td>8.50</td>
<td>0.55</td>
<td>15.58</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>
Table A.24.2A. Two-way analysis of variance for whole plant dark respiration (µmol C·m⁻²·s⁻¹) of two greenhouse cultivars grown at 40 and 91 Pa CO₂ in Table 4.2.

### Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS¹</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>3</td>
<td>0.39</td>
<td>0.57</td>
<td>0.6401</td>
<td>0.0398</td>
<td>18.75</td>
</tr>
<tr>
<td>Error</td>
<td>40</td>
<td>9.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>43</td>
<td>9.49</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>0.23</td>
<td>1.00</td>
<td>0.3234</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>1</td>
<td>0.12</td>
<td>0.51</td>
<td>0.4781</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*CO₂</td>
<td>1</td>
<td>0.01</td>
<td>0.01</td>
<td>0.8123</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹Sum of squares for model parameters are those of type III (SAS)

Table A.24.2B. Numerical difference and standard error of the estimate for whole plant dark respiration (µmol C·m⁻²·s⁻¹) to compare greenhouse cultivars grown at 40 and 91 Pa CO₂ in Table 4.2.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>Dark respiration</td>
<td>40 Pa CO₂</td>
<td>0.03</td>
<td>0.11</td>
<td>0.20</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Dark respiration</td>
<td>91 Pa CO₂</td>
<td>0.04</td>
<td>0.18</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Table A.24.2C. Numerical difference and standard error of the estimate for whole plant dark respiration (µmol C·m⁻²·s⁻¹) of two greenhouse cultivars to compare growth at 40 and 91 Pa CO₂ in Table 4.2.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 vs. 91 Pa CO₂</td>
<td>Dark respiration</td>
<td>GI</td>
<td>0.14</td>
<td>0.20</td>
<td>0.69</td>
</tr>
<tr>
<td>40 vs. 91 Pa CO₂</td>
<td>Dark respiration</td>
<td>GIV</td>
<td>0.07</td>
<td>0.21</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Table A.24.3A. Two-way analysis of variance for whole plant transpiration (mmol H₂O·m⁻²·s⁻¹) of two greenhouse cultivars grown at 40 and 91 Pa CO₂ in Table 4.2.

### Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS¹</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>3</td>
<td>0.44</td>
<td>3.37</td>
<td>0.0289</td>
<td>0.2192</td>
<td>12.78</td>
</tr>
<tr>
<td>Error</td>
<td>36</td>
<td>1.57</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>39</td>
<td>2.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>0.08</td>
<td>1.74</td>
<td>0.1958</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>1</td>
<td>0.23</td>
<td>5.37</td>
<td>0.0263</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*CO₂</td>
<td>1</td>
<td>0.13</td>
<td>3.00</td>
<td>0.0819</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹Sum of squares for model parameters are those of type III (SAS)

Table A.24.3B. Numerical difference and standard error of the estimate for whole plant transpiration (mmol H₂O·m⁻²·s⁻¹) to compare two greenhouse cultivars grown at 40 and 91 Pa CO₂ in Table 4.2.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>Transpiration</td>
<td>40 Pa CO₂</td>
<td>0.03</td>
<td>0.09</td>
<td>0.29</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Transpiration</td>
<td>91 Pa CO₂</td>
<td>0.20</td>
<td>0.09</td>
<td>2.16</td>
</tr>
</tbody>
</table>

Table A.24.3C. Numerical difference and standard error of the estimate for whole plant transpiration/Light (mmol H₂O·m⁻²·s⁻¹) of two greenhouse cultivars to compare growth at 40 and 91 Pa CO₂ in Table 4.2.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 vs. 91 Pa CO₂</td>
<td>Transpiration</td>
<td>GI</td>
<td>0.04</td>
<td>0.09</td>
<td>0.41</td>
</tr>
<tr>
<td>40 vs. 91 Pa CO₂</td>
<td>Transpiration</td>
<td>GIV</td>
<td>0.27</td>
<td>0.09</td>
<td>2.86</td>
</tr>
</tbody>
</table>

Table A.24.4A. Two-way analysis of variance for whole plant WUE (µmol C/ mmol H₂O) of two greenhouse cultivars grown at 40 and 91 Pa CO₂ in Table 4.2.

### Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS¹</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>3</td>
<td>831.87</td>
<td>155.15</td>
<td>&lt;.0001</td>
<td>0.9154</td>
<td>6.07</td>
</tr>
<tr>
<td>Error</td>
<td>43</td>
<td>76.85</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>46</td>
<td>908.72</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>87.47</td>
<td>48.94</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>1</td>
<td>748.84</td>
<td>418.98</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*CO₂</td>
<td>1</td>
<td>3.08</td>
<td>1.72</td>
<td>0.1976</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹Sum of squares for model parameters are those of type III (SAS)
Table A.24.4B. Numerical difference and standard error of the estimate for whole plant WUE (μmol C/mmol H₂O) to compare greenhouse cultivars grown at 40 and 91 Pa CO₂ in Table 4.2.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>WUE</td>
<td>40 Pa CO₂</td>
<td>1.25</td>
<td>0.69</td>
<td>1.82</td>
<td>0.0768</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>WUE</td>
<td>91 Pa CO₂</td>
<td>4.09</td>
<td>0.72</td>
<td>5.66</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Table A.24.4C. Numerical difference and standard error of the estimate for whole plant WUE (μmol C/mmol H₂O) of two greenhouse cultivars to compare growth at 40 and 91 Pa CO₂ in Table 4.2.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 vs. 91 Pa CO₂</td>
<td>WUE</td>
<td>GI</td>
<td>4.15</td>
<td>0.69</td>
<td>5.88</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>40 vs. 91 Pa CO₂</td>
<td>WUE</td>
<td>GIV</td>
<td>6.99</td>
<td>0.72</td>
<td>9.91</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Table A.24.5A. Two-way analysis of variance for whole plant C-gain (g C·m⁻²) of two greenhouse cultivars grown at 40 and 91 Pa CO₂ in Table 4.2.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>3</td>
<td>205.72</td>
<td>140.23</td>
<td>&lt;.0001</td>
<td>0.9073</td>
<td>6.19</td>
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<tr>
<td>Error</td>
<td>43</td>
<td>21.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>46</td>
<td>226.75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
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<td>20.23</td>
<td>41.37</td>
<td>&lt;.0001</td>
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<td></td>
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<tr>
<td>CO₂</td>
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<td>186.24</td>
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<td></td>
</tr>
<tr>
<td>CV²CO₂</td>
<td>1</td>
<td>0.95</td>
<td>1.95</td>
<td>0.1697</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹Sum of squares for model parameters are those of type III (SAS)

Table A.24.5B. Numerical difference and standard error of the estimate for whole plant C-gain (g C·m⁻²) to compare greenhouse cultivars grown at 40 and 91 Pa CO₂ in Table 4.2.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>C-gain</td>
<td>40 Pa CO₂</td>
<td>1.03</td>
<td>0.29</td>
<td>3.52</td>
<td>0.0010</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>C-gain</td>
<td>91 Pa CO₂</td>
<td>1.60</td>
<td>0.28</td>
<td>5.60</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Table A.24.5C. Numerical difference and standard error of the estimate for whole plant C-loss (g C·m⁻²) of two greenhouse cultivars to compare growth at 40 and 91 Pa CO₂ in Table 4.2.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 vs. 91 Pa CO₂</td>
<td>C-loss</td>
<td>GI</td>
<td>3.70</td>
<td>0.29</td>
<td>12.67</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>40 vs. 91 Pa CO₂</td>
<td>C-loss</td>
<td>GIV</td>
<td>4.27</td>
<td>0.28</td>
<td>14.95</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Table A.24.6A. Two-way analysis of variance for whole plant C-loss (g C·m⁻²) of two greenhouse cultivars grown at 40 and 91 Pa CO₂ in Table 4.2.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>3</td>
<td>1.72</td>
<td>5.51</td>
<td>0.0027</td>
<td>0.2778</td>
<td>23.74</td>
</tr>
<tr>
<td>Error</td>
<td>43</td>
<td>4.48</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>46</td>
<td>6.21</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
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</tr>
<tr>
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<td>1.38</td>
<td>13.27</td>
<td>0.0007</td>
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<td></td>
</tr>
<tr>
<td>CV²CO₂</td>
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<td>0.006</td>
<td>0.06</td>
<td>0.8136</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹Sum of squares for model parameters are those of type III (SAS)

Table A.24.6B. Numerical difference and standard error of the estimate for whole plant C-loss (g C·m⁻²) to compare greenhouse cultivars grown at 40 and 91 Pa CO₂ in Table 4.2.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>C-loss</td>
<td>40 Pa CO₂</td>
<td>0.18</td>
<td>0.13</td>
<td>1.36</td>
<td>0.1813</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>C-loss</td>
<td>91 Pa CO₂</td>
<td>0.14</td>
<td>0.13</td>
<td>1.05</td>
<td>0.2995</td>
</tr>
</tbody>
</table>

Table A.24.6C. Numerical difference and standard error of the estimate for whole plant C-loss (g C·m⁻²) of two greenhouse cultivars to compare growth at 40 and 91 Pa CO₂ in Table 4.2.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 vs. 91 Pa CO₂</td>
<td>C-loss</td>
<td>GI</td>
<td>0.32</td>
<td>0.13</td>
<td>2.38</td>
<td>0.0217</td>
</tr>
<tr>
<td>40 vs. 91 Pa CO₂</td>
<td>C-loss</td>
<td>GIV</td>
<td>0.37</td>
<td>0.13</td>
<td>2.77</td>
<td>0.0081</td>
</tr>
</tbody>
</table>
Table A.24.7A. Two-way analysis of variance for whole plant daily C-gain (g C m⁻² day⁻¹) of two greenhouse cultivars grown at 40 and 91 Pa CO₂ in Table 4.2.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>3</td>
<td>234.95</td>
<td>144.30</td>
<td>&lt;.0001</td>
<td>0.9086</td>
<td>7.43</td>
</tr>
<tr>
<td>Error</td>
<td>43</td>
<td>23.34</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>46</td>
<td>258.29</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>15.58</td>
<td>28.71</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>1</td>
<td>219.72</td>
<td>404.83</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*CO₂</td>
<td>1</td>
<td>1.11</td>
<td>2.04</td>
<td>0.1600</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.24.7B. Numerical difference and standard error of the estimate for whole plant daily C-gain (g C m⁻² day⁻¹) to compare greenhouse grown at 40 and 91 Pa CO₂ in Table 4.2.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>daily C-gain</td>
<td>40 Pa CO₂</td>
<td>0.84</td>
<td>0.31</td>
<td>2.75</td>
<td>0.0087</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>daily C-gain</td>
<td>91 Pa CO₂</td>
<td>1.46</td>
<td>0.30</td>
<td>4.85</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Table A.24.7C. Numerical difference and standard error of the estimate for whole plant daily C-gain (g C m⁻² day⁻¹) of two greenhouse cultivars to compare growth at 40 and 91 Pa CO₂ in Table 4.2.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 vs. 91 Pa CO₂</td>
<td>daily C-gain</td>
<td>GI</td>
<td>4.02</td>
<td>0.31</td>
<td>13.07</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>40 vs. 91 Pa CO₂</td>
<td>daily C-gain</td>
<td>GIV</td>
<td>4.63</td>
<td>0.30</td>
<td>15.41</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Table A.25.1A. Two-way analysis of variance for whole plant transpiration (mmol H₂O·m⁻²·s⁻¹) of two greenhouse cultivars transient switch (TS) studies in Figure 4.2.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>1.31</td>
<td>2.62</td>
<td>0.0181</td>
<td>0.2030</td>
<td>16.91</td>
</tr>
<tr>
<td>Error</td>
<td>72</td>
<td>5.13</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>79</td>
<td>6.44</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>0.00002</td>
<td>0.00</td>
<td>0.9882</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TS</td>
<td>3</td>
<td>0.22</td>
<td>1.05</td>
<td>0.3747</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*TS</td>
<td>3</td>
<td>1.08</td>
<td>5.06</td>
<td>0.0031</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.25.1B. Numerical difference and standard error of the estimate for whole plant transpiration (mmol H₂O·m⁻²·s⁻¹) to compare greenhouse cultivar transient switch (TS) studies in Figure 4.2.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>Transpiration</td>
<td>Control 1</td>
<td>0.01</td>
<td>0.12</td>
<td>0.10</td>
<td>0.9172</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Transpiration</td>
<td>TS1</td>
<td>0.35</td>
<td>0.12</td>
<td>2.93</td>
<td>0.0046</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Transpiration</td>
<td>Control 2</td>
<td>0.30</td>
<td>0.12</td>
<td>2.52</td>
<td>0.0138</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Transpiration</td>
<td>TS2</td>
<td>0.06</td>
<td>0.12</td>
<td>0.48</td>
<td>0.6542</td>
</tr>
</tbody>
</table>

Table A.25.1C. Multiple mean comparison for whole plant transpiration (mmol H₂O·m⁻²·s⁻¹) to compare greenhouse cultivar transient switch (TS) studies in Figure 4.2.

<table>
<thead>
<tr>
<th>CV</th>
<th>Feed</th>
<th>Trans LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td>40=&gt;40</td>
<td>1.60288000</td>
<td>0.08440730</td>
<td>&lt;.0001</td>
<td>1</td>
</tr>
<tr>
<td>GI</td>
<td>40=&gt;91</td>
<td>1.32222800</td>
<td>0.08440730</td>
<td>&lt;.0001</td>
<td>2</td>
</tr>
<tr>
<td>GI</td>
<td>91=&gt;91</td>
<td>1.72008500</td>
<td>0.08440730</td>
<td>&lt;.0001</td>
<td>3</td>
</tr>
<tr>
<td>GI</td>
<td>91=&gt;40</td>
<td>1.66684200</td>
<td>0.08440730</td>
<td>&lt;.0001</td>
<td>4</td>
</tr>
<tr>
<td>GIV</td>
<td>40=&gt;40</td>
<td>1.61532800</td>
<td>0.08440730</td>
<td>&lt;.0001</td>
<td>5</td>
</tr>
<tr>
<td>GIV</td>
<td>40=&gt;91</td>
<td>1.67166600</td>
<td>0.08440730</td>
<td>&lt;.0001</td>
<td>6</td>
</tr>
<tr>
<td>GIV</td>
<td>91=&gt;91</td>
<td>1.41878300</td>
<td>0.08440730</td>
<td>&lt;.0001</td>
<td>7</td>
</tr>
<tr>
<td>GIV</td>
<td>91=&gt;40</td>
<td>1.60980300</td>
<td>0.08440730</td>
<td>&lt;.0001</td>
<td>8</td>
</tr>
</tbody>
</table>
Table A.25.2A. Two-way analysis of variance for whole plant photosynthesis (µmol C·m\(^{-2}\)·s\(^{-1}\)) of two greenhouse cultivars grown at 40 and 91 Pa CO\(_2\) and transient switch (TS) studies in Figure 4.2.

### Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS (^1)</th>
<th>Value</th>
<th>Pr&gt;F</th>
<th>R(^2)</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>1682.10</td>
<td>144.57</td>
<td>&lt;.0001</td>
<td>0.9379</td>
<td>5.83</td>
</tr>
<tr>
<td>Error</td>
<td>67</td>
<td>111.36</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>74</td>
<td>1793.46</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>53.10</td>
<td>31.97</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TS</td>
<td>3</td>
<td>1579.65</td>
<td>316.79</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*TS</td>
<td>3</td>
<td>28.61</td>
<td>5.74</td>
<td>0.0015</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)Sum of squares for model parameters are those of type III (SAS)

Table A.25.2B. Numerical difference and standard error of the estimate for whole plant photosynthesis (µmol C·m\(^{-2}\)·s\(^{-1}\)) to compare greenhouse cultivar transient switch (TS) studies in Figure 4.2.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>Photosynthesis</td>
<td>Control 1</td>
<td>2.36</td>
<td>0.58</td>
<td>4.09</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Photosynthesis</td>
<td>TS1</td>
<td>0.27</td>
<td>0.59</td>
<td>0.45</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Photosynthesis</td>
<td>Control 2</td>
<td>3.37</td>
<td>0.59</td>
<td>5.70</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Photosynthesis</td>
<td>TS2</td>
<td>0.78</td>
<td>0.63</td>
<td>1.23</td>
</tr>
</tbody>
</table>

Table A.25.2C. Multiple mean comparison for whole plant photosynthesis (µmol C·m\(^{-2}\)·s\(^{-1}\)) to compare greenhouse cultivar transient switch (TS) studies in Figure 4.2.

| CV Feed | NCER LSMEAN | Standard Error | Pr > |I| | LSMEAN Number |
|---------|-------------|----------------|-------|---|----------------|
| GI 40=>40 | 16.7715214  | 0.4076951   | <.0001| 1 |
| GI 40=>91  | 27.3661333  | 0.4297483 | <.0001| 2 |
| GI 91=>91  | 23.8986018  | 0.4297483 | <.0001| 3 |
| GI 91=>40  | 16.4689143  | 0.4872888 | <.0001| 4 |
| GIV 40=>40 | 19.1284007  | 0.4076951 | <.0001| 5 |
| GIV 40=>91 | 27.6341000  | 0.4076951 | <.0001| 6 |
| GIV 91=>91 | 27.2722711  | 0.4076951 | <.0001| 7 |
| GIV 91=>40 | 17.2480700  | 0.4076951 | <.0001| 8 |
Table A.25.3A. Two-way analysis of variance for whole plant WUE (μmol C/ mmol H₂O) of two greenhouse cultivars grown at 40 and 91 Pa CO₂ and transient switch (TS) studies in Figure 4.2.

**Two-way ANOVA**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS¹</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>1123.22</td>
<td>28.58</td>
<td>&lt;.0001</td>
<td>0.7519</td>
<td>16.35</td>
</tr>
<tr>
<td>Error</td>
<td>66</td>
<td>370.55</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>73</td>
<td>1493.77</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>19.31</td>
<td>3.44</td>
<td>0.0681</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TS</td>
<td>3</td>
<td>871.51</td>
<td>51.74</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*TS</td>
<td>3</td>
<td>224.38</td>
<td>13.32</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹Sum of squares for model parameters are those of type III (SAS)

Table A.25.3B. Numerical difference and standard error of the estimate for whole plant WUE (μmol C/ mmol H₂O) to compare greenhouse cultivar transient switch (TS) studies in Figure 4.2.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>WUE</td>
<td>Control 1</td>
<td>1.29</td>
<td>1.06</td>
<td>1.22</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>WUE</td>
<td>TS1</td>
<td>3.63</td>
<td>1.09</td>
<td>3.34</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>WUE</td>
<td>Control 2</td>
<td>6.05</td>
<td>1.09</td>
<td>5.56</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>WUE</td>
<td>TS2</td>
<td>0.44</td>
<td>1.22</td>
<td>0.36</td>
</tr>
</tbody>
</table>

Table A.25.3C. Multiple mean comparisons for whole plant WUE (μmol C/ mmol H₂O) to compare greenhouse cultivar transient switch (TS) studies in Figure 4.2.

<table>
<thead>
<tr>
<th>CV Feed</th>
<th>WUE LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI 40≥40</td>
<td>10.7050231</td>
<td>0.7492950</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>GI 40≥91</td>
<td>20.7344930</td>
<td>0.7898263</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>GI 91≥91</td>
<td>13.4904752</td>
<td>0.7898263</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>GI 91≥40</td>
<td>10.3951427</td>
<td>0.9673357</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>GIV 40≥40</td>
<td>11.9945092</td>
<td>0.7492950</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>GIV 40≥91</td>
<td>17.0966143</td>
<td>0.7492950</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>GIV 91≥91</td>
<td>19.5443086</td>
<td>0.7492950</td>
<td>&lt;.0001</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>GIV 91≥40</td>
<td>10.8330196</td>
<td>0.7492950</td>
<td>&lt;.0001</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>
### Table A.26.1A. Two-way analysis of variance for leaf photosynthesis (µmol C·m²·s⁻¹) of two greenhouse cultivars grown at 40 and 91 Pa CO₂ and transient switch (TS) studies in Figure 4.3.

**Dependent Variable: Photosynthesis (mmol C·m²·s⁻¹)**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS ¹</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>1682.10</td>
<td>144.57</td>
<td>&lt;.0001</td>
<td>0.9379</td>
<td>5.83</td>
</tr>
<tr>
<td>Error</td>
<td>67</td>
<td>111.36</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>74</td>
<td>1793.46</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>53.10</td>
<td>31.95</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trt</td>
<td>3</td>
<td>1279.64</td>
<td>316.79</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*Trt</td>
<td>3</td>
<td>28.61</td>
<td>5.74</td>
<td>0.0015</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹Sum of squares for model parameters are those of type III (SAS)

### Table A.26.1B. Numerical difference and standard error of the estimate for leaf photosynthesis (µmol C·m²·s⁻¹) to compare greenhouse cultivar grown at 40 and 91 Pa CO₂ and transient switch (TS) treatments in Figure 4.3.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>Photosynthesis</td>
<td>Control 1</td>
<td>0.06</td>
<td>1.55</td>
<td>0.38</td>
<td>0.7031</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Photosynthesis</td>
<td>TS1</td>
<td>2.40</td>
<td>1.60</td>
<td>1.50</td>
<td>0.1422</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Photosynthesis</td>
<td>Control 2</td>
<td>4.44</td>
<td>1.60</td>
<td>2.77</td>
<td>0.0085</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Photosynthesis</td>
<td>TS2</td>
<td>0.49</td>
<td>1.60</td>
<td>0.30</td>
<td>0.7626</td>
</tr>
</tbody>
</table>

### Table A.26.1C. Multiple mean comparisons for leaf photosynthesis (µmol C·m²·s⁻¹) of two greenhouse cultivars grown at 40 and 91 Pa CO₂ and transient switch (TS) studies in Figure 4.3.

<table>
<thead>
<tr>
<th>CV Feed</th>
<th>NCER</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI 40=&gt;40</td>
<td>21.3967143</td>
<td>1.0511048</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>GI 40=&gt;91</td>
<td>29.5007333</td>
<td>1.1353229</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>GI 91=&gt;91</td>
<td>25.4261000</td>
<td>1.1353229</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>GI 91=&gt;40</td>
<td>18.0191500</td>
<td>1.1353229</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>GIV 40=&gt;40</td>
<td>20.8028000</td>
<td>1.1353229</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
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<tr>
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### Table A.26.1D. Least Squares Means for effect CV*Feed

**Pr > |t| for H0: LSMean(i)=LSMean(j)**

**Dependent Variable: NCER**

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**Least Squares Means for effect CV*Feed

**Pr > |t| for H0: LSMean(i)=LSMean(j)**

**Dependent Variable: WUE**

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Table A.26.2A. Two-way analysis of variance for leaf transpiration (mmol H$_2$O·m$^{-2}$·s$^{-1}$) of two greenhouse cultivars transient switch (TS) studies in Figure 4.3.

### Two-way ANOVA

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$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.26.2B. Numerical difference and standard error of the estimate for leaf transpiration (mmol H$_2$O·m$^{-2}$·s$^{-1}$) to compare greenhouse cultivar transient switch (TS) studies in Figure 4.3.

<table>
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<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
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<td>0.3541</td>
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<td>Gl vs. GIV</td>
<td>Transpiration TS1</td>
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<tr>
<td>Gl vs. GIV</td>
<td>Transpiration Control 2</td>
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<td>0.14</td>
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<td>Gl vs. GIV</td>
<td>Transpiration TS2</td>
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Table A.26.2C. Multiple mean comparison estimate for leaf transpiration (mmol H$_2$O·m$^{-2}$·s$^{-1}$) to compare greenhouse cultivar transient switch (TS) studies in Figure 4.3.

<table>
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<th>Feed</th>
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<th>Standard Error</th>
<th>Pr &gt;</th>
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<td>1.92608500</td>
<td>0.10115519</td>
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</tr>
<tr>
<td>Gl</td>
<td>91=&gt;91</td>
<td>1.73965667</td>
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Table A.26.2D. Numerical difference and standard error of the estimate for leaf transpiration (mmol H$_2$O·m$^{-2}$·s$^{-1}$) to compare greenhouse cultivar transient switch (TS) studies in Figure 4.3.
Least Squares Means for effect CV*Feed
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: Trans

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Table A.26.3A. Two-way analysis of variance for leaf WUE (μmol C/ mmol H₂O) of two greenhouse cultivars grown at 40 and 91 Pa CO₂ and transient switch (TS) studies in Figure 4.3.

Two-way ANOVA

<table>
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<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
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†Sum of squares for model parameters are those of type III (SAS)

Table A.26.3B. Numerical difference and standard error of the estimate for leaf WUE (μmol C/ mmol H₂O) to compare greenhouse cultivar transient switch (TS) studies in Figure 4.3.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
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<th>SE</th>
<th>t-value</th>
<th>P</th>
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<td>WUE</td>
<td>Control 2</td>
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<td>0.62</td>
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</table>

Table A.26.3C. Multiple mean comparisons for leaf WUE (μmol C/ mmol H₂O) to compare greenhouse cultivar transient switch (TS) studies in Figure 4.3.

| CV Feed | WUE LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|---------|-------------|----------------|------|---|----------------|
| GI 40=>40 | 8.0795875 | 0.3790908 | <.0001 | 1 |
| GI 40=>91 | 15.4170667 | 0.4377364 | <.0001 | 2 |
| GI 91=>91 | 15.5714200 | 0.4795162 | <.0001 | 3 |
| GI 91=>40 | 7.4606167 | 0.4377364 | <.0001 | 4 |
| GIV 40=>40 | 7.5911833 | 0.4377364 | <.0001 | 5 |
| GIV 40=>91 | 15.7781500 | 0.4377364 | <.0001 | 6 |
| GIV 91=>91 | 16.3323333 | 0.4377364 | <.0001 | 7 |
| GIV 91=>40 | 8.1819667 | 0.4377364 | <.0001 | 8 |

Least Squares Means for effect CV*Feed
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: WUE

<table>
<thead>
<tr>
<th>i/j</th>
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Table A.26.4A. Two-way analysis of variance for leaf export rate (mmol C·m⁻²·s⁻¹) of two greenhouse cultivars grown at 40 and 91 Pa CO₂ and transient switch (TS) studies in Figure 4.3.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS ¹</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>445.01</td>
<td>10.69</td>
<td>&lt;.0001</td>
<td>0.6633</td>
<td>15.40</td>
</tr>
<tr>
<td>Error</td>
<td>38</td>
<td>225.89</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Corrected Total</td>
<td>45</td>
<td>670.90</td>
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</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>12.17</td>
<td>0.54</td>
<td>&lt;.0001</td>
<td>0.4689</td>
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</tr>
<tr>
<td>TS</td>
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<td>424.41</td>
<td>23.55</td>
<td>&lt;.0001</td>
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<tr>
<td>CV*TS</td>
<td>3</td>
<td>21.78</td>
<td>1.22</td>
<td>&lt;.0001</td>
<td>0.3153</td>
<td></td>
</tr>
</tbody>
</table>

¹Sum of squares for model parameters are those of type III (SAS)

Table A.26.4B. Numerical difference and standard error of the estimate for leaf export rate (mmol C·m⁻²·s⁻¹) to compare greenhouse cultivar transient switch (TS) studies in Figure 4.3.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>Export rate</td>
<td>Control 1</td>
<td>0.85</td>
<td>1.32</td>
<td>0.65</td>
<td>0.5198</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Export rate</td>
<td>TS1</td>
<td>0.47</td>
<td>1.54</td>
<td>0.30</td>
<td>0.7637</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Export rate</td>
<td>Control 2</td>
<td>2.81</td>
<td>1.54</td>
<td>1.82</td>
<td>0.0764</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Export rate</td>
<td>TS2</td>
<td>0.27</td>
<td>1.41</td>
<td>0.19</td>
<td>0.8483</td>
</tr>
</tbody>
</table>

Table A.26.4C. Multiple mean comparison for leaf export rate (mmol C·m⁻²·s⁻¹) to compare greenhouse cultivar transient switch (TS) studies in Figure 4.3.

| CV | Feed | ExpI | LSMEAN | Standard Error | Pr > |t| |LSMEAN Number |
|----|------|------|--------|---------------|------||--|----------------|
| GI | 40=>40 | 13.8838125 | 0.8620034 | <.0001 | 1 |
| GI | 40=>91 | 17.4553600 | 1.0903576 | <.0001 | 2 |
| GI | 91=>91 | 19.3859200 | 1.0903576 | <.0001 | 3 |
| GI | 91=>40 | 13.0851167 | 0.9953557 | <.0001 | 4 |
| GIV | 40=>40 | 13.0282667 | 0.9953557 | <.0001 | 5 |
| GIV | 40=>91 | 16.9884400 | 1.0903576 | <.0001 | 6 |
| GIV | 91=>91 | 22.1946400 | 1.0903576 | <.0001 | 7 |
| GIV | 91=>40 | 13.3561667 | 0.9953557 | <.0001 | 8 |
### Table A.26.5A. Two-way analysis of variance for leaf relative export flux (% of photosynthesis) of two greenhouse cultivars grown at 40 and 91 Pa CO₂ and transient switch (TS) studies in Figure 4.3. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS ¹</th>
<th>F   Value</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>0.24</td>
<td>8.33</td>
<td>&lt;.0001</td>
<td>0.5993</td>
<td>6.63</td>
</tr>
<tr>
<td>Error</td>
<td>39</td>
<td>0.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>46</td>
<td>0.39</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>0.01</td>
<td>2.72</td>
<td>0.1072</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TS</td>
<td>3</td>
<td>0.22</td>
<td>17.88</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*TS</td>
<td>3</td>
<td>0.01</td>
<td>0.82</td>
<td>0.4913</td>
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<td></td>
</tr>
</tbody>
</table>

¹Sum of squares for model parameters are those of type III (SAS)

### Table A.26.5B. Numerical difference and standard error of the estimate for leaf relative export flux (% of photosynthesis) to compare greenhouse cultivar transient switch (TS) studies in Figure 4.3. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>Relative export</td>
<td>Control 1</td>
<td>0.03</td>
<td>0.03</td>
<td>1.02</td>
<td>0.3149</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Relative export</td>
<td>TS1</td>
<td>0.08</td>
<td>0.04</td>
<td>1.98</td>
<td>0.0551</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Relative export</td>
<td>Control 2</td>
<td>0.0001</td>
<td>0.04</td>
<td>0.02</td>
<td>0.9809</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Relative export</td>
<td>TS2</td>
<td>0.01</td>
<td>0.04</td>
<td>0.23</td>
<td>0.8228</td>
</tr>
</tbody>
</table>

### Table A.26.5C. Multiple mean comparison for leaf relative export flux (% of photosynthesis) to compare greenhouse cultivar transient switch (TS) studies in Figure 4.3. Data expressed as percentage were arcsine square root transformed prior to analysis.

| CV Feed       | Ratioi LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|---------------|---------------|----------------|-------| |                |
| GI 400400     | 0.94875245    | 0.02251367     | <.0001 | 1 |                |
| GI 400900     | 0.89217465    | 0.02847780     | <.0001 | 2 |                |
| GI 900100     | 1.02667894    | 0.02847780     | <.0001 | 3 |                |
| GI 900400     | 1.02369207    | 0.02599655     | <.0001 | 4 |                |
| GIV 400400    | 0.91373706    | 0.02599655     | <.0001 | 5 |                |
| GIV 400900    | 0.81254725    | 0.02847780     | <.0001 | 6 |                |
| GIV 900100    | 1.02574973    | 0.02599655     | <.0001 | 7 |                |
| GIV 900400    | 1.01540214    | 0.02599655     | <.0001 | 8 |                |
### Table A.27.1A
Two-way and one-way analysis of variance for leaf GCO₂ of two greenhouse cultivars grown at 40 and 91 Pa CO₂ and transient switch (TS) studies in Figure 4.4.

**Two-way ANOVA**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>( F ) Value</th>
<th>Pr&gt;F</th>
<th>( R^2 )</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
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<td>18961.12</td>
<td>12.09</td>
<td>&lt;.0001</td>
<td>0.6684</td>
<td>12.30</td>
</tr>
<tr>
<td>Error</td>
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<td>9406.91</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
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<td>28368.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>69.75</td>
<td>0.31</td>
<td>0.5798</td>
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</tr>
<tr>
<td>TS</td>
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<td>18163.54</td>
<td>27.03</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*TS</td>
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<td>668.71</td>
<td>1.00</td>
<td>0.4044</td>
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<td></td>
</tr>
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</table>

*Sum of squares for model parameters are those of type III (SAS)*

### Table A.27.1B
Numerical difference and standard error of the estimate for leaf GCO₂ to compare greenhouse cultivar transient switch (TS) studies in Figure 4.4.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>GCO₂</td>
<td>Control 1</td>
<td>2.19</td>
<td>8.08</td>
<td>0.27</td>
<td>0.7873</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>GCO₂</td>
<td>TS1</td>
<td>9.28</td>
<td>8.64</td>
<td>1.07</td>
<td>0.2888</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>GCO₂</td>
<td>Control 2</td>
<td>7.34</td>
<td>8.64</td>
<td>0.90</td>
<td>0.3757</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>GCO₂</td>
<td>TS2</td>
<td>9.72</td>
<td>8.64</td>
<td>1.13</td>
<td>0.2668</td>
</tr>
</tbody>
</table>

### Table A.27.1C
Multiple mean comparisons for leaf GCO₂ to compare greenhouse cultivar transient switch (TS) studies in Figure 4.4.

| CV | Feed | GCO₂ LSMEAN | Standard Error | \( Pr > |t| \) | LSMEAN Number |
|----|------|-------------|----------------|--------|---------------|
| GI | 40=>40 | 114.651250 | 5.291194 | <.0001 | 1 |
| GI | 40=>91 | 73.093333 | 6.109745 | <.0001 | 2 |
| GI | 91=>91 | 64.287667 | 6.109745 | <.0001 | 3 |
| GI | 91=>40 | 106.727333 | 6.109745 | <.0001 | 4 |
| GIV | 40=>40 | 116.846500 | 6.109745 | <.0001 | 5 |
| GIV | 40=>91 | 82.376833 | 6.109745 | <.0001 | 6 |
| GIV | 91=>91 | 72.024667 | 6.109745 | <.0001 | 7 |
| GIV | 91=>40 | 97.003167 | 6.109745 | <.0001 | 8 |

**Least Squares Means for effect CV*Feed**

| \( Pr > |t| \) for H₀: LSMean(i)=LSMean(j) |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| GI 40=>40       | <.0001          | <.0001          | 0.3325          | 0.7873          | <.0001          |
| GI 40=>91       | <.0001          | 0.3140          | 0.0003          | 0.2888          | 0.9022          | 0.0084          |
| GI 91=>91       | <.0001          | <.0001          | 0.0424          | 0.3757          | 0.0005          |
Table A.27.2A. Two-way and one-way analysis of variance for leaf Ci of two greenhouse cultivars grown at 40 and 91 Pa CO$_2$ and transient switch (TS) studies in Figure 4.4.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
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<tbody>
<tr>
<td>Model</td>
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<td>630885.30</td>
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<td>&lt;.0001</td>
<td>0.8374</td>
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</tr>
<tr>
<td>Error</td>
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<td></td>
</tr>
<tr>
<td>Corrected Total</td>
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<td>753373.12</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>0.5403</td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
</tr>
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<td>1193.81</td>
<td>0.14</td>
<td>0.9377</td>
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<td></td>
</tr>
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</table>

$^a$Sum of squares for model parameters are those of type III (SAS)

Table A.27.2B. Numerical difference and standard error of the estimate for leaf Ci to compare greenhouse cultivar transient switch (TS) studies in Figure 4.4.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>Ci</td>
<td>Control 1</td>
<td>6.44</td>
<td>29.16</td>
<td>0.22</td>
<td>0.8264</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Ci</td>
<td>TS1</td>
<td>4.17</td>
<td>31.18</td>
<td>0.13</td>
<td>0.8942</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>Ci</td>
<td>Control 2</td>
<td>0.90</td>
<td>31.18</td>
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</tr>
<tr>
<td>GI vs. GIV</td>
<td>Ci</td>
<td>TS2</td>
<td>26.38</td>
<td>31.18</td>
<td>0.85</td>
<td>0.4023</td>
</tr>
</tbody>
</table>

Table A.27.2C. Multiple mean comparisons for leaf Ci to compare greenhouse cultivar transient switch (TS) studies in Figure 4.4.

| Contrast | CI LSMEAN | Standard Error | Pr>|t| | LSMEAN Number |
|----------|-----------|----------------|--------|----------------|
| GI 40=>40 | 177.190000 | 19.093115 | <.0001 | 1 |
| GI 40=>91 | 401.283333 | 22.046831 | <.0001 | 2 |
| GI 91=>91 | 409.663833 | 22.046831 | <.0001 | 3 |
| GI 91=>40 | 1193.81 | 22.046831 | <.0001 | 4 |
| GIV 40=>40 | 170.751667 | 22.046831 | <.0001 | 5 |
| GIV 40=>91 | 397.111667 | 22.046831 | <.0001 | 6 |
| GIV 91=>91 | 408.763500 | 22.046831 | <.0001 | 7 |
| GIV 91=>40 | 173.426167 | 22.046831 | <.0001 | 8 |

Least Squares Means for effect CV*Feed

Pr>|t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: GCO2

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.3325</td>
<td>0.0003</td>
<td>&lt;.0001</td>
<td>0.2481</td>
<td>0.0073</td>
<td>0.0002</td>
<td>0.2668</td>
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<td>5</td>
<td>0.7873</td>
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<td>&lt;.0001</td>
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<td>0.0003</td>
<td>&lt;.0001</td>
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<tr>
<td>6</td>
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<td>0.0424</td>
<td>0.0073</td>
<td>0.0003</td>
<td>0.2376</td>
<td>0.0979</td>
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</tr>
<tr>
<td>7</td>
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<td>0.3757</td>
<td>0.0002</td>
<td>&lt;.0001</td>
<td>0.2376</td>
<td>0.0061</td>
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</tr>
<tr>
<td>8</td>
<td>0.0346</td>
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<td>0.2668</td>
<td>0.0267</td>
<td>0.0979</td>
<td>0.0061</td>
<td></td>
</tr>
</tbody>
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Least Squares Means for effect CV*Feed
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: CI

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<tbody>
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<td>4</td>
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<td>&lt;.0001</td>
<td>0.3567</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.4023</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.8264</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.3567</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.9320</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>&lt;.0001</td>
<td>0.8942</td>
<td>0.6893</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.7105</td>
<td>&lt;.0001</td>
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</tr>
<tr>
<td>7</td>
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<td>0.9771</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.7105</td>
<td>&lt;.0001</td>
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</tr>
<tr>
<td>8</td>
<td>0.8979</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.4023</td>
<td>&lt;.0001</td>
<td>0.9320</td>
<td>&lt;.0001</td>
<td></td>
</tr>
</tbody>
</table>

Table A.28.1A. Two-way analysis of variance for $^{14}$C-starch (mmol C·m$^{-2}$) retained in source leaves of two greenhouse cultivars grown at 40 and 91 Pa CO$_2$ and transient switch (TS) studies in Table 4.3.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>799.54</td>
<td>16.79</td>
<td>&lt;.0001</td>
<td>0.7367</td>
<td>22.64</td>
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<tr>
<td>Error</td>
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<td></td>
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</tr>
<tr>
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<td></td>
</tr>
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</tr>
<tr>
<td>CV*TS</td>
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<td>0.98</td>
<td>0.4123</td>
<td></td>
<td></td>
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</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.28.1B. Numerical difference and standard error of the estimate for $^{14}$C-starch (mmol C·m$^{-2}$) retained in source leaves to compare greenhouse cultivar transient switch (TS) studies in Table 4.3.

<table>
<thead>
<tr>
<th>Contrasts</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-starch</td>
<td>Control 1</td>
<td>4.05</td>
<td>4.45</td>
<td>0.91</td>
<td>0.3685</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-starch</td>
<td>TS1</td>
<td>5.51</td>
<td>4.76</td>
<td>1.16</td>
<td>0.2540</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-starch</td>
<td>Control 2</td>
<td>1.58</td>
<td>4.76</td>
<td>0.33</td>
<td>0.7417</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-starch</td>
<td>TS2</td>
<td>12.52</td>
<td>4.76</td>
<td>2.63</td>
<td>0.0119</td>
</tr>
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</table>

Table A.28.1C. Multiple mean comparison for $^{14}$C-starch (mmol C·m$^{-2}$) retained in source leaves to compare greenhouse cultivar transient switch (TS) studies in Table 4.3.

<table>
<thead>
<tr>
<th>CV Feed</th>
<th>Insol LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI 40=&gt;40</td>
<td>28.9095125</td>
<td>2.9161152</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI 40=&gt;91</td>
<td>52.7057167</td>
<td>3.3672398</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI 91=&gt;91</td>
<td>48.6657000</td>
<td>3.3672398</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI 91=&gt;40</td>
<td>28.5323000</td>
<td>3.3672398</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV 40=&gt;40</td>
<td>24.8603667</td>
<td>3.3672398</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV 40=&gt;91</td>
<td>47.1983333</td>
<td>3.3672398</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV 91=&gt;91</td>
<td>47.0858167</td>
<td>3.3672398</td>
<td>&lt;.0001</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV 91=&gt;40</td>
<td>16.0141667</td>
<td>3.3672398</td>
<td>&lt;.0001</td>
<td>8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Least Squares Means for effect CV*Feed
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: Insol

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.9329</td>
<td>0.3685</td>
<td>0.0002</td>
<td>0.0002</td>
<td>0.0060</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>&lt;.0001</td>
<td>0.4010</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.2540</td>
<td>0.2446</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>&lt;.0001</td>
<td>0.4010</td>
<td>0.0001</td>
<td>&lt;.0001</td>
<td>0.7595</td>
<td>0.7417</td>
<td>&lt;.0001</td>
<td></td>
</tr>
</tbody>
</table>

285
## Table A.28.2A. Two-way analysis of variance for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in source leaves of two greenhouse cultivars grown at 40 and 91 Pa CO$_2$ and transient switch (TS) studies in Table 4.3.

### Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>11059.86</td>
<td>21.17</td>
<td>&lt;.0001</td>
<td>0.7959</td>
<td>36.70</td>
</tr>
<tr>
<td>Error</td>
<td>38</td>
<td>2836.62</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>45</td>
<td>13896.48</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>1359.79</td>
<td>18.22</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TS</td>
<td>3</td>
<td>8766.08</td>
<td>40.69</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*TS</td>
<td>3</td>
<td>336.56</td>
<td>1.50</td>
<td>0.2293</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)*

## Table A.28.2B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in source leaves to compare greenhouse cultivar transient switch (TS) studies in Table 4.3.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose</td>
<td>Control 1</td>
<td>10.22</td>
<td>4.92</td>
<td>2.08</td>
<td>0.0448</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose</td>
<td>TS1</td>
<td>20.74</td>
<td>5.80</td>
<td>3.58</td>
<td>0.0010</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose</td>
<td>Control 2</td>
<td>5.07</td>
<td>4.99</td>
<td>1.02</td>
<td>0.3155</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose</td>
<td>TS2</td>
<td>8.24</td>
<td>4.99</td>
<td>1.65</td>
<td>0.1066</td>
</tr>
</tbody>
</table>

## Table A.28.2C. Multiple mean comparison for $^{14}$C-sucrose (mmol C·m$^{-2}$) retained in source leaves to compare greenhouse cultivar transient switch (TS) studies in Table 4.3.

| CV Feed | C14Suc LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|---------|---------------|----------------|-------|---------|----------------|
| GI 40=>40 | 16.7816250 | 3.0546683 | <.0001 | 1 |
| GI 40=>91 | 40.6237500 | 4.3199533 | <.0001 | 2 |
| GI 91=>91 | 11.4102167 | 3.5272271 | 0.0025 | 3 |
| GI 91=>40 | 10.6150000 | 3.5272271 | 0.0046 | 4 |
| GIV 40=>40 | 27.0024000 | 3.8638837 | <.0001 | 5 |
| GIV 40=>91 | 61.3602000 | 3.8638837 | <.0001 | 6 |
| GIV 91=>91 | 16.4839500 | 3.5272271 | <.0001 | 7 |
| GIV 91=>40 | 18.8601167 | 3.5272271 | <.0001 | 8 |

## Table A.28.2D. Least Squares Means for effect CV*Feed

| Least Squares Means for effect CV*Feed
| Pr > |t| for H0: LSMean(i)=LSMean(j)
<p>| Dependent Variable: C14Suc |</p>
<table>
<thead>
<tr>
<th>l/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td>0.9329</td>
<td>&lt;.0001</td>
<td>0.2569</td>
<td>0.1942</td>
<td>0.0448</td>
<td>&lt;.0001</td>
<td>0.9495</td>
<td>0.6585</td>
</tr>
<tr>
<td>GIV</td>
<td>&lt;.0001</td>
<td></td>
<td>0.2569</td>
<td>0.1942</td>
<td>0.0448</td>
<td>&lt;.0001</td>
<td>0.9495</td>
<td>0.6585</td>
</tr>
<tr>
<td></td>
<td>0.3685</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.6748</td>
<td>&lt;.0001</td>
<td>0.0003</td>
<td>0.0003</td>
<td>0.0003</td>
</tr>
<tr>
<td></td>
<td>&lt;.0001</td>
<td></td>
<td>&lt;.0001</td>
<td>0.6748</td>
<td>&lt;.0001</td>
<td>0.0003</td>
<td>0.0003</td>
<td>0.0003</td>
</tr>
<tr>
<td></td>
<td>0.0002</td>
<td>0.2569</td>
<td>0.7417</td>
<td>&lt;.0001</td>
<td>0.9813</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;.0001</td>
<td></td>
<td>&lt;.0001</td>
<td>0.7417</td>
<td>&lt;.0001</td>
<td>0.9813</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.0060</td>
<td>&lt;.0001</td>
<td>0.2446</td>
<td>0.7417</td>
<td>&lt;.0001</td>
<td>0.9813</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;.0001</td>
<td></td>
<td>&lt;.0001</td>
<td>0.2446</td>
<td>&lt;.0001</td>
<td>0.9813</td>
<td>&lt;.0001</td>
<td></td>
</tr>
</tbody>
</table>

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Table A.28.3A. Two-way analysis of variance for $^{14}$C-glucose (mmol C·m$^{-2}$) retained in source leaves of two greenhouse cultivars grown at 40 and 91 Pa CO$_2$ and transient switch (TS) studies in Table 4.2.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS$^1$</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>1780.60</td>
<td>7.83</td>
<td>&lt;.0001</td>
<td>0.6035</td>
<td>48.91</td>
</tr>
<tr>
<td>Corrected Total</td>
<td>43</td>
<td>2950.37</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>274.30</td>
<td>8.44</td>
<td>0.0062</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TS</td>
<td>3</td>
<td>1208.30</td>
<td>12.40</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*TS</td>
<td>3</td>
<td>300.39</td>
<td>3.08</td>
<td>0.0395</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.28.3B. Numerical difference and standard error of the estimate for $^{14}$C-glucose (mmol C·m$^{-2}$) retained in source leaves to compare greenhouse cultivar transient switch (TS) studies in Table 4.2.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-glucose</td>
<td>Control 1</td>
<td>3.85</td>
<td>3.25</td>
<td>1.18</td>
<td>0.2442</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-glucose</td>
<td>TS1</td>
<td>15.64</td>
<td>4.35</td>
<td>3.59</td>
<td>0.0010</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-glucose</td>
<td>Control 2</td>
<td>0.26</td>
<td>3.29</td>
<td>0.08</td>
<td>0.9372</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-glucose</td>
<td>TS2</td>
<td>1.04</td>
<td>3.29</td>
<td>0.32</td>
<td>0.7537</td>
</tr>
</tbody>
</table>

Table A.28.3C. Multiple mean comparison for $^{14}$C-glucose (mmol C·m$^{-2}$) retained in source leaves to compare greenhouse cultivar transient switch (TS) studies in Table 4.2.

| CV  | Feed | C14Glu LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|-----|------|---------------|----------------|-------|-----|----------------|
| GI  | 40=>40 | 14.0404375  | 2.0153678 | <.0001 | 1   |
| GI  | 40=>91 | 11.5363333  | 3.2910818 | 0.0012 | 2   |
| GI  | 91=>91 | 8.3307333   | 2.3271463 | 0.0010 | 3   |
| GI  | 91=>40 | 4.9994500   | 2.3271463 | 0.0385 | 4   |
| GIV | 40=>40 | 17.8876400  | 2.5492610 | <.0001 | 5   |
| GIV | 40=>91 | 27.1730500  | 2.8501605 | <.0001 | 6   |
| GIV | 91=>91 | 8.5917667   | 2.3271463 | 0.0007 | 7   |
| GIV | 91=>40 | 6.0398333   | 2.3271463 | 0.0136 | 8   |

Least Squares Means for effect CV*Feed

Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: C14Glu
### Least Squares Means for effect CV*Feed

Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: C14Glu

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.0058</td>
<td>0.1136</td>
<td>0.3182</td>
<td>0.0007</td>
<td>&lt;0.0001</td>
<td>0.2823</td>
<td>0.7537</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.2442</td>
<td>0.1358</td>
<td>0.0088</td>
<td>0.0007</td>
<td>0.0203</td>
<td>0.0107</td>
<td>0.0015</td>
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</tr>
<tr>
<td>6</td>
<td>0.0006</td>
<td>0.0010</td>
<td>&lt;0.0001</td>
<td>0.0001</td>
<td>0.0203</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.0852</td>
<td>0.4698</td>
<td>0.9372</td>
<td>0.2823</td>
<td>0.0107</td>
<td>&lt;0.0001</td>
<td>0.4432</td>
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</tr>
<tr>
<td>8</td>
<td>0.0135</td>
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<td>0.4908</td>
<td>0.7537</td>
<td>&lt;0.0001</td>
<td>0.0015</td>
<td>0.0432</td>
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</tr>
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</table>

Table A.28.4A. Two-way analysis of variance for $^{14}$C-fructose (mmol C·m$^{-2}$) retained in source leaves of two greenhouse cultivars grown at 40 and 91 Pa CO$_2$ and transient switch (TS) studies in Table 4.3.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>1114.92</td>
<td>6.82</td>
<td>&lt;.0001</td>
<td>0.5842</td>
<td>48.67</td>
</tr>
<tr>
<td>Error</td>
<td>34</td>
<td>793.55</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>41</td>
<td>1908.47</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>1</td>
<td>67.98</td>
<td>2.91</td>
<td>0.0970</td>
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<td></td>
</tr>
<tr>
<td>TS</td>
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<td>679.68</td>
<td>9.71</td>
<td>&lt;.0001</td>
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<td></td>
</tr>
<tr>
<td>CV*TS</td>
<td>3</td>
<td>363.10</td>
<td>5.19</td>
<td>0.0047</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

Table A.28.4B. Numerical difference and standard error of the estimate for $^{14}$C-fructose (mmol C·m$^{-2}$) retained in source leaves to compare greenhouse cultivar transient switch (TS) studies in Table 4.3.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-fructose</td>
<td>Control 1</td>
<td>3.95</td>
<td>2.75</td>
<td>1.43</td>
<td>0.1810</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-fructose</td>
<td>TS1</td>
<td>12.31</td>
<td>2.69</td>
<td>3.34</td>
<td>0.0021</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-fructose</td>
<td>Control 2</td>
<td>5.62</td>
<td>2.92</td>
<td>1.92</td>
<td>0.0630</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-fructose</td>
<td>TS2</td>
<td>0.07</td>
<td>2.92</td>
<td>0.02</td>
<td>0.9821</td>
</tr>
</tbody>
</table>

Table A.28.4C. Multiple mean comparison for $^{14}$C-fructose (mmol C·m$^{-2}$) retained in source leaves to compare greenhouse cultivar transient switch (TS) studies in Table 4.3.

<table>
<thead>
<tr>
<th>CV</th>
<th>Feed</th>
<th>C14Fru</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>t</th>
<th></th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td>40=&gt;40</td>
<td>11.6361250</td>
<td>1.7080608</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>40=&gt;91</td>
<td>8.2121667</td>
<td>2.7892516</td>
<td>0.0058</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>91=&gt;91</td>
<td>11.5532600</td>
<td>2.1605450</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>GI</td>
<td>91=&gt;40</td>
<td>4.1964667</td>
<td>1.9722987</td>
<td>0.0407</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>40=&gt;40</td>
<td>15.5825800</td>
<td>2.1605450</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>40=&gt;91</td>
<td>20.5183500</td>
<td>2.4155627</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>91=&gt;91</td>
<td>5.9307000</td>
<td>1.9722987</td>
<td>0.0049</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>91=&gt;40</td>
<td>4.1302600</td>
<td>2.1605450</td>
<td>0.0644</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Least Squares Means for effect CV*Feed

Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: C14Fru

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3025</td>
<td>0.9762</td>
<td>0.0073</td>
<td>0.1610</td>
<td>0.0050</td>
<td>0.0357</td>
<td>0.0101</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.3025</td>
<td>0.3503</td>
<td>0.2480</td>
<td>0.0443</td>
<td>0.0021</td>
<td>0.5087</td>
<td>0.2554</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.9762</td>
<td>0.3503</td>
<td>0.0168</td>
<td>0.1961</td>
<td>0.0091</td>
<td>0.0630</td>
<td>0.0206</td>
<td></td>
</tr>
</tbody>
</table>

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### Table A.28.5A. Two-way analysis of variance for $^{14}$C-antirrhinoside (mmol C·m$^{-2}$) retained in source leaves of two greenhouse cultivars grown at 40 and 91 Pa CO$_2$ and transient switch (TS) studies in Table 4.3.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>7.23</td>
<td>8.03</td>
<td>&lt;.0001</td>
<td>0.6101</td>
<td>36.88</td>
</tr>
<tr>
<td>Error</td>
<td>36</td>
<td>462.56</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>43</td>
<td>1186.42</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>172.96</td>
<td>13.46</td>
<td>0.0008</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TS</td>
<td>3</td>
<td>284.49</td>
<td>7.38</td>
<td>0.0006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*TS</td>
<td>3</td>
<td>232.56</td>
<td>6.03</td>
<td>0.0019</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)*

### Table A.28.5B. Numerical difference and standard error of the estimate for $^{14}$C-antirrhinoside (mmol C·m$^{-2}$) retained in source leaves to compare greenhouse cultivar transient switch (TS) studies in Table 4.3.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhinoside</td>
<td>Control 1</td>
<td>3.49</td>
<td>2.19</td>
<td>1.59</td>
<td>0.1203</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhinoside</td>
<td>TS1</td>
<td>12.83</td>
<td>2.62</td>
<td>4.90</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhinoside</td>
<td>Control 2</td>
<td>0.18</td>
<td>2.07</td>
<td>0.09</td>
<td>0.9327</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhinoside</td>
<td>TS2</td>
<td>0.36</td>
<td>2.07</td>
<td>0.17</td>
<td>0.8638</td>
</tr>
</tbody>
</table>

### Table A.28.5C. Multiple mean comparison for $^{14}$C-antirrhinoside (mmol C·m$^{-2}$) retained in source leaves to compare greenhouse cultivar transient switch (TS) studies in Table 4.3.

| CV Feed | C14Antirrhide LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|---------|----------------------|----------------|------|---|----------------|
| GI 400400 | 4.61315000 | 0.72029839 | <.0001 | 1 |
| GI 400900 | 5.51157500 | 1.01865576 | <.0001 | 2 |
| GI 900100 | 2.70870500 | 0.83172894 | 0.0024 | 3 |
| GI 900400 | 3.40935167 | 0.83172894 | 0.0002 | 4 |
| GIV 400400 | 5.00764000 | 0.91111341 | <.0001 | 5 |
| GIV 400900 | 8.70660000 | 0.91111341 | <.0001 | 6 |
| GIV 900100 | 2.92707167 | 0.83172894 | 0.0011 | 7 |
| GIV 900400 | 3.27521167 | 0.83172894 | 0.0003 | 8 |

### Table A.28.5D. Least Squares Means for effect CV*Feed

<p>| Least Squares Means for effect CV*Feed | Pr &gt; |t| for H0: LSMean(i)=LSMean(j) | Dependent Variable: C14Fru |
|----------------------------------------|------|-----------------------------|-----------------------------|</p>
<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.4759</td>
<td>0.0916</td>
<td>0.2808</td>
<td>0.7360</td>
<td>0.0011</td>
<td>0.1337</td>
<td>0.2315</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.4759</td>
<td>0.0396</td>
<td>0.1182</td>
<td>0.7144</td>
<td>0.0248</td>
<td>0.0567</td>
<td>0.0972</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.0916</td>
<td>0.0396</td>
<td>0.5549</td>
<td>0.0701</td>
<td>&lt;.0001</td>
<td>0.8537</td>
<td>0.6328</td>
<td></td>
</tr>
</tbody>
</table>
## Table A.28.6A. Two-way analysis of variance for $^{14}$C-antirrhide (mmol C·m$^{-2}$) retained in source leaves of two greenhouse cultivars grown at 40 and 91 Pa CO$_2$ and transient switch (TS) studies in Table 4.3.

### Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F Value</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>143.52</td>
<td>4.94</td>
<td>0.0005</td>
<td>0.4764</td>
<td>46.52</td>
</tr>
<tr>
<td>Error</td>
<td>38</td>
<td>157.72</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>45</td>
<td>301.25</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>9.36</td>
<td>2.26</td>
<td>0.1414</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TS</td>
<td>3</td>
<td>110.63</td>
<td>8.88</td>
<td>0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*TS</td>
<td>3</td>
<td>16.87</td>
<td>1.35</td>
<td>0.2713</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)*

## Table A.28.6B. Numerical difference and standard error of the estimate for $^{14}$C-antirrhide (mmol C·m$^{-2}$) retained in source leaves to compare greenhouse cultivar transient switch (TS) studies in Table 4.3.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV $^{14}$C-antirrhide</td>
<td>Control 1</td>
<td>0.39</td>
<td>1.16</td>
<td>0.34</td>
<td>0.7360</td>
</tr>
<tr>
<td>GI vs. GIV $^{14}$C-antirrhide</td>
<td>TS1</td>
<td>3.19</td>
<td>1.27</td>
<td>2.34</td>
<td>0.0248</td>
</tr>
<tr>
<td>GI vs. GIV $^{14}$C-antirrhide</td>
<td>Control 2</td>
<td>0.22</td>
<td>1.18</td>
<td>0.19</td>
<td>0.8537</td>
</tr>
<tr>
<td>GI vs. GIV $^{14}$C-antirrhide</td>
<td>TS2</td>
<td>0.13</td>
<td>1.18</td>
<td>0.11</td>
<td>0.9098</td>
</tr>
</tbody>
</table>

## Table A.28.6C. Multiple mean comparison for $^{14}$C-antirrhide (mmol C·m$^{-2}$) retained in source leaves to compare greenhouse cultivar transient switch (TS) studies in Table 4.3.

| CV  | Feed | C14Antirrhide LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|-----|------|-----------------------|----------------|-------|-----|----------------|
| GI  | 40=>40 | 4.17806250 | 0.79855299 | <.0001 | 1 |
| GI  | 40=>91 | 8.47525000 | 0.92208957 | <.0001 | 2 |
| GI  | 91=>91 | 2.95154167 | 0.92208957 | 0.0026 | 3 |
| GI  | 91=>40 | 3.75346667 | 0.92208957 | 0.0002 | 4 |
| GIV | 40=>40 | 3.66066667 | 0.92208957 | 0.0003 | 5 |
| GIV | 40=>91 | 9.64623333 | 0.92208957 | <.0001 | 6 |
| GIV | 91=>91 | 3.31536833 | 0.92208957 | 0.0008 | 7 |
| GIV | 91=>40 | 3.65147333 | 0.92208957 | 0.0003 | 8 |

## Least Squares Means for effect CV*Feed

| Pr > |t| for H0: LSMean(i)=LSMean(j) | Dependent Variable: C14Antirrhide |
|------|-----------------------------|---------------------------------|
| i/j  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  |
| 1    | 0.0010 | 0.3204 | 0.7295 | 0.6736 | <.0001 | 0.4833 | 0.6682 |
| 2    | 0.0010 | 0.0001 | 0.0008 | 0.0006 | 0.3743 | 0.0003 | 0.0006 |
| 3    | 0.3204 | 0.0001 | 0.5419 | 0.5895 | <.0001 | 0.7816 | 0.5943 |

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### Table A.28.7A. Two-way analysis of variance for % $^{14}$C-sugars recovered from petioles of two greenhouse cultivars grown at 40 and 91 Pa CO$_2$ and transient switch (TS) studies in Table 4.3. Data expressed as percentage were arcsine square root transformed prior to analysis.

#### Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>Value</th>
<th>Pr&gt;F</th>
<th>$R^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>0.11</td>
<td>8.47</td>
<td>&lt;.0001</td>
<td>0.5851</td>
<td>3.71</td>
</tr>
<tr>
<td>Error</td>
<td>42</td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>49</td>
<td>0.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>0.03</td>
<td>18.59</td>
<td>0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TS</td>
<td>3</td>
<td>0.07</td>
<td>12.23</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*TS</td>
<td>3</td>
<td>0.004</td>
<td>0.74</td>
<td>0.5349</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)*

### Table A.28.7B. Numerical difference and standard error of the estimate for % $^{14}$C-sugars recovered from petioles to compare greenhouse cultivar transient switch (TS) studies in Table 4.3. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>% $^{14}$C-sugars</td>
<td>Control 1</td>
<td>0.06</td>
<td>0.02</td>
<td>2.71</td>
<td>0.0094</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>% $^{14}$C-sugars</td>
<td>TS1</td>
<td>0.08</td>
<td>0.02</td>
<td>3.12</td>
<td>0.0033</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>% $^{14}$C-sugars</td>
<td>Control 2</td>
<td>0.03</td>
<td>0.02</td>
<td>1.36</td>
<td>0.1810</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>% $^{14}$C-sugars</td>
<td>TS2</td>
<td>0.04</td>
<td>0.02</td>
<td>1.46</td>
<td>0.1514</td>
</tr>
</tbody>
</table>

### Table A.28.7C. Multiple mean comparisons for % $^{14}$C-sugars recovered from petioles to compare greenhouse cultivar transient switch (TS) studies in Table 4.3. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>CV</th>
<th>Feed</th>
<th>sugars</th>
<th>LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td>40040</td>
<td>1.21201729</td>
<td>0.01526038</td>
<td>&lt;.0001</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>40090</td>
<td>1.23659161</td>
<td>0.01762117</td>
<td>&lt;.0001</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>90010</td>
<td>1.18198146</td>
<td>0.01762117</td>
<td>&lt;.0001</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>GI</td>
<td>90040</td>
<td>1.11671365</td>
<td>0.01762117</td>
<td>&lt;.0001</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>40040</td>
<td>1.14851386</td>
<td>0.01762117</td>
<td>&lt;.0001</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>40090</td>
<td>1.15887995</td>
<td>0.01762117</td>
<td>&lt;.0001</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>90010</td>
<td>1.14808028</td>
<td>0.01762117</td>
<td>&lt;.0001</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>GIV</td>
<td>90040</td>
<td>1.08029839</td>
<td>0.01762117</td>
<td>&lt;.0001</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>
### Table A.28.8A. Two-way analysis of variance for % $^{14}$C-sucrose recovered from petioles of two greenhouse cultivars grown at 40 and 91 Pa $\text{CO}_2$ and transient switch (TS) studies in Table 4.3. Data expressed as percentage were arcsine square root transformed prior to analysis.

#### Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS $^1$</th>
<th>Value</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>0.47</td>
<td>9.29</td>
<td>&lt;.0001</td>
<td>0.6076</td>
<td>14.29</td>
</tr>
<tr>
<td>Error</td>
<td>42</td>
<td>0.31</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>49</td>
<td>0.79</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>0.29</td>
<td>40.32</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TS</td>
<td>3</td>
<td>0.16</td>
<td>7.87</td>
<td>0.0004</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

### Table A.28.8B. Numerical difference and standard error of the estimate for % $^{14}$C-sucrose recovered from petioles to compare greenhouse cultivar transient switch (TS) studies in Table 4.3. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>% $^{14}$C-sucrose</td>
<td>Control 1</td>
<td>0.1</td>
<td>0.05</td>
<td>2.15</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>% $^{14}$C-sucrose</td>
<td>TS1</td>
<td>0.1</td>
<td>0.05</td>
<td>2.48</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>% $^{14}$C-sucrose</td>
<td>Control 2</td>
<td>0.2</td>
<td>0.05</td>
<td>4.72</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>% $^{14}$C-sucrose</td>
<td>TS2</td>
<td>0.2</td>
<td>0.05</td>
<td>3.29</td>
</tr>
</tbody>
</table>

### Table A.28.8C. Multiple mean comparisons for % $^{14}$C-sucrose recovered from petioles to compare greenhouse cultivar transient switch (TS) studies in Table 4.3. Data expressed as percentage were arcsine square root transformed prior to analysis.

| CV Feed | suc LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|---------|------------|----------------|------|---|----------------|
| GI 400400  | 0.58416308 | 0.03016444 <.0001 | 1   |
| GI 400900  | 0.64841554 | 0.03483089 <.0001 | 2   |
| GI 900100  | 0.80690940 | 0.03483089 <.0001 | 3   |
| GI 900400  | 0.65810369 | 0.03483089 <.0001 | 4   |
| GIV 400400 | 0.48529064 | 0.03483089 <.0001 | 5   |
| GIV 400900 | 0.52603477 | 0.03483089 <.0001 | 6   |
| GIV 900100 | 0.57462808 | 0.03483089 <.0001 | 7   |
| GIV 900400 | 0.49593680 | 0.03483089 <.0001 | 8   |

### Least Squares Means for effect CV*Feed

| Pr > |t| for H0: LSMean(i)=LSMean(j) | Dependent Variable: sugars |
|------|---|-----------------------------|
| i/j  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  |
| 1    | 0.1705  | <.0001 | 0.1160 | 0.0377 | 0.2141 | 0.8371 | 0.0624 |

---

*Table A.28.8A: Two-way analysis of variance for % $^{14}$C-sucrose recovered from petioles of two greenhouse cultivars grown at 40 and 91 Pa $\text{CO}_2$ and transient switch (TS) studies in Table 4.3. Data expressed as percentage were arcsine square root transformed prior to analysis.

*Table A.28.8B: Numerical difference and standard error of the estimate for % $^{14}$C-sucrose recovered from petioles to compare greenhouse cultivar transient switch (TS) studies in Table 4.3. Data expressed as percentage were arcsine square root transformed prior to analysis.

*Table A.28.8C: Multiple mean comparisons for % $^{14}$C-sucrose recovered from petioles to compare greenhouse cultivar transient switch (TS) studies in Table 4.3. Data expressed as percentage were arcsine square root transformed prior to analysis.

---

*Least Squares Means for effect CV*Feed

| Pr > |t| for H0: LSMean(i)=LSMean(j) | Dependent Variable: sugars |
|------|---|-----------------------------|
| i/j  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  |
| 1    | 0.1705  | <.0001 | 0.1160 | 0.0377 | 0.2141 | 0.8371 | 0.0624 |
### Table A.28.9A.
Two-way analysis of variance for % $^{14}$C-antirrhinoside recovered from petioles of two greenhouse cultivars grown at 40 and 91 Pa CO$_2$ and transient switch (TS) studies in Table 4.3. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS$^1$</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>0.11</td>
<td>8.47</td>
<td>&lt;.0001</td>
<td>0.5853</td>
<td>10.57</td>
</tr>
<tr>
<td>Error</td>
<td>42</td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>49</td>
<td>0.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>0.03</td>
<td>18.59</td>
<td>0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TS</td>
<td>3</td>
<td>0.07</td>
<td>12.23</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*TS</td>
<td>3</td>
<td>0.004</td>
<td>0.74</td>
<td>0.5349</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$Sum of squares for model parameters are those of type III (SAS)

### Table A.28.9B.
Numerical difference and standard error of the estimate for % $^{14}$C-antirrhinoside recovered from petioles to compare greenhouse cultivar transient switch (TS) studies in Table 4.3. Data expressed as percentage were arcsine square root transformed prior to analysis.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>% $^{14}$C-antirrhinoside</td>
<td>Control 1</td>
<td>0.06</td>
<td>0.02</td>
<td>2.72</td>
<td>0.0094</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>% $^{14}$C-antirrhinoside</td>
<td>TS1</td>
<td>0.08</td>
<td>0.02</td>
<td>3.12</td>
<td>0.0033</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>% $^{14}$C-antirrhinoside</td>
<td>Control 2</td>
<td>0.03</td>
<td>0.02</td>
<td>1.36</td>
<td>0.1810</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>% $^{14}$C-antirrhinoside</td>
<td>TS2</td>
<td>0.04</td>
<td>0.02</td>
<td>1.46</td>
<td>0.1514</td>
</tr>
</tbody>
</table>

### Table A.28.9C.
Multiple mean comparisons for % $^{14}$C-antirrhinoside recovered from petioles to compare greenhouse cultivar transient switch (TS) studies in Table 4.3. Data expressed as percentage were arcsine square root transformed prior to analysis.

| CV | Feed | antirrhinoside | LSMEAN | Standard Error | Pr>|t| | LSMEAN Number |
|----|------|---------------|--------|---------------|-----|----------------|
| GI | 400400 | 0.35877903 | 0.01526038 | <.0001 | 1 |
| GI | 400900 | 0.33420473 | 0.01762117 | <.0001 | 2 |
| GI | 900100 | 0.38881487 | 0.01762117 | <.0001 | 3 |
| GI | 900400 | 0.45408268 | 0.01762117 | <.0001 | 4 |
| GIV | 400400 | 0.42228249 | 0.01762117 | <.0001 | 5 |
| GIV | 400900 | 0.41191637 | 0.01762117 | <.0001 | 6 |
| GIV | 900100 | 0.42271605 | 0.01762117 | <.0001 | 7 |
| GIV | 900400 | 0.49049794 | 0.01762117 | <.0001 | 8 |

Least Squares Means for effect CV*Feed
Pr>|t| for HO: LSMean(i)=LSMean(j)
Dependent Variable: antirrhinoside
Table A.29.1A. Two-way analysis of variance for the $^{14}$C-sucrose to $^{14}$C-starch ratio retained from source leaves of two greenhouse cultivars grown at 40 and 91 Pa CO$_2$ and transient switch (TS) studies in Table 4.4.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS†</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R²</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>7.06</td>
<td>10.62</td>
<td>&lt;.0001</td>
<td>0.6559</td>
<td>41.72</td>
</tr>
<tr>
<td>Error</td>
<td>39</td>
<td>3.70</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>46</td>
<td>10.76</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>2.47</td>
<td>26.01</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TS</td>
<td>3</td>
<td>3.71</td>
<td>13.02</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*TS</td>
<td>3</td>
<td>0.93</td>
<td>3.27</td>
<td>0.0314</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Sum of squares for model parameters are those of type III (SAS)

Table A.29.1B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose to $^{14}$C-starch ratio retained from source leaves to compare greenhouse cultivar transient switch (TS) studies in Table 4.4.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose: starch</td>
<td>Control 1</td>
<td>0.50</td>
<td>0.18</td>
<td>2.83</td>
<td>0.0073</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose: starch</td>
<td>TS1</td>
<td>0.40</td>
<td>0.19</td>
<td>2.03</td>
<td>0.0491</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose: starch</td>
<td>Control 2</td>
<td>0.09</td>
<td>0.18</td>
<td>0.51</td>
<td>0.6143</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose: starch</td>
<td>TS2</td>
<td>0.87</td>
<td>0.18</td>
<td>4.89</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Table A.29.1A. Multiple mean comparisons for $^{14}$C-sucrose to $^{14}$C-starch ratio retained from source leaves to compare greenhouse cultivar transient switch (TS) studies in Table 4.4.

<table>
<thead>
<tr>
<th>CV Feed</th>
<th>SucStarch LSMEAN</th>
<th>Standard Error</th>
<th>Pr &gt;</th>
<th>LSMEAN Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI</td>
<td>40=/&gt;40</td>
<td>0.60263330</td>
<td>0.10893239</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>GI</td>
<td>40=/&gt;91</td>
<td>0.89563109</td>
<td>0.13778979</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>GI</td>
<td>91=/&gt;91</td>
<td>0.26159893</td>
<td>0.12578429</td>
<td>0.0442</td>
</tr>
<tr>
<td>GI</td>
<td>91=/&gt;40</td>
<td>0.37933414</td>
<td>0.12578429</td>
<td>0.0045</td>
</tr>
<tr>
<td>GIV</td>
<td>40=/&gt;40</td>
<td>1.09943968</td>
<td>0.13778979</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>GIV</td>
<td>40=/&gt;91</td>
<td>1.29145678</td>
<td>0.13778979</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>GIV</td>
<td>91=/&gt;91</td>
<td>0.35195830</td>
<td>0.12578429</td>
<td>0.0079</td>
</tr>
<tr>
<td>GIV</td>
<td>91=/&gt;40</td>
<td>1.25001926</td>
<td>0.12578429</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Least Squares Means for effect CV*Feed
Pr > | for H0: LSMEAN(i)=LSMEAN(j)
Dependent Variable: SucStarch

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.1033</td>
<td>0.0472</td>
<td>0.1874</td>
<td>0.0073</td>
<td>0.0003</td>
<td>0.1400</td>
<td>0.0004</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.1033</td>
<td>0.0016</td>
<td>0.0866</td>
<td>0.3020</td>
<td>0.0491</td>
<td>0.0059</td>
<td>0.0649</td>
<td></td>
</tr>
</tbody>
</table>

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Least Squares Means for effect CV*Feed
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: SucStarch

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.0472</td>
<td>0.016</td>
<td>0.5120</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.6143</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.1874</td>
<td>0.0086</td>
<td>0.5120</td>
<td>0.0004</td>
<td>&lt;.0001</td>
<td>0.8785</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.0073</td>
<td>0.3020</td>
<td>&lt;.0001</td>
<td>0.0004</td>
<td>0.3305</td>
<td>0.0003</td>
<td>0.4245</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.0003</td>
<td>0.0491</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.3305</td>
<td>&lt;.0001</td>
<td>0.8254</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.1400</td>
<td>0.0059</td>
<td>0.6143</td>
<td>0.0003</td>
<td>&lt;.0001</td>
<td>0.8785</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.0004</td>
<td>0.0649</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.4245</td>
<td>0.8254</td>
<td>&lt;.0001</td>
<td></td>
</tr>
</tbody>
</table>

Table A.29.2A. Two-way analysis of variance for the $^{14}$C-antirrhinoside to $^{14}$C-antirrhide ratio retained from leaves of two greenhouse cultivars grown at 40 and 91 Pa CO$_2$ and transient switch (TS) studies in Table 4.4.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>5.36</td>
<td>5.34</td>
<td>0.0003</td>
<td>0.4958</td>
<td>16.04</td>
</tr>
<tr>
<td>Error</td>
<td>38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>10.82</td>
<td>10.82</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>1.58</td>
<td>10.99</td>
<td>0.0020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TS</td>
<td>3</td>
<td>1.24</td>
<td>2.89</td>
<td>0.0490</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*TS</td>
<td>3</td>
<td>6.81</td>
<td>3</td>
<td>0.0010</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^*$Sum of squares for model parameters are those of type III (SAS)

Table A.29.2B. Numerical difference and standard error of the estimate for $^{14}$C-antirrhinoside to $^{14}$C-antirrhide ratio retained from source leaves to compare greenhouse cultivar transient switch (TS) studies in Table 4.4.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhinoside:antirrhide</td>
<td>Control 2</td>
<td>0.28</td>
<td>0.22</td>
<td>1.29</td>
<td>0.2032</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhinoside:antirrhide</td>
<td>TS1</td>
<td>0.33</td>
<td>0.24</td>
<td>1.39</td>
<td>0.1715</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhinoside:antirrhide</td>
<td>Control 1</td>
<td>1.10</td>
<td>0.22</td>
<td>4.97</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-antirrhinoside:antirrhide</td>
<td>TS2</td>
<td>0.34</td>
<td>0.22</td>
<td>1.55</td>
<td>0.1297</td>
</tr>
</tbody>
</table>

Table A.29.2C. Multiple mean comparison estimate for $^{14}$C-antirrhinoside to $^{14}$C-antirrhide ratio retained from source leaves to compare greenhouse cultivar transient switch (TS) studies in Table 4.4.

| CV  | Feed | AntiAntirrhide LSMEAN | Standard Error | Pr > |t| | LSMEAN Number |
|-----|------|-----------------------|----------------|------|------|----------------|
| GI  | 40=>40 | 2.00335759 | 0.14322678 | <.0001 | 1  |
| GI  | 40=>91 | 1.93764012 | 0.16946821 | <.0001 | 2  |
| GI  | 91=>40 | 2.62456278 | 0.15470260 | <.0001 | 3  |
| GI  | 91=>91 | 2.18703014 | 0.15470260 | <.0001 | 4  |
| GIV | 40=>40 | 3.10535034 | 0.16946821 | <.0001 | 5  |
| GIV | 40=>91 | 2.27165554 | 0.16946821 | <.0001 | 6  |
| GIV | 91=>40 | 2.34127093 | 0.15470260 | <.0001 | 7  |
| GIV | 91=>91 | 2.52588250 | 0.15470260 | <.0001 | 8  |
Table A.29.3A. Two-way analysis of variance for the \(^{14}\text{C}\)-sucrose to \(^{14}\text{C}\)-antirrhinoside ratio retained from leaves of two greenhouse cultivars grown at 40 and 91 Pa \(\text{CO}_2\) and transient switch (TS) studies in Table 4.4.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>Value</th>
<th>Pr&gt;F</th>
<th>(R^2)</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>39.53</td>
<td>6.44</td>
<td>&lt;.0001</td>
<td>0.5428</td>
<td>39.64</td>
</tr>
<tr>
<td>Error</td>
<td>38</td>
<td>33.30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>45</td>
<td>72.84</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>0.91</td>
<td>1.04</td>
<td>0.3146</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TS</td>
<td>3</td>
<td>31.08</td>
<td>11.82</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*TS</td>
<td>3</td>
<td>6.82</td>
<td>2.59</td>
<td>0.0667</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^*\)Sum of squares for model parameters are those of type III (SAS)

Table A.29.3B. Numerical difference and standard error of the estimate for \(^{14}\text{C}\)-sucrose to \(^{14}\text{C}\)-antirrhinoside ratio retained from source leaves to compare greenhouse cultivar transient switch (TS) studies in Table 4.4.

<table>
<thead>
<tr>
<th>Contrast Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV (^{14}\text{C})-sucrose: antirrhinoside</td>
<td>Control 1</td>
<td>0.18</td>
<td>0.55</td>
<td>0.33</td>
<td>0.7452</td>
</tr>
<tr>
<td>GI vs. GIV (^{14}\text{C})-sucrose: antirrhinoside</td>
<td>TS1</td>
<td>0.98</td>
<td>0.59</td>
<td>1.65</td>
<td>0.1071</td>
</tr>
<tr>
<td>GI vs. GIV (^{14}\text{C})-sucrose: antirrhinoside</td>
<td>Control 2</td>
<td>0.86</td>
<td>0.54</td>
<td>1.60</td>
<td>0.1178</td>
</tr>
<tr>
<td>GI vs. GIV (^{14}\text{C})-sucrose: antirrhinoside</td>
<td>TS2</td>
<td>1.06</td>
<td>0.54</td>
<td>1.97</td>
<td>0.0560</td>
</tr>
</tbody>
</table>

Table A.29.3C. Multiple mean comparisons for \(^{14}\text{C}\)-sucrose to \(^{14}\text{C}\)-antirrhinoside ratio retained from source leaves to compare greenhouse cultivar transient switch (TS) studies in Table 4.4.

| CV     | Feed | SucAnti LSMEAN | Standard Error | Pr>|t| | LSMEAN Number |
|--------|------|----------------|----------------|-------|----------------|
| GI     | 40=>40 | 1.69611392 | 0.35383622 | <.0001 | 1 |
| GI     | 40=>91 | 4.40546651 | 0.41866466 | <.0001 | 2 |
| GI     | 91=>91 | 1.61706203 | 0.38218680 | 0.0001 | 3 |
| GI     | 91=>40 | 1.43555159 | 0.38218680 | 0.0006 | 4 |
| GIV    | 40=>40 | 1.87553648 | 0.41866466 | <.0001 | 5 |
| GIV    | 40=>91 | 3.42835164 | 0.41866466 | <.0001 | 6 |
| GIV    | 91=>91 | 2.48203004 | 0.38218680 | <.0001 | 7 |
| GIV    | 91=>40 | 2.50084988 | 0.38218680 | <.0001 | 8 |

Table A.29.3D. Least Squares Means for effect \(\text{CV}^*\text{Feed}\)

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 (\text{CV}^*\text{Feed})</td>
<td>0.0055</td>
<td>0.0048</td>
<td>0.0527</td>
<td>0.0429</td>
<td>0.1323</td>
<td>0.2032</td>
<td>0.6545</td>
<td></td>
</tr>
<tr>
<td>4 (\text{CV}^*\text{Feed})</td>
<td>0.3891</td>
<td>0.2839</td>
<td>0.0527</td>
<td>0.0003</td>
<td>0.7143</td>
<td>0.4851</td>
<td>0.1297</td>
<td></td>
</tr>
<tr>
<td>5 (\text{CV}^*\text{Feed})</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0429</td>
<td>0.0003</td>
<td>0.0013</td>
<td>0.0019</td>
<td>0.0159</td>
<td></td>
</tr>
<tr>
<td>6 (\text{CV}^*\text{Feed})</td>
<td>0.2341</td>
<td>0.1715</td>
<td>0.1323</td>
<td>0.7143</td>
<td>0.0013</td>
<td>0.7633</td>
<td>0.2749</td>
<td></td>
</tr>
<tr>
<td>7 (\text{CV}^*\text{Feed})</td>
<td>0.1173</td>
<td>0.0866</td>
<td>0.2032</td>
<td>0.4851</td>
<td>0.0019</td>
<td>0.7633</td>
<td>0.4041</td>
<td></td>
</tr>
<tr>
<td>8 (\text{CV}^*\text{Feed})</td>
<td>0.0177</td>
<td>0.0144</td>
<td>0.6545</td>
<td>0.1297</td>
<td>0.0159</td>
<td>0.2749</td>
<td>0.4041</td>
<td></td>
</tr>
</tbody>
</table>

Least Squares Means for effect \(\text{CV}^*\text{Feed}\)

<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (\text{CV}^*\text{Feed})</td>
<td>&lt;.0001</td>
<td>0.8802</td>
<td>0.6198</td>
<td>0.7452</td>
<td>0.0031</td>
<td>0.1396</td>
<td>0.1306</td>
<td></td>
</tr>
<tr>
<td>2 (\text{CV}^*\text{Feed})</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0001</td>
<td>0.1071</td>
<td>0.0016</td>
<td>0.0018</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table A.29.4A. Two-way and one-way analysis of variance for the $^{14}$C-sucrose to $^{14}$C-antirrhinoside ratio recovered from petioles of two greenhouse cultivars grown at 40 and 91 Pa CO$_2$ and transient switch (TS) studies in Table 4.4.

Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS’</th>
<th>F</th>
<th>Pr&gt;F</th>
<th>R$^2$</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>7</td>
<td>43.78</td>
<td>6.72</td>
<td>&lt;.0001</td>
<td>0.5282</td>
<td>42.40</td>
</tr>
<tr>
<td>Error</td>
<td>42</td>
<td>39.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>49</td>
<td>82.89</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>1</td>
<td>29.43</td>
<td>31.61</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TS</td>
<td>3</td>
<td>13.30</td>
<td>4.76</td>
<td>0.0060</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV*TS</td>
<td>3</td>
<td>1.96</td>
<td>0.70</td>
<td>0.5562</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sum of squares for model parameters are those of type III (SAS)*

Table A.29.4B. Numerical difference and standard error of the estimate for $^{14}$C-sucrose to $^{14}$C-antirrhinoside ratio recovered from petioles to compare greenhouse cultivar transient switch (TS) studies in Table 4.4.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Variable</th>
<th>Treatment</th>
<th>Differences</th>
<th>SE</th>
<th>t-value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>Control 1</td>
<td>1.21</td>
<td>0.52</td>
<td>2.33</td>
<td>0.0246</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>TS1</td>
<td>1.97</td>
<td>0.56</td>
<td>3.54</td>
<td>0.0010</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>Control 2</td>
<td>1.90</td>
<td>0.56</td>
<td>3.42</td>
<td>0.0014</td>
</tr>
<tr>
<td>GI vs. GIV</td>
<td>$^{14}$C-sucrose: antirrhinoside</td>
<td>TS2</td>
<td>1.07</td>
<td>0.56</td>
<td>1.93</td>
<td>0.0602</td>
</tr>
</tbody>
</table>

Table A.29.4C. Multiple mean comparisons for $^{14}$C-sucrose to $^{14}$C-antirrhinoside ratio recovered from petioles to compare greenhouse cultivar transient switch (TS) studies in Table 4.4.

| CV Feed | sucAnti LSMEAN | Standard Error | Pr > |L| | LSMEAN Number |
|---------|----------------|----------------|------| | | |
| GI      | 40=>40         | 2.57858333     | 0.34115064 | <.0001 | 1 |
| GI      | 40=>91         | 3.63280269     | 0.39392683 | <.0001 | 2 |
| GI      | 91=>91         | 3.82453981     | 0.39392683 | <.0001 | 3 |
| GI      | 91=>40         | 2.09960170     | 0.39392683 | <.0001 | 4 |
| GIV     | 40=>40         | 1.36332934     | 0.39392683 | 0.0012 | 5 |
| GIV     | 40=>91         | 1.66092968     | 0.39392683 | 0.0001 | 6 |
| GIV     | 91=>91         | 1.92159688     | 0.39392683 | <.0001 | 7 |
| GIV     | 91=>40         | 1.02355648     | 0.39392683 | 0.0129 | 8 |

Table A.29.4D. Least squares means for effect CV*Feed for H0: LSMean(i)=LSMean(j) with dependent variable sucAnti.
<table>
<thead>
<tr>
<th>i/j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.0214</td>
<td>0.7324</td>
<td>0.0035</td>
<td>&lt;.0001</td>
<td>0.0004</td>
<td>0.0014</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.3633</td>
<td>0.0087</td>
<td>0.0035</td>
<td>0.1934</td>
<td>0.4355</td>
<td>0.7509</td>
<td>0.0602</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.0246</td>
<td>0.0002</td>
<td>&lt;.0001</td>
<td>0.1934</td>
<td>0.5960</td>
<td>0.3220</td>
<td>0.5452</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.0855</td>
<td>0.0010</td>
<td>0.0004</td>
<td>0.4355</td>
<td>0.5960</td>
<td>0.6423</td>
<td>0.2591</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.2144</td>
<td>0.0037</td>
<td>0.0014</td>
<td>0.7509</td>
<td>0.3220</td>
<td>0.6423</td>
<td>0.1145</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.0047</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>0.0602</td>
<td>0.5452</td>
<td>0.2591</td>
<td>0.1145</td>
<td></td>
</tr>
</tbody>
</table>