Investigating the effect of postharvest parameters on ‘Redhaven’ peaches

by

Carly Flemming

A Thesis
presented to
The University of Guelph

In partial fulfillment of the requirements for the degree of Masters of Science in Food Science

Guelph, Ontario, Canada
© Carly Flemming, August 2017
Investigating the effect of postharvest parameters on ‘Redhaven’ peaches

Carly Flemming
University of Guelph 2017

Advisor: Dr. Lisa Duizer

The objective of this study was to investigate the effect that postharvest parameters, including, harvest maturity and pre-cooling treatments, have on the sensory and physicochemical profiles of ‘Redhaven’ peaches (Prunus persica cv. Redhaven). Peaches stored under refrigeration are susceptible to developing mealy texture as a result of chilling injury. Currently, sensory evaluation is the best means of measuring mealiness, however, it is costly and inaccessible to growers, thus alternative methods are needed. Visual assessment, compression analysis and predictive modeling, combining variables measured through compression, were compared to sensory evaluation. The study found that peaches of commercial maturity, treated with control delayed cooling were juicier, possessed greater peach flavour, and developed less perceivable mealy texture, compared to forced-air and passive cooling treatments. Neither visual evaluation nor compression testing were strongly associated with the perception of mealy texture. Furthermore, the predictive model was not strong enough in its prediction of mealy texture.
DEDICATION

To Mom, Dad, Julie, Dave, and caffeine, wouldn't have made it without you all!
ACKNOWLEDGEMENTS

Great appreciation is extended to Dr. Lisa Duizer and Dr. Amy Bowen for the assistance, encouragement, and support they have provided throughout the entirety of this project. The advice given, relating to this project and life has become invaluable, thank-you. Additional thanks to Dr. Gale Bozzo for being available to answer my postharvest questions and point me in the right direction.

I must express extreme gratitude to all those at Vineland Research and Innovation Centre who have assisted with this project; all your help, big and small, has been very much appreciated. Thank-you to the Consumer Insights and Postharvest Engineering teams for assisting with planning, harvests, evaluations, sensory panels, and overall keeping me on track. I could not have achieved this alone and am very appreciative that I’ve had the opportunity to work with such a great group. Special thanks to the Ontario Tender Fruit Growers and Agricultural Adaption Council for believing in the necessity of this project and to all the Cold Chain Management research team members involved.

Lastly, thank-you to my family and friends, near and far, who have helped me over the past two years by listening to my student struggles and helping to celebrate my success. Thanks to all the U of G Food Science graduate students who made living in and commuting to Guelph so enjoyable. I’m very appreciative of the communities I’ve developed over the course of my graduate studies, it’s been just peachy.
Contents

ABSTRACT ........................................................................................................................................ iii
DEDICATION ........................................................................................................................................ iii
ACKNOWLEDGEMENTS ................................................................................................................... iv
LIST OF TABLES ............................................................................................................................... vii
LIST OF FIGURES ............................................................................................................................. viii
LIST OF ABBREVIATIONS .................................................................................................................. ix
CHAPTER 1 – GENERAL INTRODUCTION ..................................................................................... 1
CHAPTER 2 – LITERATURE REVIEW ................................................................................................. 4
  2.1. Chilling injury .............................................................................................................................. 4
  2.1.1. Mealiness .............................................................................................................................. 4
  2.1.2. Measures of mealiness ......................................................................................................... 7
  2.2. Harvest parameters .................................................................................................................. 15
     2.2.1. Harvest maturity ............................................................................................................... 15
     2.2.2. Cold storage ..................................................................................................................... 16
     2.2.3. Pre-cooling treatments ................................................................................................... 18
CHAPTER 3 – THE EFFECT OF HARVEST MATURITY AND PRE-COOLING TREATMENTS ON SENSORY AND PHYSICOCHEMICAL PROFILES OF PEACHES ................................................................................. 22
  3.1. ABSTRACT ............................................................................................................................... 22
  3.2. INTRODUCTION ...................................................................................................................... 22
  3.3. MATERIALS AND METHODS ................................................................................................. 24
     3.3.1. Sourcing fruit .................................................................................................................... 24
     3.3.2. Sensory evaluation ........................................................................................................... 26
     3.3.3. Instrumental evaluations ............................................................................................... 27
     3.3.4. Statistical analyses ......................................................................................................... 27
  3.4. RESULTS AND DISCUSSION ................................................................................................. 29
     3.4.1. Preliminary panel performance ....................................................................................... 29
     3.4.2. Product evaluation of Year 1 .......................................................................................... 30
     3.4.3. Discussion of Year 1 ....................................................................................................... 38
     3.4.4. Conclusions from Year 1 ............................................................................................... 41
     3.4.5. Product evaluation of Year 2 .......................................................................................... 42
     3.4.6. Discussion of Year 2 ....................................................................................................... 45
     3.4.7. Conclusions from Year 2 ............................................................................................... 49
  3.5. CONCLUSION .......................................................................................................................... 50
CHAPTER 4 – USE OF VISUAL AND INSTRUMENTAL EVALUATIONS TO MEASURE MEALINESS IN PEACHES

4.1. ABSTRACT .................................................................................................................. 51

4.2. INTRODUCTION ........................................................................................................ 51

4.3. MATERIALS AND METHODS .................................................................................. 53
  4.3.1. Obtaining fruit ........................................................................................................ 53
  4.3.2. Sensory evaluation ............................................................................................... 53
  4.3.3. Physicochemical evaluations .............................................................................. 53
  4.3.4. Visual evaluation .................................................................................................. 54
  4.3.5. Compression analysis ......................................................................................... 54
  4.2.6. Statistical analyses .............................................................................................. 55

4.4. RESULTS ..................................................................................................................... 56
  4.4.1. Correlations .......................................................................................................... 57
  4.4.2. Multiple linear regression .................................................................................... 60

4.5. DISCUSSION ............................................................................................................... 61
  4.5.1. Use of visual evaluations to measure mealy texture ............................................ 61
  4.5.2. Association between physicochemical variables and perceivable mealiness ...... 62
  4.5.3. Use of compression analysis to measure mealy texture ....................................... 63
  4.5.4. Use of multiple linear regression to predict mealy texture ................................. 66

4.6. CONCLUSION ............................................................................................................. 68

CHAPTER 5 – CONCLUSIONS AND FUTURE DIRECTIONS ........................................... 69

5.1. Postharvest parameters ............................................................................................ 69

5.2. Measuring mealiness ............................................................................................... 70

REFERENCES .................................................................................................................... 72

APPENDICES .................................................................................................................... 79

APPENDIX A: Sensory Evaluation .................................................................................. 79
  A.1. Sensory lexicon of attributes evaluated by trained panel ........................................ 79
  A.2. Consent to participate in sensory evaluation of peaches (REB#16JN38) .................. 80

APPENDIX B: Statistical Tables and Figures .................................................................. 83
  B.1. Two-way mixed model ANOVA of products evaluated in Year 2 ......................... 83
  B.2. PCA of products evaluated in Year 2 .................................................................... 84
  B.3. Two-way mixed model ANOVA of the effect of pre-cooling treatments applied in Year 2 ............................................................................................................. 84
  B.4. Backwards multiple linear regression .................................................................... 87
LIST OF TABLES

Table 3.1. Pre-cooling treatments applied in Year 1 .................................................................24
Table 3.2. Pre-cooling treatments applied in Year 2 .................................................................25
Table 3.3. Storage, ripening and evaluation scheme applied in Year 1 and Year 2 ............25
Table 3.4. Mean intensity scores of sensory attributes evaluated in Year 1 .........................30
Table 3.5. Mean intensity scores of sensory attributes evaluated in H1 and H2 peaches ....34
Table 3.6. Means of physicochemical variables evaluated in H1 and H2 peaches ............37
Table 4.1. Variables measured using TA.XT plus compression test .....................................55
Table 4.2. Mean values of measures relating to mealiness .........................................................56
Table 4.3. Mean perceivable mealiness intensities at weekly evaluations ..........................57
Table 4.4. Mean perceivable mealiness intensities associated with visual mealiness assessment categories ........................................................................................................57
Table 4.5. Correlations between perceivable mealiness and visual mealiness .................58
Table 4.6. Length of storage at 20 °C resulting in the development of visual mealiness characteristics ........................................................................................................58
Table 4.7. Correlations between perceivable mealiness and compression analysis measures ..59
Table 4.8. Correlations between perceivable mealiness and physicochemical measures .........60
LIST OF FIGURES

Figure 3.1. PCA with orthogonal (varimax) rotation of products evaluated in Year 1 .................32
Figure 3.2. Spider plot of mean intensities of significant sensory attributes in Year 1...............36
Figure 3.3. Spider plot of mean intensities of significant sensory attributes in Year 2.............44
Figure 4.1. Four-point visual mealiness evaluation scale ..........................................................54
Figure 4.2. Compression curves of mealy and non-mealy samples ............................................59
# LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHC</td>
<td>agglomerative hierarchical cluster analysis</td>
</tr>
<tr>
<td>ANOVA</td>
<td>analysis of variance</td>
</tr>
<tr>
<td>CDC</td>
<td>control delayed cooling</td>
</tr>
<tr>
<td>CI</td>
<td>chilling injury</td>
</tr>
<tr>
<td>FAC</td>
<td>forced-air cooling</td>
</tr>
<tr>
<td>IW</td>
<td>intermittent warming</td>
</tr>
<tr>
<td>KMO</td>
<td>Kaiser-Meyer-Olkin</td>
</tr>
<tr>
<td>PCA</td>
<td>principal component analysis</td>
</tr>
<tr>
<td>PE</td>
<td>pectin esterase</td>
</tr>
<tr>
<td>PG</td>
<td>polygalacturonase</td>
</tr>
<tr>
<td>PRC</td>
<td>passive room cooling</td>
</tr>
<tr>
<td>SSC</td>
<td>soluble solids concentration</td>
</tr>
<tr>
<td>TA</td>
<td>titratable acidity</td>
</tr>
</tbody>
</table>
CHAPTER 1 – GENERAL INTRODUCTION

Peaches (*Prunus persica* (L.) Batsch) are a popular summer fruit. Canadian production of peaches is centralized within Ontario and British Columbia. Within Ontario, production of tender fruit, including, peaches, nectarines, and apricots, accounts for 82% of national production, with the Niagara Peninsula region producing 98% of the Ontario output (Ontario Tender Fruit Growers 2017). In 2011, Statistics Canada reported that the Ontario peach industry generated a yearly revenue of $27.4 million (Statistics Canada 2012); depicting the importance of the peach industry to the Niagara peninsula region. Peaches are a challenging commodity as they ripen quickly at ambient temperature and thus require cold storage to limit ripening and ensure prolonged distribution to consumers. Although cold storage is beneficial, peaches are susceptible to developing chilling injury (CI) when stored at refrigeration temperatures. Symptoms of CI in peaches, include, loss of aroma and flavour, and development of mealy texture (Brovelli et al. 1998a; Lurie and Crisosto 2005); all are known to negatively impact consumer acceptance (Crisosto et al. 2004; Lurie and Crisosto 2005; Olmstead et al. 2015). As the food industry is consumer-driven, Ontario peach growers and retailers must provide consumers with a positive eating experience or risk reduction in revenue.

A recent business action plan was conducted identifying key areas of improvement for the Ontario tender fruit industry. Through discussion with industry stakeholders strategies were developed to achieve positive change within the industry, which included creating a better eating experience for consumers. The business action plan set forth three recommendations, with two forming the basis of the Ontario Stone Fruit Harvest and Cold Chain Best Management Practices project. The recommendations that required further investigation included, the development of forced-air cooling (FAC) best management guidelines as well as investment in Fruit Tracker, a record keeping and orchard management system. The Ontario Stone Fruit Harvest and Cold Chain Best Management project set forth seven research objectives, including, harvesting and packing line systems, traceability modules within Fruit Tracker, and the effect of harvest maturity and FAC on sensory and physicochemical profiles of peaches. While all aspects of the overarching project are essential in the development of a best management practices guide for the Ontario peach industry, this thesis investigated the effect of harvest maturities and pre-cooling treatments on the sensory and physicochemical profiles of ‘Redhaven’ peaches. The ‘Redhaven’ cultivar was selected for investigation as it is one of the
most popular varieties within the Niagara Peninsula region, possessing large production acreage and is a freestone cultivar known to be susceptible to developing CI (DeEll et al. 2015).

Harvest parameters play a key role in ensuring high quality fruit are available for consumers. Current Ontario peach industry practices recommend to harvest fruit at commercial maturity; which is beneficial for enduring packing and transportation. In contrast, peaches harvested at physiological maturity are known to possess a sensory profile that is more desirable to consumers, as a result of increased ripening on the tree. In order to create a better eating experience for consumers, both commercial and physiologically mature peaches were investigated within the thesis presented. Commercial maturity was defined by the grower as fruit containing greater than 50 % red blush colour, with physiologically mature fruit defined as being “ready to eat”. In addition to maturity at harvest, application of pre-cooling treatments have been known to affect the quality of peaches (Crisosto et al. 2004). Within the Ontario peach industry, peaches are treated with passive room cooling (PRC), which is considered to be slow and non-uniform. Recently OMAFRA published recommendations for the Ontario peach industry to adopt FAC (Fraser 2014), which resulted in the business action plan identifying this as a pre-cooling treatment of interest. Contrary to the recommendations of OMAFRA, larger peach exporters, such as, California and Chile, have adopted control delayed cooling (CDC) techniques to ensure high quality peaches reach consumers. To ensure industrial applicability, the research objectives of the present thesis compared the application of FAC and CDC to the current Ontario industry standard, PRC. Chapter 3 outlines the research conducted investigating the optimal harvest maturity and pre-cooling treatment that can lead to a good eating experience of Ontario grown ‘Redhaven’ peaches. Similar to the cooling techniques being applied in California and Chile, it is hypothesized that application of CDC would benefit the Ontario peach industry by maintaining attributes deemed desirable and limiting the development of CI.

Mealiness, a symptom of CI, often develops in cold-stored peaches. Currently, sensory evaluation is considered the gold standard in the evaluation of mealy texture within susceptible fruit. However, sensory evaluation, utilizing trained panelists, is considered costly (Arana et al. 2007; Chen and Opara 2013; Piombino et al. 2013), time consuming (Arana et al. 2007; Huang and Lu 2010; Chen and Opara 2013; Piombino et al. 2013), and inaccessible to growers and retailers (Jaren et al. 2012). To date, several alternative methods of measuring mealy texture have been developed and are considered inexpensive, reliable and accessible. However, not all successful methods reported have been validated using robust sensory evaluation. In Chapter 4, a visual assessment of mealiness was conducted, using a modified mealiness intensity scale
(DeEll and Walker 2015) as well as compression analysis, which has been used to identify mealy texture in apples (Mehinagic et al. 2004; Arana et al. 2007) and tomatoes (Verkerke et al. 1998) was developed for use on peaches. To predict the development of mealiness, a regression analysis, was then performed to include a combination of variables having been measured by the alternative methods that significantly correlated with perceivable mealiness. The use of regression analysis was twofold. First, generation of a model predicting the development of mealiness has not yet been applied to peaches. Second, while successful models have been reported for apples (Mehinagic et al. 2004; Arana et al. 2007) and tomatoes (Verkerke et al. 1998), the models were not validated using robust sensory evaluation methodology, thus calling into question the effectiveness of the reported models. It was hypothesized that through use of regression analysis a predictive model could be generated to predict the development of mealy texture in ‘Redhaven’ peaches using a combination of visual and instrumentally measured variables.

In summary, this thesis has two research objectives pertaining to the eating quality of ‘Redhaven’ peaches grown in the Niagara Peninsula region. First, the effect of harvest maturity and pre-cooling treatments on the sensory and physicochemical profiles of ‘Redhaven’ peaches were investigated to assist in the development of a cold chain best management practice guide to be disseminated across Ontario peach growers. Second, two alternative methods to measuring mealy texture in peaches were explored to provide growers and retailers with a quick, easy to use tool to accurately predict the development of mealiness in peaches.
CHAPTER 2 – LITERATURE REVIEW

2.1. Chilling injury

CI can be broadly defined as damage to the fruit cell membrane (ElMasry et al. 2009). Onset of CI in peaches is known to be triggered by turbulent transportation as well as a combination of storage temperature and duration (Crisosto and Labavitch 2002; Crisosto and Crisosto 2005; Lurie and Crisosto 2005; Infante et al. 2009b; Huang and Lu 2010). Additionally, susceptibility to CI in peaches can be influenced by genetics or cultivar (Lurie and Crisosto 2005), size, orchard conditions (Crisosto and Labavitch 2002; Arefi et al. 2015) and possibly maturity at harvest. Symptoms of CI are challenging to monitor at the production and retail levels as these develop following the removal of fruit from cold storage and during the subsequent ripening period, often taking place while in the consumers’ possession (Lurie and Crisosto 2005; Infante et al. 2009b). Development of CI negatively impacts storage life and is known to reduce consumer acceptance often resulting in reduced repeat purchases if symptoms are prevalent at the time of consumption (Crisosto et al. 2004; Lurie and Crisosto 2005).

2.1.1. Mealiness

Mealiness, also referred to as woolliness, along with loss of flavour are often the first CI symptoms to develop in susceptible peach cultivars (Lurie and Crisosto 2005). With texture known to have an immense influence on consumer acceptance (Olmstead et al. 2015), understanding the development of mealiness is key in both quantifying this texture and applying postharvest strategies that promote mitigation (Lurie and Crisosto 2005; Chaib et al. 2007). The in-mouth perception of mealy texture is commonly defined using terminology such as, soft, dry, granular or sandy, although a consistent definition is not always used (Barreiro et al. 2000; Zhou et al. 2000a; Zhou et al. 2000b; Zhou et al. 2001; Arana et al. 2007; Manganaris et al. 2008). Development of mealiness is a result of an enzymatic imbalance leading to pectin degradation beyond that of normal ripening, affecting the cell wall structure.

The etiology of mealiness has been well documented in apple and tomato cultivars, and it is generally understood that cellular changes lead to this undesirable texture (Ortiz et al. 2000;
Mealiness in apples and tomatoes is caused by pectin degradation in the middle lamella within the extracellular space of the fruit flesh cells (Harker and Hallett 1992; Huang and Lu 2010; Arefi et al. 2015). As a result of the weakened middle lamella, reduced cellular adhesion and cells that separate into clumps in fruit with mealy texture as opposed to rupturing and releasing juice in non-mealy fruit (Arefi et al. 2015). Harker and Hallett (1992) conducted compression and tensile strength tests to determine that mealiness in apples is a result of reduced cellular adhesion associated with reduced surface area caused by an increase in air space from the degrading middle lamella. Applying a complimentary low-temperature scanning electron microscopy analysis, Harker and Hallett (1992) visualized non-mealy apple flesh cells to fracture and release juice as a result of their greater tensile strength and cellular adhesion paired with a weakened cell wall. Similarly, Jaren et al. (2012) concluded that mealiness in tomato is due to a combination of low cellular adhesion, increased wall rigidity, and a greater content of bound water compared to free water, thus resulting in a dry sensation where cells remain intact and retain juice.

In contrast, the process of mealiness development in tender fruit cultivars is not fully understood with several potential mechanisms and cellular components being considered. Peaches are susceptible to developing CI disorders when stored under refrigeration with susceptibility increasing within the temperature range known as the “kill zone”, 2.2 – 7.6°C (Crisosto et al. 2004; Lurie and Crisosto 2005; Lurie et al. 2011; Fruk et al. 2014). Altered pectin metabolism occurring during and following cold storage resulting in an enzymatic imbalance is postulated to be the underlying cause of flesh mealiness in peaches (Ortiz et al. 2000; Crisosto and Labavitch 2002; Infante et al. 2009b; Fruk et al. 2014; Arefi et al. 2015).

Recently, Fruk et al. (2014) reviewed the enzymatic imbalance leading to mealiness as a result of peaches being stored within the “kill-zone” temperature range as well as within optimal storage for an extended period of time. This enzymatic imbalance refers to activity levels of polygalacturonase (PG) and pectin esterase (PE). During the process of normal ripening within peaches, PG is the primary enzyme involved in pectin degradation, leading to flesh softening through hydrolysis of glycosidic bonds within pectin compounds (Prasanna et al. 2007). PG can be further classified as exo- and endo-PG on the basis of the location where hydrolysis occurs on the pectin molecule (Lurie and Crisosto 2005; Prasanna et al. 2007). Pectin esterase aids in the removal of ester linkages (de-esterification) from pectin present within the cell wall, leading to reduced cell wall integrity. The balance between PE and PG activities is required for the ripening process, as de-esterification by PE provides substrate for the PG hydrolysis reaction.
During cold storage, the ability of PG to degrade pectin within the cell wall structure is reduced whereas the de-esterification activity of PE remains stable (Lill et al. 1989; Crisosto and Labavitch 2002; Girardi et al. 2005; Fruk et al. 2014; Arefi et al. 2015). With this change in enzymatic activities, pectin degradation results in longer pectin structures with reduced methyl ester groups, forming insoluble high-molecular weight pectins. Due to their affinity for water, the insoluble pectin components bind free water (juice) within the extracellular region and through calcium facilitators a gel-like substance forms. This gel-like substance is associated with the perception of mealy texture during consumption (Crisosto and Labavitch 2002; Pavez et al. 2013; Fruk et al. 2014; Arefi et al. 2015). Activity of PE has been described to increase, decrease, or remain unchanged in peaches deemed mealy (Lurie and Crisosto 2005), as well as in non-mealy peaches (Prasanna et al. 2007), further indicating that the activity of PE is likely minimally affected by cold storage conditions. Although the majority of researchers agree that the enzymatic imbalance that occurs during cold storage results in the development of mealiness, an additional mechanism pertaining to cellular adhesion has been suggested in reviews conducted by Lurie and Crisosto (2005) and Fruk et al. (2014).

Reduced cellular adhesion between neighbouring cells is another hypothesized mechanism for the development of flesh mealiness in susceptible peach cultivars. As a result of reduced cellular adhesion, neighbouring cells are more likely to fracture between each other, forming clumps perceived as dry, granular flesh (Lurie and Crisosto 2005; Fruk et al. 2014; Arefi et al. 2015). Fruk et al. (2014) linked reduced cellular adhesion to the enzymatic imbalance of PE and PG. The change in pectin degradation activity within the cell walls culminates in reduced cell-to-cell adhesion with cells more likely to fracture as clumps as opposed to individual cells rupturing during consumption (Fruk et al. 2014). Further insight into the cellular structure of mealy peaches revealed the contact regions between cells of mealy fruit are smaller and possess a more spherical shape, relative to non-mealy cells (Pons et al. 2016). In addition to loose cellular adhesion, Pons et al. (2016) identified enlarged intercellular space containing pectic substances, insoluble polysaccharides, cellulose and hemicellulose, leading to the hypothesis that additional carbohydrates could be contributing to the cell wall changes exhibited in mealy peaches. Pons et al. (2016) concluded that peach flesh exhibiting mealy texture was associated with enhanced cell wall metabolism, which is the common mechanism between both enzymatic imbalance and reduced cellular adhesion hypotheses.

Apart from the proposed role of carbohydrate compounds in the development of flesh mealiness in peaches (Pons et al. 2016), additional enzymes and proteins have been proposed.
Expansin, a cell wall modifying protein, has been associated with the development of mealiness in peaches (Obenland et al. 2003). Increased expansin expression is associated with ripening, as expansin expression is ethylene regulated, however, Obenland et al. (2003) identified lower levels of expansin expression and free water content in mealy regions within peaches. Ethylene is a hormone present in fruit that regulates ripening which indicates the climacteric nature of peaches. Furthermore, Obenland et al. (2003) postulated that the reduced expansin expression observed in mealy fruit was associated with both reduced ethylene and PG activity which leads to the pectin imbalanced associated with mealy texture in peaches. Girardi et al. (2005) and Obenland et al. (2003) have identified the ability of ethylene to stimulate the production of PG protein, which is theorized to be advantageous in correcting the enzymatic balance that may lead to development of mealy texture in peaches. The effectiveness of ethylene in reducing or delaying the development of mealy texture in peaches can be seen in the positive results obtained from pre-cooling treatments that make use of exogenous ethylene and treatments that promote the ripening process prior to storage (Girardi et al. 2005; Lurie and Crisosto 2005; Obenland et al. 2008).

Although the mechanism leading to the development of mealiness in peaches is not completely understood, its development in Ontario grown peaches is of concern. Further research as to the mechanism of development will assist in the development of accurate measurement techniques as well as postharvest strategies that can mitigate the development of this undesirable texture. Although the research presented in this thesis does not aim to determine the mechanism of mealiness development in peaches, a better understanding of postharvest factors that affect the occurrence of mealiness will be sought. In identifying optimal postharvest parameters a best management practices can be developed and applied within the Ontario peach industry that promote a better eating experience for consumers.

2.1.2. Measures of mealiness

Mealiness is a challenging textural attribute to evaluate as it cannot be described by a single descriptor. Measuring mealiness has proved challenging due to the complexity and inconsistency of its definition as well as its relatively unknown mechanism of development in peaches. As a complex attribute, mealiness has been defined using various combinations of textural attributes including, juiciness, firmness, granular, crispness and floury, leading to the perception of soft, dry, granular or sandy flesh (Barreiro et al. 1998; Ortiz et al. 2000; Zhou et al.
Extensive research has been conducted to quantify mealiness in apples (Paoletti et al. 1993; Barreiro et al. 1998; Arana et al. 2007), tomatoes (Verkerke et al. 1998; Chaïb et al. 2007; Jaren et al. 2012), and tender fruit, including, peaches (Crisosto and Labavitch 2002; Arana et al. 2007; Infante et al. 2009b). Evaluation of mealiness in peaches has been conducted using various techniques, including, sensory evaluation, visual evaluation, and instrumental evaluations using destructive and non-destructive methods (Arefi et al. 2015). Use of sensory evaluation to measure mealiness is considered the gold standard (Infante et al. 2009b; Ross et al. 2009; Arefi et al. 2015) as no instrument can match the complexity, sensitivity and range of movement of the human mouth (Contador et al. 2016). Although the use of sensory evaluation is advantageous, it possesses disadvantages, including its inaccessibility to growers and retailers (Arana et al. 2007; Jaren et al. 2012). As mealiness has been identified to be an undesirable characteristic within peaches (Crisosto et al. 2004; Olmstead et al. 2015), the Ontario peach industry would benefit from a quick, easy to use tool designed to measure the development of this texture. As no robust instrumental method of evaluating flesh mealiness exists, this thesis aims to identify instrumental measurements that can be used to predict mealiness in Ontario grown ‘Redhaven’ peaches.

2.1.2.1 Sensory evaluation

Sensory evaluation is a useful tool in the analysis of fruit quality (Colaric et al. 2005) as such techniques are able to measure attributes deemed challenging by instrumental methods, including perceivable juiciness, mealiness and peel thickness (Chaïb et al. 2007). Humans are able to perceive minute differences in texture as well as complex textural attributes during mastication. Several types of sensory evaluation tests have been applied to measure mealiness in susceptible fruit. Unfortunately, the use of sensory analysis as an evaluation tool in postharvest horticulture is often considered to be time-consuming (Huang and Lu 2010) and costly (Arana et al. 2007; Piombino et al. 2013), leading to inconsistent methodology being used. Most commonly, sensory evaluation has been used as a comparative tool with novel instrumental methods aiming to measure mealiness accurately. Researchers have also employed sensory evaluation to identify the effect of harvest maturity (Cascales et al. 2005; Infante et al. 2012; Stanley et al. 2013), cold storage (Infante et al. 2008; Ortiz et al. 2009; Cano-Salazar et al. 2012; Stanley et al. 2013; Shinya et al. 2014; Giné-Bordonaba et al. 2016) and application of pre-cooling treatments (Cantor et al. 1992; Infante et al. 2009; Santana et al.
on the sensory profiles of tender fruit varieties. Challengingly, sensory evaluations of mealy texture in fruit have not always been conducted using a consistent definition of the texture or robust methodology. As a result of varying definitions and evaluation methods the reproducibility and validity of these findings needs to be further investigated.

Several sensory evaluation techniques including descriptive analysis (DA) (Brovelli et al. 1998b; Devaux et al. 2005; Arana et al. 2007; Echeverría et al. 2008; Infante et al. 2009a; Santana et al. 2011; Delgado et al. 2013; Piombino et al. 2013; Stanley et al. 2013; Olmstead et al. 2015) and binary questions (Crisosto and Labavitch 2002) have been used to evaluate mealiness in susceptible fruit. Descriptive analysis is considered one of the most powerful sensory evaluation tools as it provides a full description of the sensory characteristics of a specific product (Piombino et al. 2013). Additionally, Chen and Opara (2013) suggest that DA is the best means of objectively measuring food texture. Delgado et al. (2013) utilized DA effectively to evaluate the sensory profiles of peaches and nectarines in the determination of drivers of liking, including mealiness, defined as, “gritty, sandy texture, dry and not juicy”. In contrast, DA methodologies have been applied inconsistently with regard to panel size, sample presentation and scale structure in many other studies pertaining to development of mealiness. Stanley et al. (2013) and Arana et al. (2007) utilized DA in their respective evaluations of mealiness in apricots, peaches and nectarines. However, the chosen panel sizes were below recommendations of 8 – 12 judges (Heymann et al. 2012) and as such results may not be valid due to increased levels of error. Brovelli et al. (1998a) conducted DA on peaches using an optimal panel size of 10 judges. However, samples were presented side-by-side for comparison which can result in assessor bias. Use of continuous line-scales and categorical scales, most frequently ranging between 7 – 15 categories (Lawless and Heymann 2010a), have been commonly used within the DA method. While both continuous line-scales and categorical scales allow for discrimination, an adequate number of categories must be provided to the judge to elicit robust discrimination (Lawless and Heymann 2010a). In the case of Stanley et al. (2013), mealiness in apricots was rated along a three point category scale anchored between ‘no mealiness’ and ‘high mealiness’, and as such likely lacked detailed discrimination between apricot samples. In addition to DA, binary style questions, commonly used in quality control settings, have been employed in the evaluation of mealy texture in peaches (Crisosto and Labavitch 2002). Crisosto and Labavitch (2002) were able to detect mealiness through the use of a presence or absence question, however, were unable to differentiate samples based on intensity. Despite the fact that DA has been noted as the optimal sensory evaluation method,
research studies must ensure that proper methodology is followed so that findings can be reproduced and considered valid.

The definition of ‘mealiness’ utilized during sensory evaluation remains inconsistent, making comparisons between studies challenging and questions the robustness of the findings obtained. Several researchers have defined mealy texture using a single textural attribute which is contrary to the understanding that mealiness is a complex attribute invoking several sensory perceptions (Arefi et al. 2015). Crisosto and Labavitch’s (2002) trained panel evaluated mealiness as, “the feeling of graininess”, whereas Paoletti and colleagues (1993) applied the definition, “crumbling during mastication”, both excluding the lack of juiciness commonly reported. Although mealy texture may develop as a result of flesh cells separating into clumps rather than fracturing individually, the crumbling sensation rated by Paoletti et al. (1993) is not incorrect, however, the definition used does not indicate the multidimensionality of this attribute.

In contrast, researchers have measured perceivable juiciness in peaches through DA and reported results pertaining to perceivable mealiness, although there was no evaluation of granular or clumping texture (Infante et al. 2009b). Furthermore, the trained panel utilized by Arana et al. (2007) assessed woolliness in peaches and nectarines as, “dry, mealy texture, soft and dry fiber, lack of taste aroma, a decrease in flesh brightness, and the impossibility to obtain juice”. The aforementioned definition is more appropriate for CI and lesser so for the specific sensation of woolliness. Additionally, several research studies omit the definition of ‘mealiness’ evaluated by the trained sensory panel, further inhibiting the repeatability and comparability of mealiness evaluations (Lill and van der Mespel 1988; Verkerke et al. 1998; Brovelli et al. 1998b; Chaïb et al. 2007; Jaren et al. 2012). Overall, conflicting definitions of mealy texture aids in the challenging nature of evaluating its development in susceptible fruit.

Currently, there is no research indicating consumer tolerance of mealiness within any susceptible fruit cultivar and as such the application of such a threshold is arbitrary and could possibly lead to inaccurate reporting. Arana et al. (2007) utilized a trained panel to conduct DA on apples, peaches, and nectarines with intensity ratings marked along a 9 point category scale. In the subsequent analysis, values were multiplied by a factor of 5 resulting in a minimum sensory rating of 5 and a maximum rating of 45 (Arana et al. 2007). An arbitrary threshold value of 20 was then set where fruit receiving a mealiness intensity score above 20 were deemed ‘unsuitable for marketing’ (Arana et al. 2007). Similarly, Jaren et al. (2012) set a threshold value of three along a five point scale, where fruits scoring a three or above were deemed ‘mealy’. While a threshold likely does exist for the intensity of mealiness, it can only be assessed by
consumers and without a consistent definition threshold determination would be challenging. Overall, several sensory evaluation studies have been performed within the postharvest horticulture field to assess mealy texture. However, further evaluation of mealiiness using consistent, sound sensory practices is needed to better understand the impact of cold storage, application of treatments as well as in the comparison of novel measurement techniques.

2.1.2.2. Visual evaluation

Visual evaluations are commonly used in the horticultural field as it provides a quick tool for growers and retailers to ascertain a perceived level of quality. Although visual evaluations can assess indicators of marketable quality, including, size, shape, and colour (Kader 2002), the accuracy and reliability of visual evaluations of mealy texture in peaches is relatively unknown. To date, few studies have employed visual evaluations of mealiiness (Brovelli et al. 1998b; Crisosto et al. 1999; Crisosto et al. 2001; Crisosto and Labavitch 2002; Obenland et al. 2003; Cantín et al. 2010), however, even fewer have provided enough detail for replication.

Several researchers have evaluated the development of mealiiness in peaches visually with similar descriptors being used to identify the mealy texture, including the appearance of coarse, dry, and stringy flesh with little to no juice released upon squeezing (Brovelli et al. 1998b; Crisosto et al. 1999; Obenland et al. 2003). Unfortunately, rarely do researchers compare the results of such visual evaluations to that of evaluation methods known to be accurate, such as a trained sensory panel. As sensory evaluation has not been used as a validation tool, the reliability and validity of such visual evaluation methods is questioned and needs to be further investigated prior to use. Brovelli et al. (1998a) employed four trained judges to differentiate visual mealiiness as well as a trained sensory panel to assess in-mouth perceivable mealiiness in peaches. However, although Brovelli et al. (1998a) classified peaches as ‘mealy’ and ‘non-mealy’ through the use of visual evaluation, there is no mention of correlations found between these two evaluation techniques, thus accuracy and reliable cannot be inferred. In contrast, Crisosto and Labavitch (2002) compared the use of visual evaluations to that of in-mouth evaluations conducted by a trained sensory panel, with the panel able to detect mealiiness 1 week in advance of the visual evaluation method. Similarly, Obenland et al. (2003) utilized visual evaluations to assess mealiiness development in peaches, however, concluded that visual evaluations were subjective and inaccurate when compared to instrumental measurement methods. As researchers currently disagree in regard to accuracy and validity of visual mealiiness assessments further investigation into the effectiveness of such
methods is required. To date several visual evaluation scales have been developed to measure the development of mealiness in peaches, however, further research needs to be completed to determine if visual evaluation methods can be used by growers and retailers in a reliable fashion. The presented thesis aims to use robust sensory evaluation to validate a visual mealiness scale that can provide Ontario peach growers and retailers with an alternative method to measure mealy texture.

2.1.2.3. Instrumental evaluation

Instrumental means have been implemented to measure mealy texture across several commodities including, apples (Harker and Hallett 1992; Barreiro et al. 1998; Barreiro et al. 2000; Arana et al. 2007), tomatoes (Verkerke et al. 1998; Verkerke and Kersten 2000; Jaren et al. 2012) and tender fruit (Lill and van der Mespel 1988; Barreiro et al. 1998; Barreiro et al. 2000; Crisosto and Labavitch 2002; Arana et al. 2007; Infante et al. 2009b; Huang and Lu 2010). Instrumental testing has been preferred over the use of sensory evaluation as a result of the associated disadvantages previously listed. To date, mealiness has been measured with destructive instrumental tests such as, analysis of free juice (Lill and van der Mespel 1988; Crisosto and Labavitch 2002; Infante et al. 2009b), compression (Verkerke et al. 1998; Jaren et al. 2012), penetration (Arana et al. 2007), shear (Barreiro et al. 1998; Barreiro et al. 2000; Ortiz et al. 2000; Arana et al. 2007), and tensile tests (Harker and Hallett 1992). Additionally, nondestructive techniques have been proposed including hyperspectral scattering (Huang and Lu 2010) and magnetic resonance imaging (Barreiro et al. 2000), however, destructive techniques are currently considered to have better performance in measuring mealiness (Arefi et al. 2015). Although research has been conducted to determine optimal methods of evaluating mealiness, effective, easy-to-use techniques that are accessible to Ontario peach growers and retailers need to be identified and further refined.

Early research on instrumental measurement of mealiness in tender fruit has focused on single attributes (eg. juiciness). However, it is now accepted that perceivable mealiness is a multicomponent texture. Lill and van der Mespel (1988) identified mealiness in nectarines as possessing low juiciness, when free juice content was analyzed following homogenization and centrifugation. Juice content (%) was reported as the weight of the supernatant as expressed as a percentage of the initial weight of the sample. Through use of an untrained sensory panel, Lill and van der Mespel (1988) concluded that juice content (%) was highly correlated ($R^2 = 0.82$) with perceivable mealiness, suggesting free juice was an excellent indicator of mealy texture in
nectarines. By using untrained panelists, Lill and van der Mespel (1988) were more likely to encounter reduced agreement between judges as scale usage or attribute definition may not have been used in unison, however, panel agreement was not reported. More recently, Crisosto and Labavitch (2002) developed a new press apparatus to obtain free juice from peaches and nectarines and similar to previous research used homogenization and centrifugation to report free juice content as a percentage of initial sample weight. Furthermore, Crisosto and Labavitch (2002) applied sensory evaluation through use of a binary, presence or absence style question, where juice content, measured instrumentally, was highly correlated with perceivable mealiness ($R^2 = 0.91$). A drawback of both studies is the use of centrifugation being applied during juice collection, which may reduce free juice content, thus providing inaccurate results. The immense force applied during centrifugation can agitate gel forming pectins, further promoting development of gel formation thus reducing the free juice content (Crisosto and Labavitch 2002). As centrifugation may further decrease the free juice content such methods are not suggested for use in the determination of mealiness.

To avoid the amplified gelation effect imposed by centrifugation, additional free juice analyses have been developed (Infante et al. 2009b; Jaren et al. 2012). Infante and colleagues (2009) compressed peach samples between pre-weighed filter paper, calculating juice content as the change in weight of the filter paper as a percentage of the initial sample weight. To evaluate the effectiveness of this new method Infante et al. (2009) used a trained sensory panel as well as Lill and van der Mespel's (1988) free juice method as comparative tools. Both free juice methods moderately correlated ($R^2 = 0.74$ and $R^2 = 0.64$, respectively) with the perception of mealiness, as evaluated by a trained panel, which used a line-scale anchored by the terms "extremely juiceless" and "extremely juicy". Similar to Lill and van der Mespel's (1988) research design, Infante et al. (2009) evaluated the effectiveness of this paper absorption method in measuring perceivable juiciness and not mealiness, as was reported. In tomatoes and apples, juiciness has been measured as the area stained (cm$^2$) during compression (Barreiro et al. 1998; Jaren et al. 2012), however, juiciness measured instrumentally did not correlate with perceivable mealiness (Jaren et al. 2012).

In addition to measures of juice content, mechanical tests evaluating mealiness in fruit have been conducted with low cost and time requirements in an attempt to mimic mastication, with varying success being reported (Arefi et al. 2015). Mechanical testing has been conducted by compression, penetration, and shear rupture, but the validity and appropriateness of each test needs to be further investigated. As mealy texture may be caused by flesh cells with
reduced adhesion to neighbouring cells (Lurie and Crisosto 2005; Fruk et al. 2014; Arefi et al. 2015), analysis of cellular structure through mechanical testing could be useful. Paoletti et al. (1993) used mechanical tests including, compression, double compression, and penetration in an attempt to optimize the measurement of mealiness in apples. A high correlation between perceivable mealiness, defined as, “crumbling during mastication”, and double compression, measuring cohesiveness was obtained. Although these two methods were highly correlated, results are likely inflated as the definition of mealiness used by the sensory panel only takes into account a single textural attribute, cohesiveness. Similar work was conducted by Arana et al. (2007) where penetration, shear rupture and confined compression were used to evaluate mealiness in apples and woolliness in peaches. This study concluded firmness measurements are highly correlated with sensory intensity ratings. Similar to the work of Paoletti et al. (1993) the definition used by Arana and colleagues’ (2007) DA panel does not accurately define mealiness, and instead defines internal breakdown. As a result of the broad definition employed by Arana et al. (2007) it is likely that peaches exhibiting high intensities of ‘woolliness’ are likely undergoing internal breakdown, thus reduced firmness would be hypothesized with the high correlation between findings being reflective of the parameters measured. Overall, mealiness cannot be measured as a single texture attribute through use of instrumental means, instead multiple variables assessing overall texture should be included with a regression model being developed.

Significant advances have occurred in instrumental measurement methods and model generation of “pleasantness” in tomatoes which provides growers the ability to guarantee sensory profile success in the market (Verkerke et al. 1998). Verkerke et al. (1998) modeled the various components of “pleasantness” and in the process identified predictors of mealiness, including juiciness and measures of cellular structure through use of compression testing. Measures of cellular structure assessed in the aforementioned study included, slope of the force-deformation curve, breaking force of the pericarp, and total energy required to break the sample. Although Verkerke and colleagues (1998) method was applied to tomatoes, application should be considered for the peach industry since a model predicting perceivable mealiness in peaches does not exist. To date, researchers have used a combination of instrumental tests to categorize “mealy” peaches as possessing low crispness, firmness and juiciness. However, no comparison to perceivable mealiness was conducted to confirm the validity of these predictors. Furthermore, predictive models predicting the development of mealiness in peaches have not yet been developed, making the objective of the present study both novel and necessary as
alternative measurements methods to sensory evaluation would benefit the Ontario peach industry.

2.2. Harvest parameters

Both harvest maturity and postharvest management play an important role in the marketability of peaches. Harvest maturity is known to affect the ultimate flavour and market life of peaches. Peaches harvested at commercial maturity can result in fruit that ripens abnormally and possesses reduced soluble sugars and higher acid concentrations (Crisosto and Valero 2008). Comparatively, peaches harvested at physiological maturity are softer and are more prone to injury. Following harvest, cold storage is necessary to prolong shelf life as peaches deteriorate quickly at room-temperature. While cold storage can lengthen storage-life, the postharvest life of peaches is limited by CI. Ensuring that consumers are presented with high quality peaches is challenging as harvest maturity and optimal postharvest management techniques need to be considered.

2.2.1. Harvest maturity

Fruit maturity at the time of harvest plays a critical role in the marketability of peaches. Harvest maturity influences flavour development, susceptibility to physiological disorders (Murray et al. 1998), mechanical injury as well as the ability of the fruit to ripen normally (Crisosto and Mitchell 2002). In general, peaches harvested at physiological maturity are associated with a better eating experience as increased time on the tree results in higher sugar content, decreased acidity, and greater development of flavour. The fruit softens and has elevated juiciness (Infante et al. 2012). However, peaches of physiological maturity are more prone to mechanical injury during packaging and transportation as well as microbial infection (Crisosto and Mitchell 2002) as a result of reduced firmness. In contrast, peaches harvested immaturely are susceptible to slow and irregularly ripening behavior and increased susceptibility to water loss during cold storage as a result of an underdeveloped surface cuticle (Crisosto and Mitchell 2002). From a distribution point of view, the firm characteristic of immature fruit is beneficial in reducing mechanical injury, including, impact and compression bruising incurred over the packing line as well as abrasions and cuts (Crisosto and Valero 2008). Thus, optimal harvest maturity can be defined as the highest maturity point that does not limit postharvest handling and management (Crisosto and Mitchell 2002; Layne 2007).
Most commonly, growers assess harvest maturity of peaches based on background colour and firmness measurements (Crisosto and Valero 2008). However, other criteria including, size, shape, and sugar and acid development have been used as indicators (Gonçalves et al. 2016). As a peach reaches optimal maturity, the peel colour changes from completely green to partially yellow. This change in colour is due to a loss of chlorophyll pigmentation and carotenoid synthesis (Murray et al. 1998). Correlations between background colour and flesh firmness have been observed (Infante et al. 2012), further strengthening the application of colour measurement as an optimal harvest maturity index (Gonçalves et al. 2016). Crisosto (2002) has further defined harvest maturity parameters using measurements of firmness, where peaches ready for “commercialization” have a flesh firmness between 26.5 – 35.5 N and fruits “ready for consumption” fall between 8.8 – 13.2 N force required to penetrate the flesh. Measuring firmness as a means of maturity is less economical when compared to background colour as firmness measurements result in destruction of the fruit beyond marketability. Although maturity is challenging to evaluate, harvesting peaches at an optimal maturity is key in ensuring high quality fruits are marketed to consumers, however, there are postharvest management tools that can assist in the storage and delivery of peaches that meet consumers’ expectations. Based on the literature summarized, it is hypothesized that through use of robust sensory and physicochemical evaluations, harvest maturity will affect the profiles of Ontario grown ‘Redhaven’ peaches.

2.2.2. Cold storage

Cold storage is an effective means of extending the shelf life of fresh fruit and vegetables (Lurie 2002). Storage at low temperature is a critical component of postharvest management for many commodities with high perishability due to its effectiveness in minimizing physiological (Brovelli et al. 1998a; Lurie and Crisosto 2005; Mitcham 2011) and biochemical (Brackmann et al. 1993) changes, reducing development of rot organisms and fungus (Mitchell and Kader 1989; Lurie 2002) and limiting water loss resulting in peel shriveling (Mitchell and Kader 1989; Mitcham 2011). Tender fruit benefit from cold storage temperatures between -0.5 to 0 °C and high RH. Strict temperature management is key as peaches and nectarines are most susceptible to developing CI when stored between 2.2 – 7.6°C (Brovelli et al. 1998; Lurie and Crisosto 2005; Lurie et al. 2011; Fruk et al. 2014; Crisosto et al. 2004). Physiological symptoms of CI include flesh mealiness and reduced aroma and flavour characteristics as early indicators, as well as development of flesh browning, reddening and translucency with the
potential of failure to ripen (Brovelli et al. 1998a; Lurie and Crisosto 2005). Such CI symptoms become apparent after the fruit is removed from cold storage and with the initiation ripening (von Mollendorff and de Villiers 1988).

Biochemical changes associated with cold storage can include changes to ethylene production, soluble solid content (SSC), titratable acidity (TA) and aromatic volatile intensity. Ethylene production is limited during cold storage as low temperatures inhibit the ripening pathways (Prasanna et al. 2007). However, SSC has been shown to both, increase and decrease during cold storage. Infante et al. (2008) acknowledged that SSC does not change as sugar accumulation is stalled by inhibited ripening pathways, however water loss (Shinya et al. 2014) as well as solubilization and synthesis of carbohydrates (Girardi et al. 2005) have been suggested as mechanisms for increased SSC observed during cold storage. In contrast, levels of TA decrease during storage which is likely due to the negative effect temperature has on ethylene production and respiration (Girardi et al. 2005) as well as the ease to which acid compounds oxidize (Shinya et al. 2014). Both SSC and TA content contribute to the overall taste of peaches, with elevated SSC linked with greater consumer acceptability in both high and low acid designated cultivars. The ratio of sugar to acid (SSC/TA) has been identified as an indicator of perceivable sweetness and consumer liking (Crisosto et al. 2005). In addition to SSC and TA content, volatile intensity plays an important role in flavour composition (Baldwin 2002). Volatile content can be impaired by extended cold storage as well as a result of CI development in susceptible fruit cultivars (Giné-Bordonaba et al. 2016). Volatile suppression has been extensively studied in apples, with reduced volatile content linked with cold storage that limits the ripening process resulting in diminished enzyme production required to produce esters responsible for flavours and aromas (Brackmann et al. 1993).

Use of cold storage is beneficial in reducing the development of microbial content. Growth of rot organisms, Rhizopus rot (Rhizopus stolonifera), is inhibited below 5°C (Lurie 2002), with grey mold (Botrytis cinerea) and brown rot (Monilinia fructicola) also having reduced growth activity at low temperatures (Mitchell and Kader 1989). Maintaining high levels of relative humidity (RH) (90-95%) within cold storage is optimal as water loss (also referred to as weight loss) is influenced by both temperature and RH parameters (Lurie 2002). Water loss begins to occur after harvest with loss amplified during storage as a result of vapour pressure differences between internal fruit content and the air present within storage atmosphere (Waelti 1991). Weight loss resulting in visual shrinkage and wilting has been reported in peaches; however the point at which visual cues develop has been disputed. Mitchell and Kader (1989) identified
visual shrinkage occurring at 3 – 5% weight loss, whereas, Crisosto et al. (2004) was not able to identify shriveling until weight loss exceeded 10%. Ensuring that high RH exists within storage conditions leads to reduced vapour pressure differences between the internal peach content and the external storage atmosphere, thus resulting in minimized water loss experienced. Additionally, as cold air has less potential to carry water vapour, as compared to warm air, water loss can be mitigated by applying cold temperature and high RH during storage (Lurie 2002). Overall, application of cold storage is necessary to extend the shelf life of fresh fruit and vegetables, however, several considerations are required to ensure products that meet consumer standards are being marketed. To combat the potential negative characteristics occurring as a result of cold storage research into pre-cooling techniques and optimal cold storage conditions is imperative and creates the basis of this research project.

2.2.3. Pre-cooling treatments

Application of cooling treatments prior to cold storage can serve as effective means of reducing the development of CI symptoms, as well as maintaining optimal postharvest characteristics upon delivery to consumers. Currently, within the Ontario peach industry, room cooling is utilized as an industry standard, where peaches are placed in storage conditions and cold air (0°C) passively cools the fruit. Disadvantages of room cooling include slow rate of cooling, and non-uniform cooling amongst fruit due to the lack of circulating air. Additional pre-cooling methods have been researched and are being applied with success, with the application of room cooling suggested if alternative pre-cooling is not available (Mitcham 2011).

FAC has commonly been used to quickly and uniformly remove field heat from several commodities prior to cold storage (Lill et al. 1989; Lurie 2002). This used for products with diverse perishability, including asparagus, berries, sweet cherries, peaches, and plums (Fraser 2014). Internationally, Agar et al. (2006) noted that FAC is an effective means for maintenance of high quality characteristics in apricots harvested within Turkey and transported across Europe. Various FAC techniques exist. The serpentine vertical or horizontal airflow system is preferred due to a small floor area requirement and the ability to cool bulk produce prior to packaging (Fraser 2014). Through the use of a fan, low pressure is created drawing cold air through the system across the fruit with the resulting warm air being deposited back into the refrigerated storage unit to be cooled and the process then repeated. The optimal airflow rate depends on the relative perishability of the commodity being cooled. Peaches should be cooled under FAC conditions using an airflow rate of 0.5 – 1.5 L/s*Kg (Fraser 2014). It has been further
recommended that the RH of the circulating air be greater than 80% to reduce moisture loss from the fruit, as FAC has been known to cause excessive water loss in some commodities (Lurie 2002). Furthermore, Kader and Mitchell (1989) suggested that FAC be applied immediately following harvest with the final storage temperature achieved no more than 18 – 24 hours after harvest. FAC is most often applied at 7/8th of the final temperature as this temperature ensures that most of the field heat is removed and this practice does not result in excessive drying (Mitcham 2011; Fraser 2014). A cooling time of 7/8th can be easily determined using the following formula, \[(\text{starting fruit temperature} – \text{cool room air temperature}) \times 0.875\] (Mitcham 2011). Use of FAC in the postharvest management of peaches allows for minimal time spent within the “kill-zone” temperature range.

Although FAC can be beneficial, Crisosto et al. (2004) identified superior results when a delayed cooling technique is applied prior to cold storage. Crisosto et al. (2004) compared the effects of FAC applied for 6 – 8 hours immediately after harvest to that of a delayed cooling approach. Control delayed cooling involves holding fruit at a specified temperature for a specific duration, allowing fruit to pre-ripen prior to cold storage. Overall, Crisosto et al. (2004) determined that although peaches treated with FAC maintained a higher firmness over the course of 20 days in cold storage, a delayed cooling approach was optimal as it resulted in higher levels of juice (%) and reduced CI symptoms. As a result of this research, additional pre-cooling techniques that pre-ripen peaches prior to cold storage or during storage using exogenous ethylene have been utilized within international tender fruit industries to maintain high quality peaches throughout the cold chain process.

Early research reviewed by Lill et al. (1989) indicated that delayed storage techniques were beneficial in delaying onset and reducing the intensity of CI symptoms, which lead to extended shelf life. Storage of peaches at 20 °C for 24 – 48 hours prior to immediate temperature reduction using FAC to cold storage temperature have been identified as optimal delayed cooling parameters (Choi and Lee 2001; Crisosto et al. 2004). Holding temperatures of 5°C, 10°C (Crisosto et al. 2004), and 30°C (Mitchell 1987) have also been investigated and have correlated with greater development of CI symptoms. Although delayed ripening leads to a reduction of CI symptoms and increased juice content, a reduction in flesh firmness occurs. This may provide logistical challenges in packaging and transportation processes (Lill et al. 1989; Choi and Lee 2001; Crisosto et al. 2004). Different results have been observed when delayed cooling is applied to peaches of advanced maturity. For example, an increase in flesh browning and greater water loss has been reported in physiologically mature peaches having been
treated with delayed cooling (Mitchell 1987), which suggests that peaches of commercial maturity would benefit most from this pre-cooling treatment. As the Ontario peach industry does not currently employ delayed cooling techniques, this research project aims to identify whether or not its application could benefit the industry by providing consumers with a better eating experience.

Similar to delayed cooling, intermittent warming (IW) and application of exogenous ethylene have been utilized to stimulate the production of ethylene within cold stored peaches. IW involves transferring cold-stored fruit to higher temperatures at regular intervals. Ben-Arie et al. (1970) implemented a warming period of two days at room temperature (23 – 25 °C) applied every two weeks to stimulate ethylene production in peaches. Positive results have been observed in tomatoes (Biswa et al. 2012), bell peppers (Liu et al. 2015), and peaches (Artés et al. 1996; Girardi et al. 2005) treated with IW, and most notably the reduction of CI symptoms. Artés et al. (1996) and Girardi et al. (2005) further studied the beneficial effects of IW on reduction of CI symptoms in peaches. Both studies concluded that IW was effective when warming was applied at 20 °C for 24 hours every 8 days (Artés et al. 1996) and following 14 days (Girardi et al. 2005) of cold storage. However, Girardi et al. (2005) concluded that application of IW resulted in increased softening and greater incidence of decay. Overall, application of IW where peaches are warmed to 20 °C for 24 hours was determined useful in mitigating the development of CI symptoms in peaches, however, application may be challenging commercially if space or financial constraints exist and could result in reduced quality if excessive softening and decay develop (Girardi et al. 2005).

Application of exogenous ethylene during cold storage has been utilized to mitigate the development of CI in peaches (Crisosto et al. 2001; Palou et al. 2003; Girardi et al. 2005; Fruk et al. 2014). Similar to delayed cooling and IW storage techniques, application of exogenous ethylene allows fruit to ripen which stimulates the enzymatic activity necessary to maintain optimal textural properties. Relatively low amounts of ethylene need be applied with Crisosto et al. (2001) applying ethylene at 3ppm and Palou et al. (2003) applying various amounts between 0.1 – 100 µl⁻¹. To date, contrasting results have been released as to the effectiveness of exogenous ethylene application. While Crisosto et al. (2001) identified reduced development of mealiness, having been evaluated visually, Palou et al. (2003) observed delayed onset of mealiness in one of the five peach varieties evaluated. Overall, the effect of ethylene in delaying the development of CI symptoms needs to be further analyzed as the benefit of exogenous ethylene applied during cold storage is unclear (Palou et al. 2003; Lurie and Crisosto 2005).
However, it is hypothesized that delayed cooling, IW and exogenous ethylene are effective as ethylene production following removal from cold storage remains normal as compared to fruits cooled rapidly that may incur impaired metabolism, resulting in the development of CI upon removal from cold storage (Lurie 2002).

In summary, proper postharvest management of peaches is necessary to ensure high quality fruit are being presented to consumers. To date, pre-cooling treatments that allow peaches to pre-ripen prior to cold storage have been deemed beneficial within international peach production industries as a result of the ability of fruit to retain characteristics associated with increased consumer liking as well as the mitigation of CI symptoms. However, application of such pre-cooling treatments have not yet been researched within the Ontario peach industry. Thus, it is hypothesized that application of control delayed pre-cooling will result in peaches that maintain high quality characteristics for a longer duration when compared to the current Ontario industry standard, passive cooling. As mealiness is known to negatively impact a consumer’s eating experience as well as reduce opportunity for growers to retain repeat purchases, accurate measures of this undesirable texture are necessary. Currently, sensory evaluation remains the best means of measuring mealy texture in fruit. However, it is not always considered accessible to Ontario growers. As indicated, alternative measurement methods that have previously been reported as successful in measuring mealy texture need to be further validated through comparison with sensory evaluation. As such, this study aims to use sensory evaluation to validate the use of a visual mealiness assessment scale, a quick detection tool, as well as use of compression analysis, which has been deemed successful in detecting mealy texture in other fruit.
CHAPTER 3 – THE EFFECT OF HARVEST MATURITY AND PRE-COOLING TREATMENTS ON SENSORY AND PHYSICOCHEMICAL PROFILES OF PEACHES

3.1. ABSTRACT

Consumers are more likely to repeat purchases when presented with high quality products. As peaches are susceptible to developing chilling injury when stored under refrigeration, harvest parameters that maintain high quality fruit are necessary. The present study investigated the effect that harvest maturity and pre-cooling treatments have on the sensory and physicochemical profiles of ‘Redhaven’ peaches. Two harvest maturities were evaluated; commercial and physiological, as well as pre-cooling treatments; forced-air, passive room and control delayed cooling. Peaches harvested at physiological maturity were found to be sweeter and juicer than those harvested at commercial maturity, but were less firm. Pre-cooling treatments resulted in differing sensory and physicochemical profiles. Peaches treated with control delayed cooling yielded characteristics previously associated with consumer liking, including elevated juiciness and characteristic peach flavour and reduced mealy texture. Overall, application of control delayed cooling at commercial harvest maturity should be adopted by Ontario growers to obtain quality peaches.

3.2. INTRODUCTION

Ensuring that consumers are presented with fruit that generates an optimal eating experience is key for profitability within the peach industry. Research has shown that the ideal peach is described as sweet and possessing a “melting” texture with good flavour (Olmstead et al. 2015). The main drivers of initial peach purchases are appearance and aroma based, whereas repeat purchases are due to flavour and texture characteristics (Olmstead et al. 2015). Negative qualities that impede the purchase of peaches are mealy, pasty, and dry textures (Olmstead et al. 2015) as well as fruit that is unripe, lacks taste and fails to ripen normally (Crisosto 2006). As peaches are soft-fleshed and climacteric fruit that ripen quickly at ambient temperature, cold storage is necessary to prolong shelf-life and ensure availability for consumers. Although cold storage is beneficial in slowing metabolism and ripening processes, peaches are known to develop CI when stored below 10 °C (Mitchell and Kader 1989).
CI development in peaches is most severe during storage between 2.2 – 7.6 °C, the temperature range identified as the “kill-zone”. Symptoms of CI in peaches include, reduced aroma and flavour characteristics, flesh mealiness, off-flavours, as well as flesh bleeding, browning and translucency. Reduced aroma and flavour characteristics as well as development of mealy texture as a result of CI are most often researched due to their negative impact on consumer acceptance (Olmstead et al. 2015). Mealiness is defined as the perception of dry, granular, or floury flesh upon consumption and is known to develop in apple and tomato cultivars, in addition to tender fruit. During normal ripening, the activity of cellular enzymes, PE and PG remain consistent, whereas cold storage disrupts this balance by reducing the activity of PG. As a result of this metabolic imbalance, there is an accumulation of high-molecular weight pectins that possess a high affinity for water instead of normal cellular breakdown. These high-molecular weight pectins trap water, which contains lactones that contribute to characteristic peach flavour and thereby generate the perception of dryness and lack of flavour upon consumption (Ben-Arie and Lavee 1971). Thus, employing optimal pre-harvest and post-harvest management techniques that result in high quality fruit with minimal CI symptoms is necessary for growers and retailers to retain repeat customers and remain profitable within the peach industry.

Various types of pre-cooling treatments have been utilized prior to cold storage as a means of reducing the length of time fruit spends in the “kill-zone”. To date, application of FAC, the rapid application of cool air, as well as CDC, where fruit are held at a temperature that promotes ripening prior to storage are alternative methods to the conventional PRC method. Application of FAC quickly reduces the internal temperature of fruit, reducing the development of CI due to limited exposure to the “kill-zone” (Crisosto et al. 1999). Similarly, application of CDC is a successful pre-cooling treatment for peaches as the ripening of fruit prior to cold storage is beneficial in maintaining normal cell wall metabolism. CDC alleviates the development of mealiness due to the retention of higher levels of PG activity through cold storage (Zhou et al. 2000b).

To date, there is no published research that has compared the sensory and physicochemical profiles of Canadian grown peaches harvested at commercial and physiological maturity and treated with FAC, PRC, and CDC treatments prior to cold storage. Presently, Ontario peach growers apply PRC, putting fruit at risk of developing CI as a result of the slow rate of temperature decline to cold storage temperature. Strategies preventing CI development need to be found. Therefore, the objective of this research is to identify optimal
harvest maturity and pre-cooling parameters that can aid Ontario peach growers in presenting fruit to consumers for a longer period of time and that result in a good eating experience.

3.3. MATERIALS AND METHODS

3.3.1. Sourcing fruit

Peaches (*Prunus persica* cv. Redhaven) were harvested from a commercial grower in Niagara-on-the-Lake, Ontario. In 2015 (Year 1), peaches were harvested at both commercial and physiological maturity. However, only commercial maturity was evaluated in 2016 (Year 2). Commercial maturity (H1) was defined as fruit possessing 50% or more red blush colour, while physiological maturity (H2) was defined as ‘ready to eat’ by the grower. In Year 1, H1 were obtained on August 8\textsuperscript{th} (16 °C, 88 % RH) and H2 fruit were harvested on August 17\textsuperscript{th} (24 °C, 80 % RH). Similarly, in Year 2, peaches of commercial maturity were picked on August 6\textsuperscript{th} (20 °C, 83 % RH) and August 9\textsuperscript{th} (19.5 °C, 66 % RH). Following harvest, peaches were sorted to ensure similar size and absence of bruises and irregularities. Pre-cooling treatments were then applied to the peaches. Specific details of the treatments applied in Year 1 and Year 2 are summarized in Table 3.1 and Table 3.2, respectively.

*Table 3.1. Pre-cooling treatments applied in Year 1 on peaches of commercial and physiological maturity*

<table>
<thead>
<tr>
<th>Pre-cooling treatment</th>
<th>Commercial maturity (H1)\textsuperscript{1}</th>
<th>Physiological maturity (H2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forced-air cooling (FAC)</td>
<td>Cold air (0 °C and 90 % RH) applied at 1.5 L/s*Kg to 0 °C</td>
<td></td>
</tr>
<tr>
<td>Passive room cooling (PRC)</td>
<td>Passive cooling within cold storage unit to 0 °C</td>
<td></td>
</tr>
<tr>
<td>Control delayed cooling (CDC)</td>
<td>Held at 20 °C for 48 hours, then forced-air cooled to 0 °C</td>
<td>-</td>
</tr>
</tbody>
</table>

\textsuperscript{1}1,200 peaches were obtained in each harvest
### Table 3.2. Pre-cooling treatments applied in Year 2 on peaches of commercial maturity

<table>
<thead>
<tr>
<th>Pre-cooling treatment</th>
<th>Year 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pick¹ 1</td>
</tr>
<tr>
<td>Forced-air cooling (FAC)</td>
<td>Cold air (0 °C and 90 % RH) applied at 1.5 L/s*Kg to 0 °C</td>
</tr>
<tr>
<td>Passive room cooling (PRC)</td>
<td>Passive cooling within cold storage unit to 0 °C</td>
</tr>
<tr>
<td>Control delayed cooling (CDC-20)</td>
<td>-</td>
</tr>
<tr>
<td>Control delayed cooling (CDC-10)</td>
<td>Held at 20 °C for 24 hours, then passively cooled to 0 °C</td>
</tr>
<tr>
<td></td>
<td>Pick 2</td>
</tr>
<tr>
<td></td>
<td>Held at 10 °C for 24 hours, then passively cooled to 0 °C</td>
</tr>
</tbody>
</table>

¹1,200 peaches were obtained in each pick

Each pre-cooling treatment was applied once each year, with sensory and physicochemical evaluations conducted in triplicate. Replicates contained 10 randomly assigned fruit from the same pre-cooling treatment application as it was not feasible to conduct the pre-cooling treatments in triplicate. Following the application of pre-cooling treatments, peaches were held in cold storage conditions (0 °C, 90 % RH) until removed for evaluation. Baseline evaluations were conducted on 100 fruit that had not undergone pre-cooling or cold storage. Sensory evaluations were conducted on ripe fruit, whereas physicochemical evaluations were taken on both unripe and ripened fruit, as per the scheme provided in Table 3.3.

### Table 3.3. Storage, ripening and evaluation scheme applied in Year 1 and Year 2

<table>
<thead>
<tr>
<th>Storage</th>
<th>Ripening at 20 °C (Year 1)</th>
<th>Ripening at 20 °C (Year 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvest (0 day)¹</td>
<td>→</td>
<td>3 d</td>
</tr>
<tr>
<td></td>
<td>→</td>
<td>2 d</td>
</tr>
<tr>
<td></td>
<td>→</td>
<td>2.5 d</td>
</tr>
<tr>
<td>7 day (0 day)¹</td>
<td>→</td>
<td>1 – 3 d</td>
</tr>
<tr>
<td></td>
<td>→</td>
<td>1 d</td>
</tr>
<tr>
<td></td>
<td>→</td>
<td>2.5 d</td>
</tr>
<tr>
<td>14 day (0 day)¹</td>
<td>→</td>
<td>0.5 – 2 d</td>
</tr>
<tr>
<td></td>
<td>→</td>
<td>1 d</td>
</tr>
<tr>
<td></td>
<td>→</td>
<td>2.5 d</td>
</tr>
<tr>
<td>21 day (0 day)¹</td>
<td>→</td>
<td>0 – 3.5 d</td>
</tr>
<tr>
<td></td>
<td>→</td>
<td>1 d</td>
</tr>
<tr>
<td></td>
<td>→</td>
<td>2.5 d</td>
</tr>
</tbody>
</table>

¹Fruit evaluated upon removal from cold storage, with 0 day ripening considered unripe

Unripe fruit were removed from cold storage and held at 20 °C for 3 hours prior to evaluations (Nanos and Mitchell 1991). In Year 1, fruit were considered ripe upon achieving flesh firmness within the range of 4.5 – 17.8 N (Crisosto and Crisosto 2005). Table 3.3 summarizes the length to ripening required for each pre-cooling treatment, at each evaluation.
day, to achieve such firmness. As a result of minimal flesh mealiness development in Year 1, the ripening protocol was changed for Year 2 of the project. Within Year 2, a standardized ripening period of 2.5 days was applied to all pre-cooling treatments, at all weekly evaluations to ensure each treatment had the same opportunity to develop mealy texture. Flesh firmness was measured following the method of Crisosto and Crisosto (2005), using a texture analyzer (TA.XT plus; Stable Micro Systems Ltd., UK) with an 8 mm rounded tip probe puncturing to a maximum distance of 6 mm (test speed: 20 mm/s). Ripe fruit were labelled with a randomly generated 3-digit code enabling each peach to be tracked through instrumental and sensory evaluations.

3.3.2. Sensory evaluation

All sensory evaluations took place at Vineland Research and Innovation Centre within the Sensory lab and were conducted by Vineland’s employed, trained sensory panel. This panel was comprised of individuals from the Niagara region. To ensure adequate panelist numbers for testing of the peaches, individuals who were employees of Vineland campus were recruited in 2015 to supplement this panel. Supplementary panelists attended two, separate 1.5 hour training sessions prior to combining with the original panel. During training sessions, the panelists were taught the basics of evaluating food, which included training to identify basic taste and mouthfeel sensations as well as gaining familiarity with characteristics commonly evaluated within peaches. In total, the combined panel consisted of 19 panelists (2 males and 17 females) in Year 1 and 14 panelists (2 males and 12 females) in Year 2. Seven training sessions took place with this panel between March 18th and August 5th to generate a lexicon of 14 attributes with reference standards developed for taste/mouthfeel attributes (Appendix A.1).

The panel evaluated peaches for the 14 attributes using descriptive analysis (Lawless and Heymann 2010b). A maximum of 10 panelists from the pool of trained panelists participated in each evaluation. In total, eight, 1.5 hour evaluation sessions were conducted each year between August 11th and September 8th, 2015 (Year 1) and August 8th and September 1st, 2016 (Year 2). For testing, 15 cm line-scales, labelled with appropriate anchors and reference standards (Appendix A.1) were used. Evaluations were conducted under red light to mask any differences in appearance. Sensory booths were equipped with a computer and product evaluations were recorded using EyeQuestion (Logic8, Netherlands). Each panelist was assigned a unique, whole peach for each evaluation. Two wedges per peach were presented in a monadic and randomized order. Samples were presented in a 2-ounce cup labelled with an
assigned 3-digit code. Panelists were instructed to rinse their palates with filtered water and a piece of unsalted cracker between samples. A maximum of 4 products were presented between breaks to limit panelist fatigue.

Ethics approval was obtained from the University of Guelph Research Ethics Board (REB#16JN38) prior to Year 2 and all participants provided consent (Appendix A.2). Ethics was not obtained prior to Year 1 as full-time student status had not yet been obtained.

3.3.3. Instrumental evaluations

Thirty, unripe fruit per replicate were monitored weekly for weight loss (%) over the course of storage. Peaches were individually weighed and flesh firmness was measured as previously described. An additional measure of flesh firmness was evaluated in Year 2, where the peel was not removed prior to the method described.

For the analysis of SSC, TA, and pH, juice was obtained by pressing one wedge per peach wrapped within 4 layers of cheesecloth (Crisosto and Labavitch 2002). A composite juice sample was collected from each unripe treatment replicate, whereas ripe fruit were evaluated individually. SSC (%) was measured using a portable refractometer (model PR-101α, Atago, Japan). Fresh juice was then frozen for future biochemical analyses (Obenland and Carroll 2000; Orazem et al. 2011). Samples were thawed 1 – 2 months later and TA and pH were evaluated using an automatic titrator (Metrohm AG, Switzerland). TA was measured through titration of 2 mL juice samples with 0.1M NaOH to an endpoint of 8.1 and expressed as percent malic acid (% malic acid) (Kader and Mitchell 1989b). As part of method development, TA of fresh and frozen juice were compared with no differences observed. The ratio of SSC/TA (%) was then calculated.

3.3.4. Statistical analyses

Two-way mixed model Analysis of Variance (ANOVA) was conducted to evaluate descriptive sensory and physicochemical data. Fisher’s least significant difference (LSD) pairwise comparison was used as a post-hoc test. Levene’s test of homogeneity of variance was used to assess attribute variance of sensory and instrumental variables. Data with heterogeneous variance were transformed using Box Cox with optimal lambda. Variables remaining in violation of homogenous variance were analyzed with Welch statistic to determine if one-way ANOVA results could be analyzed reliably. In the case that Welsh statistic was not
deemed reliable, Kruskal-Wallis non-parametric test was used to evaluate samples with Dunn’s post-hoc test applied. A preliminary assessment of panel performance, reviewing replicate effects and assessor interactions, was performed each year to ensure accurate interpretation of results.

The significant descriptive sensory attributes were averaged by product and submitted to covariance (n-1) Principal Component Analysis (PCA). Kaiser-Meyer-Olkin measure of sampling adequacy (KMO) was used to determine which significant attributes should be retained in the PCA models. Within the PCA generated in Year 1, an adequate KMO of 0.680 was obtained with the removal of OAI-smell, whereas acidic, smoothness of flesh, and chewy attributes were removed from the Year 2 PCA and a KMO of 0.812 was obtained. In Year 1, an orthogonal rotation (varimax) was applied to the PCA to force complex attributes onto a single factor for ease of interpretation. Parallel Analysis was used to determine the number of statistically significant dimensions to be retained in the PCA; two factors in Year 1 and one factor in Year 2 were retained. Supplementary variables were overlaid onto the PCA, including the removed significant sensory attributes, as well as physicochemical measurements. Agglomerative Hierarchal Cluster (AHC) analysis using dissimilarities in Euclidean distance and Ward’s method was used to segment products into groups containing similar sensory characteristics. Subsequent ANOVAs were conducted to determine the effect of harvest maturity and pre-cooling treatments as this could not be gleaned from the analysis of products. Pearson coefficients of correlations were calculated between sensory attributes and instrumental variables.

Data were analyzed using XLSTAT® (Addinsoft, France) and SPSS® (IBM, USA) with an alpha of 0.05 used to test assumptions and an alpha of 0.1 to evaluate significant differences between products. Within Year 1, perceivable mealiness significantly differentiated the products at p < 0.06. As mitigating the development of mealy texture was of importance to the project and is key in the identification of an optimal harvest maturity and pre-cooling treatment an alpha of 0.1 was utilized to display differences between the products with focus on perceivable mealiness.
3.4. RESULTS AND DISCUSSION

Due to the collaborative nature and industrial relevancy of this project, research objectives and parameters were altered between Year 1 and Year 2. As a result of these differences, the results and discussion of Year 1 will be reviewed prior to that of Year 2. A brief conclusion is provided for Year 1 which directs the research objectives and project trajectory into Year 2. As Vineland’s trained sensory panel was utilized in both years, a preliminary panel performance assessment is provided that encompasses the findings obtained over the entirety of the project.

3.4.1. Preliminary panel performance

Significant assessor effects were seen across all descriptive attributes in both Year 1 and Year 2, due to the inherent physiological variability between assessors as well as differing scale usage behaviour. Significant assessor effects are commonly observed in sensory evaluation and are not considered problematic in regard to interpreting results (Cliff et al. 2016).

Horticulture variation and the large panel roster utilized are likely contributors to the replicate effects and assessor interactions observed. Additionally, as panelists received wedges from unique peaches such effects and interactions may arise from variation present within treatment replicates and evaluation days. To ensure that results could be accurately interpreted assessors were removed on the basis of performance, as evaluated using post-hoc tables. With the removal of assessors some replicate effects and assessor interactions were decreased to a level of non-significance. In the case that assessor removal did not reduce the significant interactions a comparison of F-values between interactions and product effects were conducted with F-values an indicator of importance or strength of the difference. In regard to all attributes, the F-value obtained by the product effect was greater than the F-value obtained by the assessor interaction (in both Year 1 and Year 2). As the significant product effects accounted for more variance within the ANOVA model than the interaction, significant product effects were interpreted with confidence. The secondary analysis conducted to identify the effect of harvest maturity (Year 1) and pre-cooling application (Year 1 and 2) were reviewed for main effects. Although other interactions exist for some attributes they were not further investigated as panel performance was assessed in the initial ANOVA product outputs.
3.4.2. Product evaluation of Year 1

The sensorial profiles of 17 peach products were initially compared for differences between maturity at harvest, pre-cooling treatment applied, and length of storage. A two-way mixed model ANOVA was utilized to elicit differences between the products. Ten of the 14 attributes evaluated by the trained panel discerned the products (Table 3.4).

Table 3.4. Mean intensity scores of sensory attributes evaluated in Year 1 (n = 17)

<table>
<thead>
<tr>
<th>Attributes(^1)</th>
<th>Year 1</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>SD</td>
<td>p-value(^3)</td>
</tr>
<tr>
<td>OAI-smell(^4)</td>
<td>41.4</td>
<td>21.01</td>
<td>0.026</td>
</tr>
<tr>
<td>citrus(^5)</td>
<td>31.4</td>
<td>15.83</td>
<td>0.368</td>
</tr>
<tr>
<td>tropical fruit(^5)</td>
<td>31.1</td>
<td>18.54</td>
<td>0.150</td>
</tr>
<tr>
<td>vegetal</td>
<td>18.8</td>
<td>16.76</td>
<td>0.004</td>
</tr>
<tr>
<td>OAI-taste(^6)</td>
<td>41.7</td>
<td>20.56</td>
<td>0.018</td>
</tr>
<tr>
<td>sweet</td>
<td>40.0</td>
<td>16.01</td>
<td>0.005</td>
</tr>
<tr>
<td>acidic</td>
<td>41.7</td>
<td>15.02</td>
<td>0.006</td>
</tr>
<tr>
<td>bitter</td>
<td>25.2</td>
<td>16.16</td>
<td>0.111</td>
</tr>
<tr>
<td>astringent</td>
<td>24.4</td>
<td>18.72</td>
<td>0.493</td>
</tr>
<tr>
<td>juicy</td>
<td>47.5</td>
<td>19.63</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>chewy</td>
<td>46.4</td>
<td>18.01</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>smoothness of flesh</td>
<td>44.2</td>
<td>19.43</td>
<td>0.119</td>
</tr>
<tr>
<td>firmness(^7)</td>
<td>55.1</td>
<td>20.52</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>mealy</td>
<td>14.2</td>
<td>17.89</td>
<td>0.055</td>
</tr>
</tbody>
</table>

\(^1\)Attributes rated from 0 (low) to 100 (high)
\(^2\)SD, standard deviation
\(^3\)Evaluated using a p-value ≤ 0.1
\(^4\)Overall aromatic intensity (OAI) – smell is defined as characteristic peach aroma
\(^5\)Attribute was analyzed using Kruskal-Wallis’ non-parametric test and Dunn’s multiple comparison
\(^6\)Overall aromatic intensity (OAI) – taste is defined as characteristic peach taste
\(^7\)Attribute was analyzed using 1-way ANOVA

As instrumental evaluations are often utilized by growers and retailers to characterize peaches, the similarity between findings obtained from sensory and instrumental evaluations needs to be assessed. Pearson’s correlation matrix was used to determine the relationship between the two evaluation methods. Low to moderate correlations were observed between sensory and instrumental evaluations conducted on ‘Redhaven’ peaches. Flesh firmness, measured instrumentally, was positively correlated with perceivable firmness ($r = 0.444, p < 0.0001$) and negatively correlated with perceivable juiciness ($r = -0.376, p < 0.0001$). Comparatively, SSC was not correlated with perceivable sweetness ($r = 0.012, p = 0.787$), however, the ratio of SSC/TA was correlated with both perceivable sweetness ($r = 0.190, p <
Several sensory attributes were significantly correlated with perceivable juiciness, including, perceptions of OAI-taste \( (r = 0.190, p < 0.0001) \), sweetness \( (r = 0.190, p < 0.0001) \), firmness \( (r = -0.244, p < 0.0001) \), and mealiness \( (r = 0.190, p < 0.0001) \).

An additional comparison of products was conducted with the sensory attributes that were identified as differentiating the products (Table 3.4). To this end, the multivariate approach, PCA, was used to depict sensory differences based on the significant sensory attributes. A two-factor PCA accounting for 76.2% of the variance was constructed to observe trends between harvest maturities, pre-cooling treatments and evaluation days (Figure 3.1). Factor 1 (39.3% of variance) was positively loaded with chewy, firmness, and vegetal attributes. Factor 2 (36.9% of variance) is described as a CI continuum as it is positively defined by OAI-taste and juicy attributes while negatively defined by mealy texture. Attributes, sweet, acidic, and bitter were included in the PCA (Figure 3.1) as they were used to significantly differentiate the 17 products, however, did not correlate with either Factor 1 or Factor 2. Instrumental variables, firmness with peel, SSC, TA, SSC/TA, pH, and weight were included as supplementary variables to further explore the relationship between instrumental and sensory attributes in a multivariate fashion, however, only weight contributed to the PCA (Figure 3.1), along Factor 2.
Figure 3.1. PCA with orthogonal (varimax) rotation constructed to include 8 significant sensory attributes (red vectors) identified in Year 1. The overall variance accounted for by the PCA was 76.2% with Factor 1 and Factor 2 accounting for 39.3% and 36.9%, respectively. Six physicochemical variables (blue vectors) and 1 sensory attribute (grey vector; OAI-smell) that didn’t contribute to the variance within the model are overlaid as supplementary variables.
Cluster analysis was used to group products of similar sensory profiles, with 6 groupings identified in Year 1 (identified by the label “Group”, Figure 3.1). H1 products generally grouped based on day of evaluation while all H2 products shared a similar sensory profile (Group 3). Group 1, contained H1 baseline fruit, evaluated without the application of pre-cooling and cold storage, as well as CDC evaluated at day 7 and 14 postharvest and were defined by high OAI-taste and juiciness characteristics, as well as chewy and firm in texture. Similarly, Group 6 encompassed H2 baseline and was defined by OAI-taste and juiciness attributes. Near the origin, Group 3 included all H2 products as well as H1 CDC evaluated on day 21 and was not defined by the attributes contributing to Factors 1 and 2 in the PCA. Groups 2, 4, and 5 show the progression of the H1 FAC and PRC product profiles. Evaluations on day 7 postharvest (Group 5) were not defined by the contributing attributes, however evaluations on day 14 and 21 show the development of CI as mealy texture develops along with reductions in OAI-taste and juicy characteristics. Although FAC and PRC products evaluated at day 14 and 21 are clustered together (Group 2 and 4, respectively), FAC is positioned further along the CI continuum at both evaluation days. Furthermore the sensory profile of H1 CDC products remained relatively consistent, showing minimal movement along the CI continuum, however, elevated chewiness was identified at day 21 postharvest.

To determine the effect of harvest maturity and pre-cooling treatments on sensory and physicochemical profiles of ‘Redhaven’ peaches, additional ANOVAs were conducted. These additional analyses were necessary as the research questions could not be robustly answered from the initial evaluation of products and the resulting PCA. The effect of harvest maturity was evaluated on pre-cooling treatments that were applied to both H1 and H2 fruit, thus CDC fruit were removed from the analysis. Additionally, the effect of pre-cooling treatments were evaluated within H1 and H2 maturities separately.

Harvest maturity

In the investigation of the effect of harvest maturity on the sensory profile of ‘Redhaven’ peaches, three of the 14 attributes evaluated by the panel were affected. Harvest maturity affected perceivable sweetness ($F_{1, 278} = 5.08, p = 0.08$), firmness ($F_{1, 278} = 4.72, p = 0.03$) and juiciness ($F_{1, 278} = 46.01, p < 0.0001$), as summarized in Table 3.5.
Table 3.5. Mean overall intensity scores of sensory attributes evaluated in H1 and H2 peaches within Year 1 (n = 420)

<table>
<thead>
<tr>
<th>Attributes</th>
<th>F-value</th>
<th>p-value</th>
<th>LSD$_{0.1}^1$</th>
<th>H1</th>
<th>H2</th>
</tr>
</thead>
<tbody>
<tr>
<td>OAI-smell</td>
<td>0.32</td>
<td>0.630</td>
<td>3.08</td>
<td>39.9a$^2$ ± 1.09$^3$</td>
<td>41.7a ± 1.09</td>
</tr>
<tr>
<td>tropical fruit$^4$</td>
<td>0.10</td>
<td>0.749</td>
<td>2.71</td>
<td>31.0a ± 1.26</td>
<td>30.0a ± 1.24</td>
</tr>
<tr>
<td>citrus$^4$</td>
<td>1.02</td>
<td>0.314</td>
<td>2.71</td>
<td>31.9a ± 1.12</td>
<td>29.5a ± 0.99</td>
</tr>
<tr>
<td>vegetal</td>
<td>11.57</td>
<td>0.143</td>
<td>17.42</td>
<td>20.47a ± 0.74</td>
<td>16.2a ± 0.74</td>
</tr>
<tr>
<td>OAI-taste</td>
<td>0.45</td>
<td>0.563</td>
<td>6.62</td>
<td>38.7a ± 1.01</td>
<td>43.1a ± 1.01</td>
</tr>
<tr>
<td>sweet</td>
<td>5.08</td>
<td>0.081</td>
<td>1.94</td>
<td>36.4b ± 0.70</td>
<td>43.3a ± 0.70</td>
</tr>
<tr>
<td>acidic</td>
<td>0.38</td>
<td>0.792</td>
<td>6.85</td>
<td>43.4a ± 0.86</td>
<td>39.3a ± 0.86</td>
</tr>
<tr>
<td>bitter</td>
<td>0.08</td>
<td>0.800</td>
<td>10.17</td>
<td>26.8a ± 0.68</td>
<td>23.0a ± 0.68</td>
</tr>
<tr>
<td>astringent</td>
<td>2.12</td>
<td>0.200</td>
<td>2.05</td>
<td>25.4a ± 0.57</td>
<td>23.6a ± 0.57</td>
</tr>
<tr>
<td>firmness$^5$</td>
<td>4.72</td>
<td>0.030</td>
<td>3.30</td>
<td>58.0a ± 1.41</td>
<td>51.1b ± 1.41</td>
</tr>
<tr>
<td>juicy</td>
<td>46.01</td>
<td>&lt; 0.0001</td>
<td>2.59</td>
<td>41.4b ± 0.96</td>
<td>51.6a ± 0.96</td>
</tr>
<tr>
<td>chewy</td>
<td>1.78</td>
<td>0.328</td>
<td>2.34</td>
<td>46.0a ± 0.99</td>
<td>44.1a ± 0.99</td>
</tr>
<tr>
<td>smoothness of flesh</td>
<td>1.64</td>
<td>0.284</td>
<td>2.42</td>
<td>43.9a ± 0.97</td>
<td>46.0a ± 0.97</td>
</tr>
<tr>
<td>mealy$^6$</td>
<td>33.11</td>
<td>0.156</td>
<td>3.68</td>
<td>18.7a ± 0.11</td>
<td>10.4a ± 0.11</td>
</tr>
</tbody>
</table>

$^1$LSD, least significant difference
$^2$Mean values with the same letter in a row are not significantly different at $p \leq 0.1$
$^3$Standard error
$^4$Attributes analyzed using Kruskal-Wallis non-parametric evaluation and Dunn’s post-hoc
$^5$Attribute was analyzed using 1-way ANOVA
$^6$Attribute was transformed using Box Cox transformation, with original means reported

In addition to impacting sensory characteristics, maturity at harvest significantly affected the physicochemical profiles of ‘Redhaven’ peaches. The physicochemical profiles of unripe fruit, evaluated immediately upon harvest were investigated to identify the effect of harvest maturity. Differences between harvest maturities were recorded for weight ($F_{1, 54} = 154.85$, $p = 0.01$), flesh firmness (without peel) ($F_{1, 54} = 203.34$, $p = 0.01$), SSC ($F_{1, 2} = 37.23$, $p = 0.03$), TA ($F_{1, 2} = 46.16$, $p = 0.02$), and pH ($F_{1, 2} = 82.80$, $p = 0.01$). Baseline H1 fruit were firmer ($\bar{x} = 54.4a ± 1.8$ N) and possessed greater SSC ($\bar{x} = 9.6a ± 0.09$ %) and TA ($\bar{x} = 8.0a ± 0.22$ % malic acid) at the time of harvest, while H2 fruit weighed more ($\bar{x} = 145.1a ± 2.3$ g) and possessed a greater ratio of SSC/TA ($\bar{x} = 1.5a ± 0.04$ %) and pH ($\bar{x} = 3.8a ± 0.03$).

Although pH measurements differentiated the harvest maturities, this was marginal as all pH measurements were within a small range of 3.5 – 3.8 and near that of the reported range (3.3 – 3.6) from Italian grown ‘Redhaven’ fruit (Versari et al. 2002). Evaluation of weight and pH are useful in characterizing the peaches evaluated and can provide comparative information.
between studies; however, such variables were not further investigated. Differences observed in regard to weight loss are reported as this is a critical variable in the evaluation of fruit storability.

The effect of harvest maturity, as reported in unripe, baseline fruit, remained consistent over the course of the project. As similar findings were obtained from both unripe and ripe fruit at weekly evaluation intervals, only the baseline results have been reported for brevity. Additionally, H2 fruit ripened quicker upon removal from cold storage, reaching the standardized flesh firmness range of 4.5 – 17.8 N in less time than H1 fruit.

Weight loss over the course of cold storage was evaluated to determine the effect of harvest maturity on the storability of fruit. Peaches harvested at H1 (\(\bar{x} = 3.4 \pm 0.1\) %) generally incurred greater weight loss when compared to H2 fruit (\(\bar{x} = 2.3 \pm 0.1\) %). However, this trend is only apparent for peaches treated with FAC, as weight loss incurred by PRC remained consistent across maturity levels.

**Pre-cooling treatments**

The effects of pre-cooling treatments on both sensory and physicochemical profiles of ‘Redhaven’ peaches were investigated on H1 and H2 fruit separately to ensure all differences were elucidated. Sensory profiles of H1 maturity fruit having undergone pre-cooling treatments, differed significantly in regard to, OAI-taste \((F_{2, 172} = 13.88, p = 0.04)\), sweet \((F_{2, 172} = 5.83, p = 0.02)\), juicy \((F_{2, 172} = 22.89, p = 0.01)\), chewy \((F_{2, 172} = 11.08, p = 0.02)\), and mealy \((F_{2, 172} = 7.43, p = 0.01)\) attributes, as summarized in Figure 3.2.
Figure 3.2. Spider plot of mean overall intensities of 5 attributes significantly (p ≤ 0.1) differentiating the pre-cooling treatments applied to H1 fruit in Year 1 (n=300)

Comparatively, chewiness, evaluated using Welsh statistic, ($H (2) = 7.95$, $p = 0.05$), was the only attribute differentiating the pre-cooling treatments (baseline, FAC, and PRC) when applied to H2 maturity fruit. Elevated chewiness was observed in FAC ($\bar{x} = 45.9a \pm 1.8$) and PRC ($\bar{x} = 45.3a \pm 1.8$) treatments when compared to baseline fruit, evaluated without the application of pre-cooling and cold storage ($\bar{x} = 35.1b \pm 3.1$).

Instrumental evaluations were conducted on both unripe and ripened fruit to determine the effect that application of pre-cooling treatments have on physicochemical profiles of H1 and H2 fruit. Physicochemical profiles of H1 and H2 fruit remained relatively consistent across unripe and ripened fruit, and as such only ripe evaluations will be reported (Table 3.6).
Table 3.6: Overall means of physicochemical variables evaluated in H1 and H2 peaches within Year 1

<table>
<thead>
<tr>
<th>Harvest maturity</th>
<th>Pre-cooling treatment</th>
<th>Firmness (without peel) (N)</th>
<th>SSC (%)</th>
<th>TA (% malic acid)</th>
<th>SSC/TA (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>baseline</td>
<td>9.8a ± 0.673</td>
<td>10.5c ± 0.15</td>
<td>8.3a ± 0.15</td>
<td>1.3a ± 0.03</td>
</tr>
<tr>
<td></td>
<td>FAC</td>
<td>11.0a ± 0.09</td>
<td>11.2a ± 0.09</td>
<td>7.9b ± 0.09</td>
<td>1.4a ± 0.02</td>
</tr>
<tr>
<td></td>
<td>PRC</td>
<td>10.2a ± 0.09</td>
<td>10.8b ± 0.09</td>
<td>7.3c ± 0.09</td>
<td>1.5a ± 0.02</td>
</tr>
<tr>
<td></td>
<td>CDC</td>
<td>8.2b ± 0.38</td>
<td>11.0ab ± 0.09</td>
<td>7.4c ± 0.09</td>
<td>1.5a ± 0.02</td>
</tr>
<tr>
<td>F-value</td>
<td>13.21</td>
<td>3.91</td>
<td>4.97</td>
<td>1.93</td>
<td></td>
</tr>
<tr>
<td>p-value</td>
<td>&lt; 0.0001</td>
<td>0.021</td>
<td>0.082</td>
<td>0.259</td>
<td></td>
</tr>
<tr>
<td>LSD0.14</td>
<td>0.90</td>
<td>0.20</td>
<td>0.21</td>
<td>0.31</td>
<td></td>
</tr>
<tr>
<td>H2</td>
<td>baseline</td>
<td>6.3c ± 0.65</td>
<td>9.1a ± 0.16</td>
<td>5.8a ± 0.11</td>
<td>1.6a ± 0.04</td>
</tr>
<tr>
<td></td>
<td>FAC</td>
<td>9.7a ± 0.09</td>
<td>9.7a ± 0.09</td>
<td>5.4a ± 0.07</td>
<td>1.8a ± 0.02</td>
</tr>
<tr>
<td></td>
<td>PRC</td>
<td>8.6b ± 0.38</td>
<td>9.8a ± 0.09</td>
<td>5.5a ± 0.07</td>
<td>1.8a ± 0.02</td>
</tr>
<tr>
<td>F-value</td>
<td>4.29</td>
<td>0.01</td>
<td>1.51</td>
<td>0.77</td>
<td></td>
</tr>
<tr>
<td>p-value</td>
<td>0.040</td>
<td>0.941</td>
<td>0.345</td>
<td>0.474</td>
<td></td>
</tr>
<tr>
<td>LSD0.1</td>
<td>0.89</td>
<td>0.99</td>
<td>0.95</td>
<td>0.40</td>
<td></td>
</tr>
</tbody>
</table>

1 n = 300  
2 Mean values with the same letter in a column were not significantly different at p ≤ 0.1  
3 Standard error  
4 LSD, least significant difference  
5 n = 210  

In addition to the observations summarized within Table 3.6, measurements of firmness, SSC, TA, and SSC/TA were affected by the length of cold storage applied. Within H1 fruit, firmness decreased ($F_{3, 281} = 20.48$, $p ≤ 0.0001$) as length of cold storage increased, with the same trend observed in evaluations of TA. Furthermore, SSC ($F_{3, 281} = 8.22$, $p ≤ 0.0001$) as cold storage continued with the same trend observed for SSC/TA. Similarly, within H2 maturity fruit, SSC and SSC/TA tended to increase while TA ($F_{2, 191} = 7.41$, $p = 0.045$) decreased with cold storage, however firmness was not affect by the length of cold storage applied.

In regard to weight lost during cold storage, H1 peaches treated with FAC ($\bar{x} = 4.5 ± 0.11$ %) tended to incur greater loss when compared to CDC ($\bar{x} = 3.5 ± 0.14$ %) and followed by PRC ($\bar{x} = 2.4 ± 0.11$ %). A significant treatment*replicate interaction was identified, with CDC replicate 3 differing immensely from the other two CDC replicates. With the removal of this CDC replicate the interaction was reduced to a level of insignificance and further confirmed the trend that FAC resulted in greater loss. Comparatively, within H2 fruit no differences in weight loss ($F_{1, 4} = 0.02$, $p = 0.89$) were observed between FAC ($\bar{x} = 2.4 ± 0.06$ %) and PRC ($\bar{x} = 2.3 ± 0.06$ %) treatments.
3.4.3. Discussion of Year 1

Investigating the sensory and physicochemical profiles of ‘Redhaven’ peaches harvested at two harvest maturities and treated with pre-cooling treatments provides insightful information to growers and retailers who aim to present consumers with an optimal peach eating experience. Drivers of consumer acceptance in peaches have been well documented. The most common key attributes linked with liking or acceptance in peach cultivars, include, sweetness (Crisosto et al. 2005; Delgado et al. 2013), juiciness (Giné-Bordonaba et al. 2016) and characteristic peach flavour (Infante et al. 2008; Ortiz et al. 2009; Delgado et al. 2013). Any reduction in perceivable intensity of these key attributes could limit revenue potential for peach growers and retailers and as such practices should be employed to maintain their presence.

Fruit maturity at the time of harvest is known to affect the sensory and physicochemical profiles of peaches. Researchers have suggested that peaches harvested at physiological maturity possess a better eating quality (Bonghi et al. 1999; Kader 1999). Peaches of physiological maturity possess elevated sweetness (Cascales et al. 2005; Infante et al. 2012), further development lactones that contribute to the characteristic peach flavour (Baldwin 2002), as well as reduced flesh firmness and TA (Ziosi et al. 2008; Infante et al. 2012; Lopresti et al. 2016). Results obtained in the current study align with the existing understanding of physiologically mature peach profiles. Although peaches harvested at physiological maturity in the present study possessed lower SSC this was determined to be a result of variation within the ‘Redhaven’ cultivar or within the orchard. Perceivable sweetness is linked with SSC (Delgado et al. 2013), although higher correlations exist between perceivable sweetness and the ratio of SSC/TA (Colaric et al. 2005), including those revealed in this thesis. This finding fits with those reported by Crisosto and Crisosto (2005) who have suggested that the ratio of SSC/TA is a better indicator of taste in peaches as compared to SSC alone. Furthermore, peaches of physiological maturity are known to ripen rapidly upon removal from cold storage when compared to commercially mature fruit (Stanley et al. 2013), with similar results reported through sensory and instrumental evaluations in the current study. Although peaches harvested at advanced maturity possess characteristics desired by consumers, both Stanley et al. (2013) and Agar et al. (2006) have identified that reduced firmness leads to shortened shelf life of tender fruits, which can be detrimental to retail practices.

The effect that harvest maturity plays on the development of juiciness within peaches has been debated. Infante et al. (2012) observed no difference in regard to perceivable juiciness
in the evaluation of three harvest maturity levels across three peach and two nectarine cultivars. Comparatively, Cascales et al. (2005) observed elevated juiciness in peaches of advanced maturity, as did the current study. In comparison to the study conducted by Infante et al. (2012), a less restrictive flesh firmness range was applied to all ripe fruit evaluations. The application of a strict flesh firmness range (8.8 – 13.2 N) by Infante et al. (2012) could have hindered the development of perceivable juiciness. In this study, there was a correlation between perceivable juiciness and firmness which is consistent with previous research findings (Chauvin et al. 2010; Arefi et al. 2015; Contador et al. 2016), which leads to the conclusion that strict control over flesh firmness (Infante et al. 2012) could result in minimal differences in regard to perceivable juiciness. Furthermore, perceptions of juiciness, peach flavour, and sweetness are correlated (Cano-Salazar et al. 2013), indicating that juice released upon consumption contains sugars and flavour compounds. As perceivable juiciness was correlated with characteristic peach taste and sweetness the current study supports the conclusion of Cano-Salazar et al. (2013).

Mealy texture is one of the most common complaints from retailers and consumers in regard to the quality of peaches (Crisostio et al. 2004). Although mealy texture has been researched extensively, the impact of harvest maturity on its development in peaches is still debated. Immature fruit were considered to be more susceptible to the development of mealiness as compared to fruit of advanced maturity and vice versa, as stated in a review conducted by Lurie and Crisosto 2005. Within the current study, harvest maturity alone had no impact on the development of mealiness, however when combined with the application of pre-cooling treatments, trends were observed during weekly evaluations of the peaches over the course of 21 days in cold storage. In fruit harvested at commercial maturity, FAC and PRC pre-cooling treatments resulted in the development of mealy texture and reduced juiciness and characteristic peach taste as early as day 7 postharvest. Conversely, sensory profiles changed very little in peaches harvested at physiological maturity over the course of storage, regardless of the pre-cooling treatment applied. Giné-Bordonaba et al. (2016) suggest that high sugar content in peaches could act as a membrane protectant and aid in the mitigation of mealy texture in peaches. Although ‘Redhaven’ peaches harvested at physiological maturity did not possess higher SSC, these fruit did possess a greater SSC/TA ratio which may contribute to the mitigation of mealiness.

As peaches ripen rapidly at room-temperature, cold storage is necessary to lengthen the shelf life and availability of these fruit for consumers. Cold storage is necessary for the transport and distribution of peaches, but storage within the temperature range known as the “kill-zone”
can trigger the development of mealiness and other undesirable CI symptoms. Pre-cooling treatments have been applied prior to cold storage in Californian and Chilean peach industries to mitigate the development of CI and retain high quality fruit (Crisosto and Valero 2008). The Ontario peach industry currently employs passive cooling, which is considered non-uniform and slow. Further investigation into pre-cooling treatments applied to Ontario grown peaches is necessary for growers to adopt these practices and help to ensure high quality peaches are reaching consumers. Application of FAC has been recommended (Lurie 2002; Mitcham 2011; Fraser 2014) with the quick reduction of flesh temperature known to slow respiration and lead to increased shelf life (Fraser 2014). The application of rapid, uniformly applied cold air culminates in minimal changes to physiological characteristics, including, reduced development of decay and minimal water lost during storage (Agar et al. 2006; Mitcham 2011; Fraser 2014). However, application of CDC treatments has been identified as optimal in mitigating the development of CI in peaches (Nanos and Mitchell 1991; Zhou et al. 2000b; Crisosto et al. 2004; Miguel-Pintado et al. 2013) and retaining characteristics desired by consumers (Crisosto et al. 2004; Infante et al. 2009a).

Results from the present study align with the findings of Crisosto et al. (2004) where peaches allowed to pre-ripen through application of CDC were juicer and possessed a greater intensity of characteristic peach flavour (Cantor et al. 1992) as compared to fruit treated with FAC. Additionally, fruit treated with CDC developed less mealy texture than FAC and PRC, which is attributed to the advanced ripeness state achieved with use of CDC. Peaches allowed to pre-ripen prior to or during cold storage have shown a rapid rise in PG with the ratio of PG:PE activity remaining balanced upon removal from cold storage (Zhou et al. 2000b; Girardi et al. 2005). Although application of CDC has resulted in mitigation of mealy texture, the application of pre-ripening promotes flesh softening (Nanos and Mitchell 1991) which may pose a logistical challenge in the retail of such fruit. Similarly, within the present study ‘Redhaven’ peaches treated with CDC were softer as detected by instrumental measurements of flesh firmness, however the trained panel was not able to discern the fruit from the various pre-cooling treatments based on firmness. This lack of perceivable difference is likely a result of the standardized flesh firmness range applied to all evaluations of ripe fruit in Year 1. An additional disadvantage of CDC is increased weight lost during cold storage (Crisosto and Valero 2008). Contrary to the literature (Agar et al. 2006; Crisosto and Valero 2008; Mitcham 2011; Fraser 2014), peaches treated with FAC incurred greater weight loss when compared to CDC and PRC treatments applied in the present study. Weight loss has been seen to differ between cultivars (Crisosto et al. 2004) which may account of the results observed in this study. Overall, weight
loss incurred in all pre-cooling treatments was below that of the threshold identified by Crisosto et al. (2004) where visual symptoms of shrinkage become apparent.

Peaches treated with CDC tend to possess characteristics deemed desirable by consumers (Crisosto et al. 2004; Infante et al. 2009a). In contrast, this study found that application of CDC resulted in a greater intensity of perceivable chewiness, when compared to FAC and PRC. To date, chewiness has not been identified in peaches treated with CDC or other pre-cooling treatments for that matter, however, chewiness has been associated with firmness in peaches (Cascales et al. 2005; Chauvin et al. 2010; Contador et al. 2016). Although greater firmness, often identified in immature fruit, has been correlated with increased chewiness, this is likely not applicable to the current study, as instrumental measures of firmness identified CDC fruit to be softer. Further investigation into the effect that CDC has on the texture of the peach flesh and peel is needed to further understand this finding. Additionally, as perceivable chewiness was greater in FAC and PRC treatments applied to H2 fruit, further defining the term used by sensory panel prior to Year 2 is required to understand the perception being measured.

3.4.4. Conclusions from Year 1

Peaches harvested at physiological maturity were identified as possessing a sensory profile that aligned with the characteristics desired by consumers (Bonghi et al. 1999; Kader 1999). Physiologically mature fruit were perceivably sweeter, juicier, and saw minimal development of mealy texture. Although physiologically mature fruit possessed characteristics known to be desired by consumers, the reduced flesh firmness and rapid ripening upon removal from cold storage was thought to pose a logistical concern for growers and retailers. As such, peaches of physiological maturity were not evaluated in Year 2.

Peaches treated with CDC possessed elevated juiciness and characteristic peach flavour, two attributes that are linked with increased consumer liking (Infante et al. 2008; Ortiz et al. 2009; Delgado et al. 2013; Giné-Bordonaba et al. 2016), when compared to the profiles of FAC and PRC treatments subjected to cold storage for up to three weeks. To align with the research being conducted by other members of the Cold Chain Management project, two CDC treatments were evaluated in Year 2. Through discussions with the research team, which includes commercial growers, CDC treatments were applied with the use of passive-cooling to reduced flesh temperature to cold storage temperature. Application of passive cooling following
the holding temperature is advantageous for Ontario peach growers and retailers as it requires less energy input as well as no additional equipment or alterations to current operations.

Although application of CDC was determined to mitigate the development of mealiness, the overall intensity of perceivable mealiness within fruit harvested in Year 1 was low. As ‘Redhaven’ peaches are known to be susceptible to CI symptoms this finding is likely associated with the standardized flesh firmness range applied. By standardizing the flesh firmness of ripe fruit, mealiness was not apparent in peaches that required less time ripening at room temperature, specifically the CDC treatment. To further investigate the development of mealiness and ensure its development, ripe peaches evaluated in Year 2 were not subjected to a standardized flesh firmness, instead, a standardized ripening period would be applied to ensure consistency between the pre-cooling treatments applied. A standardized ripening period of 2.5 days at 20 °C was applied in Year 2 as this length of time was identified as the average ripening duration required by FAC and PRC of commercial maturity to obtain the standardized flesh firmness range employed in Year 1. Although peaches treated with CDC ripened quicker, than FAC and PRC applied to H1 fruit, it was hypothesized that by standardizing the length of ripening a true evaluation of mealiness development could be carried out. Similar parameters have been observed within the literature, where a standardized ripening period of 2 – 3 days at 20 °C has been applied prior to conducting evaluations (Buescher and Furmanski 1978; Brovelli et al. 1998b; Peano et al. 2001; Cantín et al. 2010; Cáceres et al. 2016; Pons et al. 2016).

Prior to Year 2, the sensory attribute “chewy” was further refined through discussions with the panel. The definition of chewiness was refined to take into consideration the entirety of the sample, including both the flesh and the peel, when masticating the sample; a description that was not discussed prior to Year 1.

3.4.5. Product evaluation of Year 2

Similar to Year 1, products evaluated in Year 2 were initially analyzed to identify overall differences between pre-cooling treatments and as a function of storage period. A two-way mixed model ANOVA identified that 11 of the 14 attributes evaluated significantly differentiated the 14 products assessed by the panel (Appendix B.1). The attributes that significantly discerned the products included OAI-smell ($F_{13, 202} = 2.20, p = 0.09$), citrus ($F_{13, 202} = 4.33, p = 0.002$), tropical fruit ($F_{13, 202} = 2.74, p = 0.01$), OAI-taste ($F_{13, 202} = 5.90, p < 0.0001$), sweet ($F_{13, 202} = 2.56, p = 0.01$), acidic ($F_{13, 202} = 2.35, p = 0.03$), firmness ($F_{13, 202} = 16.01, p < 0.0001$),
Correlations were reviewed to determine the relationships between instrumental and sensory evaluations conducted in Year 2. Overall, correlations were deemed low-moderate. The instrumental measurements of flesh firmness, on samples with and without peel were correlated with perceivable firmness as rated by the panel \( (r = 0.512, p < 0.0001) \) and \( (r = 0.550, p < 0.0001) \), respectively. Furthermore, both instrumental evaluations of firmness were correlated to perceivable chewiness, however, a greater correlation was obtained with fruit where the peel was not removed \( (r = 0.508, p < 0.0001) \). In regard to measures of taste, perceivable sweetness was not correlated with the ratio of SSC/TA \( (r = 0.079, p = 0.136) \), but was minimally correlated with SSC \( (r = 0.095, p = 0.074) \). Perceivable acidity was correlated with TA \( (r = 0.259, p < 0.0001) \). Several sensory attributes were correlated with perceivable juiciness, including, tropical fruit \( (r = 0.358, p < 0.0001) \), OAI-taste \( (r = 0.418, p < 0.0001) \), sweet \( (r = 0.214, p < 0.0001) \), and mealiness \( (r = -0.452, p < 0.0001) \).

A PCA was constructed to further visualize the similarities and differences between the 14 products evaluated, using the 11 discriminating attributes identified as well as the physicochemical variables assessed (Appendix B.2). Similar to the findings from Year 1, the PCA constructed included a factor that could be described as a CI continuum. Overall, the PCA accounted for 90.2% of the variance within the model where Factor 1 (74.8% of the variance) was positively defined by juicy and OAI-taste attributes and negatively driven by mealiness and firmness. Through use of AHC, 3 product clusters were identified. Similar to the commercially mature fruit evaluated in Year 1, products were primarily grouped based on length of storage. Group 1, including baseline products from both picks, all products evaluated on day 7 as well as CDC-20 evaluated on day 14 postharvest was defined as aromatic, flavourful and juicy. Group 2 and 3 showed movement along the CI continuum away from descriptors of juiciness and aroma/flavour, with Group 3 being defined by mealiness and firmness. Group 2 included PRC and CDC-10 treatments evaluated on day 14 as well as CDC-20 evaluated on day 21 postharvest while Group 3 encompassed FAC, PRC, and CDC-10 evaluated on day 21 as well as FAC assessed on day 14 postharvest.

Effect of pre-cooling treatments

In order to determine the effect of pre-cooling treatments applied to commercially mature fruit, a two-way mixed model ANOVA was conducted and main treatment effects were
interpreted. Of the 14 sensory attributes evaluated, seven attributes differentiated the pre-cooling treatments (Appendix B.3). Attributes that discerned the pre-cooling treatments included, citrus ($F_{3, 254} = 25.57, p = 0.06$), tropical fruit ($F_{3, 254} = 7.80, p = 0.04$), OAI-taste ($F_{3, 254} = 3.56, p = 0.09$), acidic ($F_{3, 254} = 4.57, p = 0.09$), firmness ($F_{3, 254} = 42.41, p = 0.002$), juicy ($F_{3, 254} = 15.10, p = 0.001$), and chewy ($F_{1, 254} = 44.47, p = 0.001$). The overall mean values of each of the seven significant attributes are displayed for each treatment in Figure 3.3, below.

![Spider plot of overall mean intensities (%) of 7 attributes significantly (p ≤ 0.1) differentiating the pre-cooling treatments applied in Year 2 (n = 387)](image)

Prior to determining the effect that pre-cooling treatments have on the physicochemical profiles of peaches, baseline fruit obtained from the two harvest picks were characterized. Baseline peaches possessed similar weight ($F_{1, 54} = 5.26, p = 0.15$), flesh firmness measured with peel ($F_{1, 54} = 0.76, p = 0.48$), and TA ($F_{1, 54} = 0.17, p = 0.70$), however differed with respect to firmness measured without peel ($F_{1, 54} = 9.88, p = 0.09$), SSC ($F_{1, 54} = 13.59, p = 0.02$), SSC/TA ($F_{1, 54} = 5.74, p = 0.08$), and pH ($F_{1, 54} = 4.55, p = 0.10$). The differences between measurements of SSC, SSC/TA, and pH were minimal and is likely a result of variation between peaches. Fruit from pick 2 were firmer ($\bar{x} = 43.8a \pm 2.0$ N) than pick 1 ($\bar{x} = 38.2b \pm 2.0$ N), although both picks were considered to be commercially mature by the grower. Thus, the two baseline evaluations were combined and compared to the four pre-cooling treatments applied. Furthermore, measurements of weight and pH were used to characterize fruit and will not be
further investigated as the measure of weight loss better relates to the storability of the fruit. Additionally, the range of pH remained consistent across all subsequent unripe and ripe evaluations, between 3.7 – 3.9, and as such was not further investigated.

The effect of pre-cooling treatments on physicochemical measurements were conducted at both unripe and ripened stages to identify changes occurring as a result of the ripening process. Overall, the measurements conducted on unripe and ripe fruit produced similar trends for the evaluations of firmness and SSC, thus only values obtained from ripe fruit will be reported for these two evaluations. CDC-20 treated peaches were \( (F_{3,367} = 38.00, p \leq 0.001) \) less firm \( (\bar{x} = 4.2d \pm 0.78 \, \text{N}) \), as per the evaluation of flesh firmness (without peel), whereas peaches treated with FAC remained the firmest \( (\bar{x} = 15.8a \pm 0.85 \, \text{N}) \). Although SSC differed across pre-cooling treatments \( (F_{3,370} = 9.20, p \leq 0.001) \), all mean values were within the range of 9.7 – 10.4 %. Unripe fruit were not differentiated based on TA \( (F_{3,373} = 0.85, p = 0.48) \), but there were differences in ripened fruit \( (F_{3,370} = 27.20, p = 0.001) \), where fruit treated with CDC treatments possessed less TA. A similar observation is made for the measurement of SSC/TA where no difference is observed in unripe fruit \( (F_{3,370} = 0.73, p = 0.54) \), however, upon ripening peaches treated with CDC-10 \( (\bar{x} = 1.9a \pm 0.03 \, \% ) \) possessed a greater ratio of SSC/TA \( (F_{3,370} = 9.74, p = 0.01) \), followed by FAC \( (\bar{x} = 1.8b \pm 0.03 \, \% ) \), CDC-20 \( (\bar{x} = 1.8b \pm 0.03 \, \% ) \), PRC \( (\bar{x} = 1.7b \pm 0.03 \, \% ) \), and baseline \( (\bar{x} = 1.5c \pm 0.04 \, \% ) \) fruit. Furthermore, TA \( (F_{2,370} = 38.43, p = 0.002) \) and SSC/TA \( (F_{3,370} = 36.28, p = 0.003) \) in ripe fruit were altered over the course of storage. TA decreased as the length of cold storage increased, whereas SSC/TA increased as cold storage increased.

Application of pre-cooling treatments had no effect on the percent weight loss incurred during cold storage. A general trend was observed with FAC incurring greater loss at day 21 \( (\bar{x} = 2.1 \pm 0.09 \, \% ) \) when compared to CDC-20 \( (\bar{x} = 1.2 \pm 0.09 \, \% ) \), PRC \( (\bar{x} = 1.0 \pm 0.09 \, \% ) \), and CDC-10 \( (\bar{x} = 0.7 \pm 0.09 \, \% ) \) treatments. Although no visual shrinkage was observed, a greater occurrence of mold developed on peaches treated with FAC.

3.4.6. Discussion of Year 2

Application of pre-cooling treatments prior to cold storage are generally deemed beneficial in their ability to reduce the development of mealiness and retain high quality peaches, as seen presented in the current project as well as within the literature. To date, use of CDC methods have been considered optimal (Nanos and Mitchell 1991; Zhou et al. 2000b;
Crisosto et al. 2004; Infante et al. 2009a) as a result of the pre-ripening incurred prior to cold storage. Following the results obtained in Year 1 of the project, CDC treatments were applied with passive cooling used to reduce the flesh temperature to 0 °C following the 24 hour holding period. Use of PRC is considered slow, with fruit enduring a greater length of time within the temperature range known to inflict CI. However, investigation into the use of passive cooling combined with CDC within the Ontario peach industry was deemed advantageous as application requires no additional upgrade to current equipment and infrastructure utilized by growers. Although research has been conducted investigating the physicochemical profiles of peaches pre-ripened and passively cooled prior to cold storage (Miguel-Pintado et al. 2013), no sensory evaluations have been conducted thus far. Furthermore, such pre-cooling treatments are novel to the Ontario peach industry.

**Effect of pre-cooling**

Investigation into the effect of pre-cooling treatments on ‘Redhaven’ peaches is critical to ensure that growers and retailers can present high quality products to consumers. With direct industry involvement research was conducted to compare pre-cooling treatments that could be applied by Ontario growers with minimal alterations to their current infrastructure. To date, application of control delayed pre-cooling treatments is considered optimal and is currently applied as the industrial standard within several peach industries that export product internationally (Crisosto and Valero 2008). Crisosto et al. (2004) suggest pre-conditioning at 20 °C for 24 hours, followed by FAC to cold storage temperature results in an optimal eating experience with fruit possessing the characteristic peach flavour and juiciness.

Similar to the findings displayed in Year 1 as well as those reported in the literature, peaches pre-ripened at 20 °C prior to cold storage were juicier (Crisosto et al. 2004), softer (Zhou et al. 2000b) and possessed a greater intensity of characteristic peach flavour (Cantor et al. 1992). However, unique to Year 2, the sensory panel differentiated the pre-cooling treatments based on perceivable firmness, which is likely due to the altered ripening protocol. As all peaches were subjected to a standardized ripening period of 2.5 days at 20 °C prior to evaluation, significant differences in perceivable firmness are as expected as peaches treated with CDC are known to ripen quickly upon removal from cold storage (Crisosto et al. 2004). Contrary to Year 1, CDC-treated peaches did not possess a greater intensity of perceivable chewiness. As this finding comes after attribute refinement with the panel, the effect that pre-ripening has on the perceivable texture of both the peel and flesh of peaches needs to be further monitored. Furthermore, peaches pre-ripened at 10 °C prior to cold storage were less
acidic, as revealed through both sensory evaluation and instrumental measurement of TA. Infante et al. (2009) reported that peaches having undergone pre-ripening were perceivably less acidic when compared to peaches having been immediately cooled. As acid compounds are known to oxidize during normal cellular metabolism (Shinya et al. 2014) it stands to reason that peaches pre-ripened at 20 °C would be less acidic as a result of increased ripening, however, this was not the case in the present study. Furthermore, TA is unaffected when peaches are pre-ripened at 5 °C, 10 °C, or 20 °C (Crisosto et al. 2004). However, Zhou et al. (2000) reported an increase in TA within pre-ripened peaches; perceivable acidity was not evaluated in either study. Perceivable sweetness was not correlated to the ratio of SSC/TA like previously reported (Colaric et al. 2005; Crisosto et al. 2005), however, the pre-cooling treatments evaluated in Year 2 did not differ in regard to perceivable sweetness and the range of SSC/TA values obtained was small.

Similar to the results presented in Year 1 as well as by Infante et al. (2009), peaches pre-ripened at 20 °C were able to retain a sensory profile similar to that of peaches that had not been exposed to cold storage. Pre-ripening peaches at 20 °C prior to cold storage is associated with a higher degree of liking and a greater percentage of satisfied consumers within several peach cultivars (Infante et al. 2009a). Mealiness was generally unaffected by the pre-cooling treatments evaluated in Year 2, although FAC-treated fruit tended to develop mealiness earlier than all other treatments. Similar results have been reported by Crisosto et al. (2004) in which application of pre-ripening at 20 °C extended the shelf life of ‘Summer Lady’ and ‘O’Henry’ peach varieties up to two weeks beyond that of peaches that were not pre-conditioned. Similar to the presence of CI symptoms, visual shrinkage as a result of weight loss during cold storage can result in economic losses for growers and retailers. Coinciding with the results obtained in Year 1 and in contrast to the literature (Agar et al. 2006; Crisosto and Valero 2008; Mitcham 2011; Fraser 2014), peaches treated with FAC tended to incur greater weight loss over the course of three weeks in cold storage. Overall, weight loss incurred in Year 2 was less than that observed in Year 1, which is attributed to seasonal variability. Weight loss incurred in Year 2 was below that of the threshold at which visual shrinkage becomes apparent, as reported by Crisosto et al. (2004). To date, multiple values have been reported as being the threshold at which visual shrinkage becomes apparent (Kader and Mitchell 1989; Mitchell and Kader 1989; Crisosto et al. 2004) and as such weight loss should be monitored routinely by growers and retailers involved within the cold chain management of peaches.
Similar to the findings present in Year 1, the overall intensity of perceivable mealiness within commercially mature fruit harvested in Year 2 was low. Although all pre-cooling treatments were subjected to a standardized ripening period of 2.5 days prior to evaluations of ripe fruit this did not increase the development of mealiness as previously hypothesized. While sensory evaluation is considered the gold standard in evaluating mealy texture (Arefi et al. 2015) very few researchers report the range of perceivable mealiness rated by trained panels. Delgado et al. (2013) utilized descriptive analysis using an unstructured 10 cm line-scale, comparable to 15 cm line-scale utilized in the present study, to rate the intensity of mealiness having developed in 7 peach and nectarine cultivars. Overall, the panel employed by Delgado et al. (2013) rated the perception of mealiness as low, with average cultivar ratings ranging between 0.5 – 2.2 along the 10 cm line-scale, thus using only 22 % of the scale. Further investigation into consumers’ acceptance or tolerance of mealiness within peaches would assist researchers in drawing conclusions based on the low intensity rating having been observed. While descriptive analysis makes use of extensively trained panelists’ previous eating experiences of extremely mealy peaches may unintentionally influence the results and result in low intensity ratings within the descriptive sensory data collected if the samples presented possess less mealy texture than those previously purchased for consumption. Alternatively, the low intensity ratings observed in both the present study and by Delgado et al. (2013) could indicate minimal development of mealiness which could be a result of seasonal variability as the ‘Redhaven’ cultivar profiled in the present study are indeed known to be susceptible to developing mealiness (DeEll et al. 2015). To date, mealiness has been identified as a texture that negatively impacts consumer liking and willingness to purchase, however, more research is required to completely understand this perception including consumers’ threshold for acceptance.

Comparison of CDC treatments

Optimal CDC parameters have been defined by Crisosto et al. (2004) to include a holding temperature of 20 °C for 24 hours with forced-air applied to reduce the temperature of peaches prior to cold storage. Similar to the work of Crisosto et al. (2004), CDC treatments employing holding temperatures of 10 °C and 20 °C were employed in the present study however, passive cooling was utilized to reduce flesh temperature prior to cold storage. In spite of these technical differences, when comparing the two pre-cooling techniques the current study identified similar trends to those reported by Crisosto et al. (2004). Crisosto et al. (2004) conclude that CDC held at 20 °C is more effective for prevention of CI symptoms than a delay at
10 °C. Similar results were observed in the current study for fruit evaluated after 14 days in cold storage. Minimal detail is presented by Crisosto et al. (2004) with respect to the method used to evaluate mealiness as well as other CI symptoms being monitored. As mealiness has been most accurately measured by a trained sensory panel (Arefi et al. 2015) the results presented by Crisosto et al. (2004) may not provide a true indication of the development of mealiness within CDC treatments as no panel was employed. Furthermore, the present study found peaches treated with CDC-20 were perceivably juicer (Crisosto et al. 2004) and possessed greater intensities of peach flavour, citrus, and tropical fruit perceptions when compared to peaches pre-ripened at 10 °C. Although a pre-ripening temperature of 10 °C is outside the temperature range known as the “kill-zone”, symptoms of CI have been reported within the range of 0 – 10 °C (Mitchell and Kader 1989). It is hypothesized that peaches pre-ripened at 10 °C prior to cold storage experienced CI, as seen with the reduced aroma and flavour profile, when compared to peaches pre-ripened at 20 °C.

Although application of forced-air following CDC treatments is deemed optimal (Crisosto et al. 2004) application of passive cooling following the pre-ripening delay should be further explored. As stated previously, the use of passive cooling is advantageous for Ontario growers as it does not require current infrastructure to be upgraded. Miguel-Pintado et al. (2013) observed no physicochemical differences between peaches and nectarines treated with forced-air or passive cooling following a pre-ripening delay held at 20 °C for 24 hours. While Miguel-Pintado et al. (2013) conclude that application of forced-air following a delay had no beneficial effect on fruit, sensory characteristics were not investigated which could result in missed information. Within Year 1 and Year 2 of the present study, CDC treatments applied with forced-air and passive cooling applied following pre-ripening, respectively, were deemed beneficial in maintaining desirable sensory characteristics, however, a direct comparison of sensory profiles associated with the two CDC parameters has yet to be conducted.

3.4.7. Conclusions from Year 2

Similar to the findings of Crisosto et al. (2004) and Infante et al. (2009), peaches pre-ripened at 20 °C prior to cold storage maintained a sensory profile that aligned with known drivers of consumer liking for a longer duration than other pre-cooling treatments. Although perceivable mealiness was low and did not differentiate the pre-cooling treatments, trends were observed indicating that peaches treated with FAC, PRC and CDC-10 developed symptoms of CI earlier than fruit treated with CDC-20.
Contrary to the literature, ‘Redhaven’ peaches treated with delayed cooling regimes did not incur greater weight loss during three weeks of cold storage when compared to FAC or PRC treatments. Overall, weight loss incurred was minimal, however, as weight loss is known to be cultivar dependent this should be monitored throughout storage to ensure economic losses associated with weight loss are held to a minimum.

3.5. CONCLUSION

Although application of cold storage is known to negatively impact the sensory profiles of peaches, application of pre-cooling treatments that promote ripening prior to storage have been deemed optimal. Over the course of the study, peaches pre-ripened at 20 °C were consistently juicier and possessed a greater intensity of characteristic peach flavour, both of which are known to positively impact consumers' liking of peaches. When pre-ripening at 20 °C was applied for 48 hours followed by FAC prior to cold storage in Year 1, the development of mealinness was reduced when compared to FAC and PRC treatments. Comparatively, application of pre-ripening at 20 °C for 24 hours followed by passive cooling to cold storage temperature in Year 2 did not reduce the development of mealinness. However, fruit tended to incur CI later when compared to pre-ripening applied at 10 °C as well as FAC and PRC treatments. To further our understanding of delayed cooling treatments the comparison of forced-air and passive cooling applied following a 24 hour delay at 20 °C should be further investigated with robust sensory and physicochemical evaluations conducted.

With the Ontario peach industry currently employing passive cooling, the transition to application of pre-ripening at 20 °C could mitigate the development of mealinness and retain sensory profiles aligned with consumer liking for a longer duration. By mitigating the development of symptoms associated with CI Ontario peach growers and retailers could see increased profit as a result of increased repeat purchases by consumers.

Lastly, further investigation into the development, measurement, and consumer perception of mealinness is required. Although development of mealinness has been reduced with application of pre-ripening treatments, means of measuring mealinness that are accessibility to growers and retailers are still lacking within the industry. Furthermore, mealinness has been identified as a texture that reduces consumers' liking of peaches. However, minimal information is available as to the threshold level at which consumers identify the texture as being unacceptable.
CHAPTER 4 – USE OF VISUAL AND INSTRUMENTAL EVALUATIONS TO MEASURE MEALINESS IN PEACHES

4.1. ABSTRACT

Mealy texture in fruit is known to negatively impact consumer liking. Mealiness is a symptom of chilling injury in peaches; which occurs during ripening following removal from cold storage. Sensory evaluation is the current gold standard to detect mealiness. However, it is considered costly and inaccessible, making alternative methods necessary. The present study investigates the use of visual evaluation and compression analysis as alternative methods to measure mealy texture. The study found that no single measured variable was strongly associated with perceivable mealiness, as rated by a trained sensory panel. Multiple linear regression was used to generate a predictive model. The final regression equation included three compression test variables and obtained an adjusted $R^2$ value of 0.286, indicating the inaccuracy of the equation. Overall, sensory evaluation remains the best means of measuring mealy texture in peaches, as visual evaluation, compression analysis, nor the combination of multiple instrumentally measured variables within a predictive model were associated with perceivable mealy texture.

4.2. INTRODUCTION

Texture is a critical component influencing consumers' acceptance of fruit. Within horticultural products, texture is defined by the cellular structure of the product. Mealiness, an undesirable texture (Delgado et al. 2013; Bruhn, 1995), is known to develop in several horticultural commodities, including, apples, tomatoes, kiwis, peaches, and nectarines. Alterations in pectin metabolism occurring during and following cold storage result in an enzymatic imbalance that is postulated to be the cause of mealiness development in peaches (Ortiz et al. 2000; Crisosto and Labavitch 2002; Infante et al. 2009b; Fruk et al. 2014; Arefi et al. 2015). Mealiness is a complex attribute and cannot be evaluated accurately except by use of a trained sensory panel (Infante et al. 2009b; Ross 2009; Arefi et al. 2015). Although sensory evaluation is an optimal evaluation method, it is often considered time consuming (Arana et al. 2007; Piombino et al. 2013), costly (Chen and Opara 2013), and inaccessible to growers and
retailers (Jaren et al. 2012). As a result of the disadvantages associated with sensory evaluation, alternative techniques to measuring mealiness have been proposed.

In other fruit, predictive models of mealiness have been generated with compression testing parameters (Verkerke et al. 1998; Mehinagic et al. 2004; Arana et al. 2007). This has not been done for peaches. Due to the complex nature of mealy texture, regression analysis has been employed to combine multiple instrumental measures to generate a predictive model. The slope of compression curves, as well as a measure of maximum resistance generated during compression testing have been incorporated into the models (Verkerke et al. 1998; Mehinagic et al. 2004; Arana et al. 2007). Compression force has been applied to peaches as a means of investigating cellular structure (Ortiz et al. 2000; Arana et al. 2007) and measuring juice content associated with mealy texture (Lill and van der Mespel 1988; Crisosto and Labavitch 2002). However, no models have been generated predicting mealy texture in peaches. Therefore, the present research investigates the use of compression testing as a means of developing predictive models for mealiness in ‘Redhaven’ peaches with the aim of finding alternative methods to sensory testing for mealiness measurement.

Visual assessments of fruit are commonly conducted as quick, routine measures of quality (Kader 2002). Although visual evaluation would provide growers with an inexpensive means of assessing mealiness, the accuracy of such methodologies is debated. Lack of juice upon squeezing is the most commonly reported visual indicator of mealiness in peaches (Crisosto and Labavitch 2002; Obenland et al. 2003; Cantín et al. 2010). However, inconsistent outcomes have been reported. Additional visual assessment tools have been presented combining visual indicators of juiciness and stringy flesh (Brovelli et al. 1998a), yet no direct comparison to in-mouth sensory evaluation was conducted. The visual assessments used to measure mealy texture in peaches are rarely reported in detail which challenges any robust replication. Furthermore, robust sensory evaluation is rarely used as a comparative tool to determine the accuracy of the visual indicators used. Further investigation into the accuracy of visual assessments is necessary before such methods can be considered valid alternatives to sensory evaluation. The aim of this research was examine alternative approaches to mealiness measurements with the aim of identifying a technique that can easily be applied by growers and retailers that is more efficient than sensory testing.
4.3. MATERIALS AND METHODS

4.3.1. Obtaining fruit

Peaches (*Prunus persica* cv. Redhaven) of commercial maturity having been obtained in 2016, following the description provided in Section 3.3.1 were further evaluated for the development of mealy texture. Following harvest, fruit were held in cold storage conditions (0 °C and 90 % RH) for up to 21 days. Peaches were evaluated for sensory and physicochemical profiles, development of visual signs of flesh mealliness, and compression analysis. For all evaluations, fruit were evaluated after 0, 7, 14, and 21 days of storage; for each sampling fruit were subsequently ripened at 20 °C for 2.5 days. Each individual peach was labeled with a unique, random 3-digit code to ensure accurate tracking throughout. In total, 420 fruit were allocated for these evaluations, which included 60 fruit tested on day 0, and 120 fruit tested on each of the remaining test days (day 7, 14, and 21 postharvest).

Additionally, upon weekly removal from cold storage, 30 fruit per pre-cooling treatment were allocated for shelf-life evaluations. Fruit analyzed for shelf-life characteristics were held at 20 °C for up to 10 days. Fruit were evaluated for the onset of mealiness with visual mealliness assessments conducted daily on three fruit per treatment.

4.3.2. Sensory evaluation

All sensory evaluations were conducted by a trained panel at Vineland Research and Innovation Centre, as per the details provided in Section 3.3.2. Descriptive analysis (Lawless and Heymann 2010b) was conducted using a lexicon of 14 attributes (Appendix A.1). Fourteen attributes were evaluated by the trained panel, but only the perception of mealiness will be further discussed within the context of the current research objective.

4.3.3. Physicochemical evaluations

Physicochemical evaluations were conducted to characterize the fruit as well as to identify relationships with perceived mealliness. Physicochemical measures were conducted for weight, flesh firmness, evaluated through penetration tests (with and without peel) using a TA.XT plus (Stable Micro Systems, UK), SSC (%), TA (% malic acid), SSC/TA (%), and pH, as per the descriptions provided in Section 3.3.3. Background colour was evaluated using a four
point scale to assess the degree of yellow colouration on the fruit peel (1 = fully green; 2 = more green than yellow; 3 = more yellow than green; 4 = fully yellow).

4.3.4. Visual evaluation

To visually evaluate the development of mealy texture, one wedge per fruit was gently squeezed by hand. Visual texture and juiciness characteristics were evaluated using a modified mealiness intensity scale developed by DeEll and Walker (2015). The four-point categorical scale ranged from “juicy and firm” fruit to fruit that “does not produce any juice” which were considered mealy and received a score of 1 (Figure 4.1).

4 - Peach flesh is juicy and firm.
3 - Peach flesh is juicy, however, flesh is starting to separate in strands or chunks.
2 - Peach flesh produces juice when squeezed but not enough to drip out of the fruit; juice bubbles up. The flesh is very stringy.
1 - Peach flesh does not produce any juice when squeezed.

Figure 4.1. Four point visual mealiness evaluation scale. Categories are depicted from left (4) to right (1).

4.3.5. Compression analysis

Compression analysis was applied using a TA.XT plus (Stable Micro Systems, UK) with compression curves being generated. Three cylindrical samples were excised from different regions of the fruit (upper cheek, mid-cheek, and stem). The three samples were cut to size (7 mm diameter, 7.5 mm long) with the peel removed, prior to being weighed. Samples were then wrapped, in a standing position, between two layers of cheesecloth and held between 2 pre-weighed filter paper circles. Samples were compressed to a final distance of 5.5 mm at a speed of 10 mm/s by a 25 mm compression platen, resulting in a deformation rate of 73 %. Following compression, the filter papers were re-weighed and the juice content (%) was calculated as the
change in weight of the filter papers divided by the initial sample weight (Verkerke et al. 1998). The resulting compression curves were first evaluated for their general shape with non-mealy fruit hypothesized to possess a fracture point denoted by a plateau at the mid-way point of the applied compression force. This was hypothesized during initial program optimization and through the testing of peaches deemed non-mealy by in-mouth evaluations conducted by the researchers. In contrast, compression curves of “mealy” samples were hypothesized to differ from those of “non-mealy” and were identified to lack a fracture upon compression; hypothesized to indicate reduced cellular adhesion. Compression curves were then analyzed for 5 compression related variables, as summarized in Table 4.1.

Table 4.1. Variables measured using TA.XT plus compression test

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>force at fracture</td>
<td>Force applied resulting in structural damage&lt;sup&gt;1&lt;/sup&gt;, measured in g</td>
</tr>
<tr>
<td>compression at fracture</td>
<td>Distance travelled by platen at the point of fracture, measured in mm</td>
</tr>
<tr>
<td>slope</td>
<td>Increased force overtime measured from 0.01 s until point of fracture&lt;sup&gt;2&lt;/sup&gt;, measured in g/s</td>
</tr>
<tr>
<td>force at final distance</td>
<td>The force exerted to reach a final compression distance of 5.5 mm, measured in g</td>
</tr>
<tr>
<td>area under curve (AUC)</td>
<td>Total energy applied on the sample, measured in g*s</td>
</tr>
</tbody>
</table>

<sup>1</sup> Defined as first peak on compression curve
<sup>2</sup> Measurement of slope initiated at 0.01 s to avoid negative force readings as a result of human or instrument error

4.2.6. Statistical analyses

The physicochemical, visual, and compression evaluations were analyzed to determine their ability to predict the presence of mealy texture as identified by the trained panel. Prior to analysis, box-plot diagrams were analyzed for the presence of outliers. Outliers were identified and removed from physicochemical and compression analysis variables. Pearson correlation analysis was applied to identify relationships between the perception of mealiness and physicochemical and compression evaluation variables. Relationships between background colour, visual mealiness and perceived mealiness were identified through Spearman’s correlation analysis, which is more appropriate for ordinal variables. As no single variable was strongly correlated with perceivable mealiness, backwards multiple linear regression was
conducted to identify a combination of variables that could be modeled to predict perceivable mealiness in 'Redhaven' peaches. Variables that possessed significant correlations with perceivable mealiness were included in the regression analysis with the optimal model being selected based on adjusted $R^2$ ($R^2_{adj}$) and Akaike information criterion (AIC) values. Data were analyzed using XLSTAT® (Addinsoft, France) with an alpha of 0.05.

4.4. RESULTS

The overall mean values obtained for perceivable mealiness and visual mealiness indicate the relatively low levels of mealiness were detected by the trained panel and through use of the visual mealiness assessment scale (Table 4.2).

**Table 4.2. Mean values of measures relating to mealiness (n = 387)**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>perceivable mealiness$^2$</td>
<td>11.7 ± 14.36</td>
</tr>
<tr>
<td>visual mealiness$^3$</td>
<td>3.4 ± 0.72</td>
</tr>
<tr>
<td><strong>Physicochemical evaluations</strong></td>
<td></td>
</tr>
<tr>
<td>weight</td>
<td>166.2 ± 19.87 g</td>
</tr>
<tr>
<td>firm w/o peel$^4$</td>
<td>6.6 ± 3.14 N</td>
</tr>
<tr>
<td>firm w/ peel$^5$</td>
<td>19.3 ± 7.83 N</td>
</tr>
<tr>
<td>SSC</td>
<td>10.1 ± 0.75 %</td>
</tr>
<tr>
<td>TA</td>
<td>5.9 ± 0.98 % malic acid</td>
</tr>
<tr>
<td>pH</td>
<td>3.8 ± 0.14</td>
</tr>
<tr>
<td>SSC/TA</td>
<td>1.7 ± 0.31 %</td>
</tr>
<tr>
<td>background colour$^6$</td>
<td>3.1 ± 0.83</td>
</tr>
<tr>
<td><strong>Compression analysis</strong></td>
<td></td>
</tr>
<tr>
<td>force at fracture</td>
<td>784.1 ± 501.08 g</td>
</tr>
<tr>
<td>compression at fracture</td>
<td>2.4 ± 1.80 mm</td>
</tr>
<tr>
<td>slope</td>
<td>5651.0 ± 3710.84 g/s</td>
</tr>
<tr>
<td>force at 5.5mm</td>
<td>5513.8 ± 3305.12 g</td>
</tr>
<tr>
<td>AUC</td>
<td>693.2 ± 331.30 g*s</td>
</tr>
<tr>
<td>juice content</td>
<td>32.0 ± 9.19 %</td>
</tr>
</tbody>
</table>

$^1$ Standard deviation  
$^2$ Evaluated by the trained panel from low (0) to high (100)  
$^3$ Evaluated using a visual scale from no mealy (1) to high mealy (4)  
$^4$ Firmness without peel measured using TA.XT plus penetration test  
$^5$ Firmness with peel measured using TA.XT plus penetration test  
$^6$ Evaluated using a visual scale from green (1) to yellow (4)
Furthermore, perceivable mealiness tended to increase as the length of cold storage increased, as detected by the trained sensory panel however, relatively low intensities were recorded. The intensity of perceivable mealiness at each evaluation day, for each pre-cooling treatment is summarized in Table 4.3, below.

Table 4.3. Mean perceivable mealiness intensities and standard deviation at each weekly evaluation

<table>
<thead>
<tr>
<th>Pre-cooling treatments</th>
<th>Length of cold storage</th>
<th>Day 0 $^1$</th>
<th>Day 7</th>
<th>Day 14</th>
<th>Day 21</th>
</tr>
</thead>
<tbody>
<tr>
<td>baseline</td>
<td>-</td>
<td>6.6 ± 8.66$^2$</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>FAC</td>
<td>-</td>
<td>7.5 ± 15.51</td>
<td>24.0 ± 17.32</td>
<td>20.0 ± 18.03</td>
<td></td>
</tr>
<tr>
<td>PRC</td>
<td>-</td>
<td>5.3 ± 8.91</td>
<td>13.2 ± 9.77</td>
<td>17.5 ± 17.34</td>
<td></td>
</tr>
<tr>
<td>CDC-20</td>
<td>-</td>
<td>5.8 ± 6.82</td>
<td>5.8 ± 7.62</td>
<td>16.2 ± 18.16</td>
<td></td>
</tr>
<tr>
<td>CDC-10</td>
<td>-</td>
<td>7.5 ± 10.84</td>
<td>12.6 ± 16.83</td>
<td>16.2 ± 14.25</td>
<td></td>
</tr>
</tbody>
</table>

$^1$Fruit was held at 20 °C for 2.5 days prior to sensory evaluation  
$^2$Evaluated by the trained panel from low (0) to high (100)  
$^3$Standard deviation

4.4.1. Correlations

Sensory evaluation and visual mealiness assessment

Overall, 363 fruit were evaluated for mealiness using the visual mealiness assessment scale and the trained sensory panel. Majority of the fruit evaluated did not develop visual indicators of mealiness (Table 4.4). A summary of the number of fruit associated with each visual mealiness score as well as the mean perceivable mealiness rating associated with each category is provided in Table 4.4, below.

Table 4.4. Mean perceivable mealiness intensities for each of the four visual mealiness categories (n = 363)

<table>
<thead>
<tr>
<th>Visual mealiness score$^1$</th>
<th>Number of fruit$^2$</th>
<th>Mean perceivable mealiness$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>241</td>
<td>9.3</td>
</tr>
<tr>
<td>3</td>
<td>71</td>
<td>16.4</td>
</tr>
<tr>
<td>2</td>
<td>46</td>
<td>16.8</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>12.1</td>
</tr>
</tbody>
</table>

$^1$Evaluated using a visual scale from no mealy (4) to high mealy (1)  
$^2$Fruit evaluated by trained panel following 2.5 days storage at 20 °C  
$^3$Evaluated by the trained panel from low (0) to high (100)

Furthermore, nine individual peach samples obtained perceivable mealiness ratings greater than 50 % by the trained sensory panel. Of the nine samples obtained relatively high
perceivable mealiness intensities, four samples were given visual mealiness scores of four, indicating a firm and juicy appearance. Overall, a weak, negative association was obtained between perceivable mealiness and visual assessment of mealiness, as summarized in Table 4.5.

Table 4.5. Correlations between perceivable mealiness and visual mealiness (n = 363)

<table>
<thead>
<tr>
<th>Variables</th>
<th>perceivable mealiness</th>
<th>visual mealiness</th>
</tr>
</thead>
<tbody>
<tr>
<td>perceivable mealiness</td>
<td>1</td>
<td>-0.204</td>
</tr>
<tr>
<td>visual mealiness</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

1Spearman's correlation matrix with values in bold significant at p ≤ 0.05
2Evaluated by the trained panel from low (0) to high (100)
3Evaluated using a visual scale from no mealy (4) to high mealy (1)

In the evaluation of shelf-life characteristics, the mean visual mealiness assessment score obtained by each pre-cooling treatment at day 0 (baseline samples from pick 1 and pick 2) as well as day 7 (FAC, PRC, CDC-20, AND CDC-10) did not reach a score of 3 or less on the 4-point visual scale. At day 14 and 21 postharvest, the onset of visual mealiness characteristics (a mean visual mealiness assessment score of 3 or less) tended to develop earlier in peaches treated with CDC-20 (Table 4.6).

Table 4.6. Length of storage (20 °C) required to develop visual mealiness characteristics following removal from cold storage at weekly intervals

<table>
<thead>
<tr>
<th>Pre-cooling treatment</th>
<th>Length of cold storage (0 °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day 7</td>
</tr>
<tr>
<td>FAC</td>
<td>-</td>
</tr>
<tr>
<td>PRC</td>
<td>-</td>
</tr>
<tr>
<td>CDC-20</td>
<td>-</td>
</tr>
<tr>
<td>CDC-10</td>
<td>-</td>
</tr>
</tbody>
</table>

\(^1\)Length of storage applied at 20 °C until onset of mealiness identified, using visual mealiness assessment scale; with a mean score of ≤ 3 depicting the onset of mealiness

As per Table 4.3 and 4.6, perceivable mealiness was detected prior to the development of visual mealiness characteristics for all pre-cooling treatments evaluated at day 7 and 14 postharvest, as sensory evaluation was conducted following 2.5 days of storage at 20 °C. However, at day 21 postharvest, visual mealiness characteristics developed following 2 days of storage at 20 °C, which occurred on the same day as sensory evaluation (Table 4.6). Only peaches treated with CDC-20 possessed visual mealy characteristics prior to sensory evaluation taking place following 21 days in cold storage.
Sensory evaluation and compression analysis

The shape of the compression curves were first analyzed to determine the presence or absence of a fracture point (Figure 4.2).

![Figure 4.2. Compression curves, Sample 'a' identified as mealy by the trained panel (49 % rating on 100-point line-scale) with no fracture point; Sample 'b' identified as non-mealy by trained panel (0 % rating on 100-point line-scale) with fracture point (highlighted by red circle)](image)

Of the 23 peach samples that obtained a perceivable mealiness rating greater than 30 % by the trained sensory panel, 8 samples possessed compression curves that lacked a fracture point. Overall, this resulted in a 35 % detection accuracy when compression curve shapes were compared to the perception of mealy texture, as rated by the trained panel. Furthermore, in the analysis of compression curve variables measured, four variables were moderately correlated with the perception of mealiness, as rated by the trained panel (Table 4.7).

Table 4.7. Correlations between perceivable mealiness and compression analysis measures (n = 261)

<table>
<thead>
<tr>
<th>Variables¹</th>
<th>perceivable mealiness²</th>
<th>force ¹³</th>
<th>compression ¹⁴</th>
<th>slope</th>
<th>force ²⁵</th>
<th>AUC</th>
<th>juice</th>
</tr>
</thead>
<tbody>
<tr>
<td>perceivable mealiness</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>force 1</td>
<td>0.343</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>compression 1</td>
<td>0.062</td>
<td>0.705</td>
<td>0.175</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>slope</td>
<td>0.404</td>
<td>0.773</td>
<td>-0.147</td>
<td>0.266</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>force 2</td>
<td>0.045</td>
<td>0.007</td>
<td>-0.159</td>
<td>-0.135</td>
<td>0.518</td>
<td>0.279</td>
<td>1</td>
</tr>
<tr>
<td>AUC</td>
<td>0.224</td>
<td>0.372</td>
<td>-0.005</td>
<td>0.633</td>
<td>0.881</td>
<td></td>
<td></td>
</tr>
<tr>
<td>juice</td>
<td>-0.316</td>
<td>-0.297</td>
<td>-0.159</td>
<td>-0.135</td>
<td>0.518</td>
<td>0.279</td>
<td>1</td>
</tr>
</tbody>
</table>

¹Pearsons correlation matrix with values in bold significant at p ≤ 0.05
²Evaluated by the trained panel from low (0) to high (100)
³Force at fracture
⁴Compression at fracture
⁵Force at final distance (5.5 mm)
Sensory evaluation and physicochemical variables

Measures of firmness (firm w/o peel and firm with peel) were positively associated with perceivable mealiness (Table 4.8). However, all physicochemical variables, assessed on ripe ‘Redhaven’ fruit obtained weak associations with perceivable mealiness, as shown in Table 4.8.

**Table 4.8. Correlations between perceivable mealiness and physicochemical measures (n = 319)**

<table>
<thead>
<tr>
<th>Variables</th>
<th>perceivable mealiness</th>
<th>weight</th>
<th>firm w/o peel</th>
<th>firm w/ peel</th>
<th>SSC</th>
<th>TA</th>
<th>SSC:TA</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>perceivable mealiness</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>weight</td>
<td>0.066</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>firm w/o peel</td>
<td>0.168</td>
<td>-0.147</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>firm w/ peel</td>
<td>0.196</td>
<td>-0.082</td>
<td>0.811</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSC</td>
<td>0.017</td>
<td>-0.041</td>
<td>0.092</td>
<td>0.151</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TA</td>
<td>-0.076</td>
<td>-0.085</td>
<td>0.369</td>
<td>0.309</td>
<td>0.376</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSC:TA</td>
<td>0.103</td>
<td>0.066</td>
<td>-0.322</td>
<td>-0.237</td>
<td>0.163</td>
<td>-0.840</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>-0.134</td>
<td>-0.149</td>
<td>-0.156</td>
<td>-0.163</td>
<td>-0.288</td>
<td>-0.390</td>
<td>0.249</td>
<td>1</td>
</tr>
<tr>
<td>background colour</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Pearson’s correlation matrix with values in bold significant at p ≤ 0.05
2. Evaluated by the trained panel from low (0) to high (100)
3. Firmness without peel measured using TA.XT plus penetration test
4. Firmness with peel measured using TA.XT plus penetration test
5. Evaluated using Spearman’s correlation matrix
6. Evaluated using a visual scale from green (1) to yellow (4)

4.4.2. Multiple linear regression

To ensure a robust interpretation of the multiple linear regression equation, assumptions of multicollinearity, undue influence of outliers and normal distribution of residuals were assessed. Multicollinearity did not exist between the predictors as all variables obtained tolerance values greater than 0.1 (Field 2013). Furthermore, Cook’s distance indicated that no outliers existed within the data set as all distance values were ≤ 0.325. Finally, normality of studentized residuals was evaluated with a Shapiro-Wilk test of normality. Significantly non-normally distributed residuals were identified (W = 0.947, p < 0.0001), however the Shapiro-Wilk value was greater than 0.9 and the Q-Q plot of studentized residuals indicated a generally normal distribution. Although Shapiro-Wilk test of normality was significant, large data sets have
been known to obtain significant values when residual scores deviated slightly from normal distribution (Field 2013) and as such the results obtained through multiple linear regression analysis will be interpreted with confidence.

The correlation analysis revealed that perceivable mealiness was not strongly correlated with any single measurable attribute. Backward multiple linear regression was used to identify a combination of variables that could predict perceivable mealiness in ‘Redhaven’ peaches (n = 230) (Appendix B.4.). The results of the regression analysis indicated that inclusion of three predictors accounted for the greatest amount of variance within the model ($R^2_{adj} = 0.286$, $F_{3,226} = 31.64$, $p < 0.0001$). The three predictor variables included were, slope ($F_{1,226} = 4.96$, $p = 0.03$), AUC ($F_{1,226} = 9.39$, $p = 0.002$), and juice content ($F_{1,226} = 16.20$, $p < 0.0001$), with the regression model depicted in Equation 4.1.

\[
\text{Perceivable mealiness} = 15.38 + 1.46^3(\text{slope}) + 1.17^2(\text{AUC}) - 0.55(\text{juice content})
\]

[Equation 4.1]

4.5. DISCUSSION

To date, visual assessments and instrumental tests measuring the presence of mealiness in peaches have been reported as successful. However, their ability to accurately measure mealy texture is not commonly validated using robust sensory evaluation. Currently, sensory evaluation remains the gold standard in measuring the presence of mealy texture in fruit (Infante et al. 2009b; Ross 2009; Arefi et al. 2015) and should be used as a comparative tool when novel mealiness measurement methods are generated.

4.5.1. Use of visual evaluations to measure mealy texture

Visual evaluations are commonly conducted to quickly assess the quality of horticultural commodities (Kader 2002). Mealy texture in tender fruit has been evaluated through visual cues with the amount of juice released upon squeezing and the presence of stringy flesh both commonly used indicators (Fernández-Trujillo et al. 1998; Brovelli et al. 1998b; Crisosto et al. 1999; Crisosto and Labavitch 2002; Obenland et al. 2003; Girardi et al. 2005; Cantín et al. 2010; Jin et al. 2011; Giné-Bordonaba et al. 2016). However, the ability of visual cues to accurately reflect the perception of mealy texture has been questioned (Crisosto and Labavitch 2002; Obenland et al. 2003). To date, very few studies have compared visual evaluation of mealy
texture with in-mouth evaluations conducted by a trained panel; thus the true accuracy of visual cues to indicate the development of mealininess is relatively unknown. Visual evaluation of mealy texture has been reported to be inaccurate when compared to sensory evaluation (Zhou et al. 2000b; Obenland et al. 2003). A similar conclusion is drawn within the present study as the visual mealininess scale did not reflect an increase in perceivable mealininess intensity, as rated by the trained panel. Additionally, a weak association exists between the two evaluations of mealininess in ‘Redhaven’ peaches, indicating that the visual mealininess scale was not accurate in reporting perceivable mealininess. Furthermore, Crisosto and Labavitch (2002) identified that trained panels could perceive mealininess in peaches up to 1 week earlier than the development of visual cues. The present study saw similarities to the work of Crisosto and Labavitch (2002) where FAC-treated peaches evaluated at day 14 postharvest possessed perceivably mealy characteristics following 2.5 days of storage at 20 °C. However, visual indicators of mealininess were not apparent until 8 days of storage at 20 °C. In contrast, perceivable mealininess generally increased across all pre-cooling treatments when evaluated at day 21 postharvest with onset of visual mealininess characteristics occurring following 1 – 2 days of 20 °C storage. Although this finding does not mirror the results of Crisosto and Labavitch (2002) it further displays the inaccuracy of the visual mealininess scale used.

Although use of visual evaluation methods are quick and accessible, their use should be limited when monitoring the development of mealininess in peaches as such techniques are inaccurate. In the present study a modified mealininess intensity scale (DeEll and Walker 2015) was used, where only visual cues were considered and in-mouth evaluations conducted by the researchers were removed to save time and reduce subjectivity. Similar to the conclusions reached by Crisosto and Labavitch (2002), visual indicators alone do not accurately predict the perception of mealininess within peaches and in-mouth evaluations conducted by the researchers should be explored prior to suggesting this method be used by growers and retailers.

4.5.2. Association between physicochemical variables and perceivable mealininess

Recently, Giné-Bordonaba et al. (2016) suggested that higher SSC can reduce the susceptibility of tender fruit cultivars to the development CI, following the evaluation of 7 peach and nectarine cultivars. Within the current study, the lack of relationship between SSC and perceivable mealininess is not surprising as only one peach cultivar was evaluated, thus the range of SSC was relatively small in comparison to the findings of Giné-Bordonaba et al. (2016). Although cultivars with greater SSC could be less susceptible to developing CI symptoms, it
appears that changes in SSC within one cultivar are not linked to the development of mealiness. Comparatively, no research to date has identified a link between acidity and the development of mealy texture in peaches. The present study indicates a weak correlation between pH and mealy texture, but this is likely indicative of variability within the peaches evaluated.

As mealiness is known to develop following removal from cold storage and upon subsequent ripening, the possibility remains that an inverse relationship exists between mealy texture and changes in flesh firmness. Negative correlations between mealinss and flesh firmness are known for susceptible fruit (Mehinagic et al. 2004; Stanley et al. 2013), including peaches (Arana et al. 2007). Within the present study, positive correlations were obtained between perceivable mealiness and measures of flesh firmness, evaluated through penetration tests. The positive correlations obtained in the present study contradict the work of others (Fernández-Trujillo et al. 1998; Verkerke et al. 1998; Mehinagic et al. 2004; Arana et al. 2007; Chaïb et al. 2007; Jaren et al. 2012; Stanley et al. 2013). Although the results presented in the current study are contrary to the findings of others who investigate the relationship between firmness and mealiness in other fruit, such comparisons within peaches has been challenging. Arana et al. (2007) used instrumental measures of firmness to predict the development of mealiness in ‘Redhaven’ peaches however, no indication of the firmness of such fruit is provided. Without an indication of the flesh firmness of the fruit evaluated, a direct comparison between the present study and the work of others, specific to peaches (Arana et al. 2007), cannot be made as such parameters may influence the perceived intensity of mealiness by the trained sensory panel. Furthermore, a positive correlation could indicate that a flesh firmness threshold exists, where firmness below a certain point results in mealiness becoming undetectable as a result of cellular breakdown associated with advanced ripeness. Similarly, von Mollendorff and de Villiers (1988) identified mealy texture to develop in ‘Peregrine’ peaches, yet upon further ripening ‘mealy’ fruit became juicy as a result of tissue breakdown and senescence processes. Thus, additional research is necessary to further investigate the perception of mealiness in peaches. Ultimately, the results presented in this study indicate that flesh firmness, measured by penetration, cannot accurately detect perceivable mealiness in ‘Redhaven’ peaches of the flesh firmness range evaluated.

4.5.3. Use of compression analysis to measure mealy texture

Compression testing has been used across many horticultural commodities to assess the structural properties of fruit and vegetables as it is easy to perform (Arana et al. 2007) and
imitates mastication (Chen and Opara 2013). As mealy texture in peaches is thought to develop as a result of gel-formation and potentially reduced adhesion between cells, application of compression force has been used to evaluate structural differences between mealy and non-mealy fruit. Although compression analysis has been reportedly successful in predicting the development of mealy texture in apples (Paoletti et al. 1993; Barreiro et al. 2000; Mehinagic et al. 2004; Arana et al. 2007), tomatoes (Verkerke et al. 1998), and peaches (Ortiz et al. 2000; Arana et al. 2007), this was not the case in the present study. The initial evaluation of compression curve shapes was unable to predict the development of mealy texture with the accuracy necessary for this method to be considered for future use. As previously hypothesized, samples that did not possess a fracture point, denoted as a plateau, within their respective curve were deemed mealy. However, as a result of low detection accuracy, it was determined that the lack of fracture point was likely indicative of low flesh firmness or probe samples that were improperly cut resulting samples that had already experience cell fracture. To date, compression curve shapes have not been analyzed as a means of detecting mealy texture in peaches. As very few curves depicted discernably different shapes, it is hypothesized that this approach is not accurate as a means of detecting mealiness in peaches using the current compression test parameters. Further optimization of the compression test method could include reduced deformation as extensive deformation could have resulted in the loss of structural differences between samples.

Similar to measures of flesh firmness, researchers have identified negative correlations between mealliness and compression variables of maximum force (Mehinagic et al. 2004; Arana et al. 2007), slope of compression curve (Mehinagic et al. 2004; Arana et al. 2007), and cohesiveness (Paoletti et al. 1993) as measured through various compression tests. Similar to the flesh firmness results previously discussed, compression variables were positively correlated with perceivable mealiness in the present study. The positive associations obtained are hypothesized to be associated with, the compression deformation rate applied, the low perceivable intensity of mealliness detected by the trained panel, or the possibility of a firmness threshold where fruit below a certain flesh firmness no longer display mealy texture as a result of advanced senescence. Furthermore, non-uniform development of mealliness within a single fruit has been reported (Crisosto and Labavitch 2002). This finding by Crisosto and Labavitch (2002) could explain the weak association between compression variables and perceived mealiness as the three sample probes excised to undergo compression analysis were not excised from the same area of fruit that was present to the trained sensory panelist. To further optimize this compression method, excision of sample probes from various regions around the
peach could be done however, this limits the area available for physicochemical and sensory evaluations.

Overall, the weak relationship between compression variables and perceived mealiness is indicative of the complexity of the mealy texture and its inability to be defined by a single measure of structural integrity. However, it is in contrast with the findings of others. Although others (Ortiz et al. 2000; Mehinagic et al. 2004; Arana et al. 2007) have identified compression analysis as successful in detecting mealinness in fruit, the lack of robust sensory evaluation applied in previous studies could attribute to the differences observed in the present study. In contrast to the work of Mehinagic et al. (2004), where mealiness in apples was strongly associated with several variables measured through application of compressive force, the definition of mealiness applied during sensory evaluation was not provided. Without a clear sensory attribute description the true perception evaluated by Mehinagic et al. (2004) is unknown and could very well be focused on the perception of firmness which could account for the strong associations with compression variables. Additionally, the etiology of mealy texture in apples is known to differ from that of peaches, with the middle lamella region losing strength during storage thus resulting in reduced adhesion between cells which leads to the dry sensation that is mealy (Harker and Hallett 1992). Use of compression analysis could be more appropriate in apples as mealiness is related to the loss of firmness and strength within the middle lamella region. Such methods may not be entirely appropriate for mealiness evaluation in peaches as mealy texture is known to develop as a result of an enzymatic imbalance. While this enzymatic imbalance could lead to reduced cellular adhesion between neighbouring cells the mechanism of mealliness development in peaches is not completely understood and may not follow the same etiology as that identified within apples.

To date, Ortiz et al. (2000) and Arana et al. (2007) have validated compression analysis through use of sensory evaluation on peach cultivars, identifying that compressive force can successfully predict mealy texture. Although success has been reported, Arana et al. (2007) defined mealiness as, “dry and mealy texture, soft and dry fiber, lack of taste and aroma, a decrease in flesh brightness and lack of juice” which is more appropriate in the definition of symptoms of CI and could be indicative of overall fruit deterioration. Although the present study obtained weak, positive associations with variables measured through compression the contrast with Arana et al. (2007) could be indicative of a sensory attribute that solely evaluated mealy texture as opposed to CI as a whole. The perception of mealiness in peaches has been further defined by Ortiz et al. (2000) to include lack of crispiness and juiciness, with strong associations
obtained between variables measured through compression. Although the term ‘crispiness’ has been used to define the strength and elasticity of fruit flesh cell walls this term is seldom used in the definition of mealy texture in peaches. As a result of the definition used by Ortiz et al. (2000) it is hypothesized that the compression test employed is measuring a perception that differs from the perception of mealiness in peaches and thus differs from the results and overall objective of the current study.

Finally, juice released from fruit samples upon compression has been reported as a successful technique for evaluating mealy texture in peaches (Crisosto and Labavitch 2002). Within the current study, juice released was negatively correlated with perceivable mealiness (Lill and van der Mespel 1988; Crisosto and Labavitch 2002; Infante et al. 2009b), indicating that as mealiness increases, the amount of juice released decreases. Although this result is aligned with the work of others (Lill and van der Mespel 1988; Crisosto and Labavitch 2002; Infante et al. 2009b), the moderate association between juice content and perceivable mealiness obtained in the present study indicates that mealy texture in ‘Redhaven’ peaches cannot be described by a single variable.

4.5.4. Use of multiple linear regression to predict mealy texture

As mealiness is a complex textural attribute, predictive models have been generated within apple (Arana et al. 2007; Mehinagic et al. 2004) and tomato (Verkerke et al. 1998) cultivars to include several explanatory variables. Similarly, in the present study, the slope of the compression curves (Verkerke et al. 1998; Mehinagic et al. 2004; Arana et al. 2007), the area under the compression curve (an indicator of total energy required for compression), and juice content (Verkerke et al. 1998) when combined, predict perceivable mealiness. However, contrary to the previously generated models, the current model was only able to predict 29% of the variance within the model. Although others have reported higher regression values for their generated models, in addition to differing compression test parameters, the sensory evaluation methods employed by these researchers differ from the robust methodology employed in the current study (Verkerke et al. 1998; Mehinagic et al. 2004; Arana et al. 2007). Even though all researchers utilized descriptive analysis (Verkerke et al. 1998; Mehinagic et al. 2004; Arana et al. 2007), the definition of mealiness used by the panels was not always provided (Verkerke et al. 1998; Mehinagic et al. 2004); thus replicating the research is challenging. As a result of differing sensory definitions of mealiness it is likely that varying prediction model accuracies would be expressed as panels may not truly be rating the intensity of mealy texture. By
excluding the definition of the perception of mealiness being evaluated, it is unknown whether researchers were accurately portraying the mealy texture or if the trained panel and compression variables instead measured perceptions and variables that differed from the objectives of the present study. Moving forward, a ubiquitous definition of mealiness should be applied in the validation of novel measurement methods to ensure that the same perception is consistently being measured. Overall, it is challenging to compare the results of the present study to those of researchers who have not provided a description of the mealiness perception that was used in the validation of their predictive models. Furthermore, Arana et al. (2007) applied an arbitrary threshold in the evaluation of mealy texture, where an intensity rating greater than 20 (out of a possible 45) was deemed “mealy”. To date, no threshold identifying perceivable mealiness exists, likely because an optimal measurement method has yet to be determined. By applying a threshold value, Arana et al. (2007) likely imposed bias on the generated model as intensity scores below the threshold could very well be considered “extremely mealy” to a consumer. However, this was not investigated with a consumer population.

Although the regression model generated in the present study is not strong enough to predict the presence of mealy texture in ‘Redhaven’ peaches, several areas for future consideration have been identified. The present study evaluated the compression curves of samples having undergone a deformation of 73 %, where samples 7.5 mm tall were compressed to a final height of 2.0 mm. Compression analyses having been applied to evaluate mealy texture in susceptible fruit have used a range of deformation percentages, spanning from 1.4 to 80 % (Verkerke et al. 1998; Ortiz et al. 2000; Mehinagic et al. 2004; Arana et al. 2007; Huang and Lu 2010). It is hypothesized that application of compression to a final deformation of 73 % is likely not optimal and could have resulted in the compression of samples beyond the point at which mealy texture can be discerned. Furthermore, the present study, being industry applicable, utilized optimal cold storage conditions (0 °C and 90 % RH). However, if peaches had been stored for up to three weeks under improper conditions, such as within the “kill-zone” temperature range, a greater occurrence of mealy texture would have been measured, perhaps altering the results of the compression analysis and prediction model. Although the present study found low development of mealiness, as rated by the trained panel, such work should be used as a benchmark in the application of robust sensory evaluation when additional novel methods are developed for the measurement of mealy texture in peaches.
4.6. CONCLUSION

As sensory evaluation is currently considered the gold standard for detection of mealy texture in susceptible fruit, it is imperative that novel measurement techniques are validated through comparison with robust sensory testing. However, this research showed that no single instrumental measurement was related to perceivable mealiness evaluated by a well-trained descriptive analysis panel. In addition, a visual assessment mealiness scale incorporating degree of juiciness and flesh separation were not associated with the perceived mealiness. Similarly, multiple linear regression showed that no combination of instrumental variables could predict the presence of perceivable mealiness in ‘Redhaven’ peaches within the firmness range tested in the present study. Further investigation into the development of mealy texture in peaches is necessary before a robust analytical method can be proposed as an alternative to sensory evaluation.
CHAPTER 5 – CONCLUSIONS AND FUTURE DIRECTIONS

Overall, the findings presented within the current study will be used to assist in the development of a cold chain best management practices guide for the Ontario peach industry. In combination with other research objectives being examined by collaborators, the results presented in this thesis will aid Ontario peach growers in presenting an optimal eating experience to consumers.

5.1. Postharvest parameters

As peaches ripen quickly at room temperature, cold storage becomes necessary to delay ripening processes and ensure fruit are adequately distributed to consumers. When stored under refrigeration, peaches are susceptible to developing CI, with symptoms of mealiness and loss of aroma and flavour commonly observed. As a result, postharvest parameters, including harvest maturity and application of pre-cooling treatments should be considered as they can positively impact the quality of fruit.

The presented thesis identified sensorial and physicochemical differences existing between peaches harvested at commercial and physiological maturity levels. Peaches harvested at physiological maturity were perceivably sweeter, juicer, and less firm. ‘Redhaven’ peaches of physiological maturity possessed sensory profiles that aligned with characteristics known to be desired by consumers, but the reduced firmness and rapid ripening upon removal from cold storage represent logistical concerns for growers and retailers. As a result of reduced flesh firmness, peaches harvested at physiological maturity were not considered viable for the Ontario peach industry. However, sale of physiologically mature fruit as “ready to consume” products at the farm gate may be a more appropriate approach to selling this product.

Application of pre-cooling treatments affected both sensory and physicochemical profiles of ‘Redhaven’ peaches. The current study found that commercially mature ‘Redhaven’ peaches pre-ripened at 20 °C prior to cold storage maintained sensory profiles that aligned with characteristics known to positively impact consumer liking, such as, greater juiciness and characteristic peach flavour, and reduced mealy texture. These findings are aligned with the current industrial practices of California and Chile (Crisosto et al. 2004). However, they are in contrast to the recent recommendations of OMAFRA (Fraser 2014), who have suggested that FAC is optimal in the cold management of Ontario grown peaches. By transitioning to use of
CDC, that employs pre-ripening at 20 °C prior to cold storage, Ontario peach growers will be able to present high quality fruit to consumers that will likely lead to increased revenue as a result of increased repeat purchases.

Overall, this study has gleaned an understanding of the impact that pre-cooling treatments have on the sensory and physicochemical profiles of Ontario grown ‘Redhaven’ peaches. However, further research is necessary to ensure that optimal pre-cooling treatment parameters are presented to Ontario growers. While similar sensorial and physicochemical trends were observed between CDC treatments applied within this study, a direct comparison of the different parameters is necessary. While pre-ripening at 20 °C prior to cold storage was deemed optimal, the application of FAC and PRC following the pre-ripening delay is necessary, as this was not compared directly in the current study. Although this direct comparison has previously been made (Miguel-Pintado et al. 2013) the research design employed did not include sensory evaluation and as such a robust evaluation utilizing a trained panel is necessary to further identify the optimal CDC treatment. This additional research is necessary as investigation into pre-cooling treatments is considered novel research being conducted within the Ontario peach industry.

5.2. Measuring mealiness

The second objective of this study was to compare the use of sensory evaluation to alternative methods in the measurement of mealy texture within ‘Redhaven’ peaches. Alternative methods to measuring mealiness are necessary as use of sensory evaluation is costly and inaccessible to growers and retailers. While sensory evaluation is considered the gold standard in the evaluation of mealiness, researchers have been applying alternative methods without validation. The current study found that neither visual assessment nor compression testing provided measures that were related to perceivable mealiness, having been evaluated by a well-trained descriptive analysis panel. The findings confirm that mealiness is a complex texture and cannot be measured by a single descriptor. A predictive model, generated through multiple linear regression, incorporated three variables as measured by compression testing. Similar to the visual evaluation method, the strength of the predictive model was not able to strongly predict the presence of mealy texture in the ‘Redhaven’ peaches evaluated in the present study. Although the results of the predictive model were not optimal, advances in the measurement of mealy texture were made within this study using robust descriptive sensory evaluation as a comparative tool to novel methods of measuring mealiness.
To date, very few studies measuring mealy texture through novel methodology have utilized robust sensory evaluation as a means of validation. The use of robust sensory evaluation employed in the current study confirms the multicomponent nature of the mealy texture as neither visual assessment or single variables measured through compression analysis were strongly associated with the perceived texture. Mealiness remains an elusive texture that warrants further investigation. Further research into novel methods measuring mealiness is necessary, yet, as previously stated, the need for such methods to be validated with robust sensory evaluation is imperative. Although the current study has suggested alterations to the compression test parameters that could lead to improved results, the use of imaging such as magnetic response imaging and near infrared may be the key to understanding the structural changes associated with the perception of mealiness. Once the structural changes are completely understood, researchers will likely be more successful in the development of a quick and easy to use tool that will be accessible to growers and retailers. While research has been reported utilizing MRI and NIR in the analysis of peach flesh, none to date has validated such methods with robust sensory evaluation.

Future research is necessary to compare the use of sensory evaluation and a mealiness intensity scale that incorporates both visual and in-mouth assessments conducted by the researcher. While the visual scale used in the present study was modified to exclude any in-mouth assessments conducted by the researcher for the sake of time and to limit bias the original scale generated by DeEll and Walker (2015) should be further reviewed. Furthermore, additional research needs to be conducted to determine consumers’ threshold of acceptance to perceivably mealy peaches. While researchers have identified that mealiness is disliked by consumers the point at which consumers are unwilling to purchase mealy products is unknown. Following the development of a tool that can successfully measure and compare the development of mealiness in peaches, researchers will be able to better understand the point at which consumers are no longer willing to make repeat purchases.
REFERENCES


### APPENDIX A: Sensory Evaluation

A.1. Sensory lexicon of attributes evaluated by trained panel with definitions and anchors/references

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Definition</th>
<th>Anchors/Reference standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>OAI-smell</td>
<td>perception of characteristic peach aroma</td>
<td></td>
</tr>
<tr>
<td>citrus</td>
<td>perception of citrus aroma/flavour including lemon, lime, and orange</td>
<td></td>
</tr>
<tr>
<td>tropical fruit</td>
<td>perception of tropical fruit aroma/flavour including mango and pineapple</td>
<td></td>
</tr>
<tr>
<td>vegetal</td>
<td>perception of vegetal and grassy aroma/flavour</td>
<td></td>
</tr>
<tr>
<td>OAI-taste</td>
<td>perception of characteristic peach taste</td>
<td></td>
</tr>
</tbody>
</table>
| sweet      | perception of reference | 10 g/L sucrose (Redpath® sugar)¹ (59%)[²]
| acid       | perception of reference | 1.2 g/L D-L Malic acid (Sigma-Aldrich)¹ (53%)[²]
| bitter     | perception of reference | 0.25 g/L caffeine (Fisher Scientific)¹ (43%)[²]
| astringent | perception of reference | 1.0 g/L aluminum sulfate hydrate (Fisher Scientific)¹ (56%)[²]
| firmness   | force required to bite through (flesh of) sample |  |
| juicy      | amount of liquid released when chewing |  |
| chewy      | time needed to rend sample (flesh and skin) prior to swallowing |  |
| smoothness of flesh | perceived homogeneity of flesh | presence of many fibres or particulates (10%); absence of fibres or particulates (90%)
| mealy      | soft, dry, granular flesh. Mealiness is associated with cells that separate and retain juices as opposed to releasing juices |  |

¹Vita Sana Peach Nectar (Imported by Molisana, Italy), diluted with 25% filtered water was used as reference matrix
²Position of reference tick along 100 point line-scale
A.2. Consent to participate in sensory evaluation of peaches (REB#16JN38)

CONSENT TO PARTICIPATE IN RESEARCH

Sensory evaluation of peaches

You are invited to participate in a research study conducted by Carly Flemming (MSc. student) under the direction of Dr. Lisa Duizer (University of Guelph) and Dr. Amy Bowen (Vineland Research and Innovation Centre).

We are looking for participants to assist in the development of sensory profiles of peaches. You are receiving this recruitment document because of your previous involvement with the trained sensory panel at Vineland Research and Innovation Centre.

If you have any questions or concerns about the research, please feel free to contact

Carly Flemming: Master’s student, Department of Food Science, University of Guelph, carly.flemming@vinelandresearch.com, 905-562-0320 ext. 809.

Dr. Lisa Duizer: Faculty, Department of Food Science, University of Guelph, lduizer@uoguelph.ca, 519-824-4120 ext. 53410.

Dr. Amy Bowen: Research Program Leader, Consumer Insights, Vineland Research and Innovation Centre, amy.bowen@vinelandresearch.com, 905-562-0320 ext. 805.

PURPOSE OF THE STUDY

The purpose of this research is to understand differences in the sensory profiles of peaches. This project is funded by the Agriculture Adaption Council as part of the Growing Forward 2 program (GF2-0297).

PROCEDURES

Sessions will be held twice per week over the course of 4 weeks. Each session will last approximately 1 ½ hours. If you agree to participate in this study, we would ask you to conduct descriptive analysis by rating the intensity of each peach sample presented in regard to 14 unique attributes, on 100 point line-scales anchored from low to high. During each session you will be asked to consume enough of each peach sample to accurately evaluate the 14 descriptive attributes.
If you would like to find out more about the samples you’ve seen during this study, we would be more than happy to provide you some information once the study is complete.

POTENTIAL RISKS AND DISCOMFORTS

You will be assessing the taste, aroma/flavour, and texture of peaches. If you know that peaches cause you discomfort or that you are allergic to them please do not take part in the study. As with any tasting, risks of choking may exist and are not greater than those you might encounter in your everyday life. We instruct you to sample a small size portion at a time and take your time to assess the product. Water is at your disposal.

POTENTIAL BENEFITS TO PARTICIPANTS AND/OR TO SOCIETY

Information collected by this study will help us to have a better understanding of the differences in the taste, aroma/flavour and texture of peaches. Such results will be presented to members of the peach industry and findings may have commercial value.

DISSEMINATION OF RESULTS

The results of this study will be published in Carly Flemming’s Master’s thesis as well as potential for presentation at conferences including the University of Guelph’s Ontario Agriculture College (OAC) graduate student’s colloquium. Additionally, the student researcher will undertake to publish the results of the project in a peer reviewed journal at the conclusion of the funding grant.

CONFIDENTIALITY

Every effort will be made to ensure confidentiality of any identifying information that is obtained in connection with this study, however, please note that confidentiality cannot be guaranteed while the data are in transit over the internet. All data collected during the research portion of this study will be treated as confidential.

All data will be stored on a password-protected computer and/or in a locked cabinet. The data will be subject to statistical analysis and will be shared with an advisory committee at the University of Guelph as well as between members of the Consumer Insights department at Vineland, however, no personal information will be reported. Personal contact information and identification data will be stored during the course of your involvement with the trained sensory panel at Vineland in a separate secured place not attached to any information with the participants' identification number (provided during experiment). There will be a master list linking your personal identification information and experimental data. This information can only be accessed by the student investigator and the Research Program Leader of the Consumer Insights department at Vineland, Dr. Amy Bowen.

REIMBURSEMENT

If you consent to take part in this project, you will be paid in accordance with the number of hours in attendance at sensory evaluation sessions as per your current contract with Vineland.
PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may exercise the option of removing your data from the study. You may also refuse to answer any questions you don’t want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise that warrant doing so.

RIGHTS OF RESEARCH PARTICIPANTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights and welfare as a research participant in this study (REB# 16JN038), please contact: Sandra Auld, Director, Research Ethics; University of Guelph; reb@uoguelph.ca; (519) 824-4120 (ext. 56606).

This project has been reviewed by the Research Ethics Board for compliance with federal guidelines for research involving human participants.

SIGNATURE OF RESEARCH PARTICIPANT

I am not allergic or sensitive to peaches. I have read the information provided for the study “Sensory evaluation of peaches” as described herein.

My questions have been answered to my satisfaction, and I agree to participate in this study. If consent is granted I will be provided with a signed copy of this consent form.

☐ Yes
☐ No

________________________                          _______________________
Signature of participant                          Date

________________________                          _______________________
Signature of researcher,                           Date
Carly Flemming, MSc. student
### APPENDIX B: Statistical Tables and Figures

#### B.1. Two-way mixed model ANOVA of products evaluated in Year 2 (p ≤ 0.1)

<table>
<thead>
<tr>
<th>Source</th>
<th>Type</th>
<th>DF</th>
<th>OAI-smell</th>
<th>citrus</th>
<th>tropical fruit</th>
<th>vegetal(^1)</th>
<th>OAI-taste</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>F</td>
<td>Pr &gt; F</td>
<td>F</td>
<td>Pr &gt; F</td>
<td>F</td>
</tr>
<tr>
<td>Assessor (A)</td>
<td>Random</td>
<td>14</td>
<td>22.49</td>
<td>&lt; 0.0001</td>
<td>25.49</td>
<td>&lt; 0.0001</td>
<td>10.05</td>
</tr>
<tr>
<td>Product (P)</td>
<td>Fixed</td>
<td>13</td>
<td>2.20</td>
<td>0.092</td>
<td>4.33</td>
<td>0.002</td>
<td>2.74</td>
</tr>
<tr>
<td>Replica (R)</td>
<td>Random</td>
<td>2</td>
<td>3.66</td>
<td>0.087</td>
<td>2.24</td>
<td>0.243</td>
<td>0.14</td>
</tr>
<tr>
<td>P*A</td>
<td>Random</td>
<td>101</td>
<td>0.86</td>
<td>0.795</td>
<td>1.05</td>
<td>0.382</td>
<td>1.69</td>
</tr>
<tr>
<td>P*R</td>
<td>Random</td>
<td>26</td>
<td>0.79</td>
<td>0.752</td>
<td>0.84</td>
<td>0.693</td>
<td>0.73</td>
</tr>
<tr>
<td>A*R</td>
<td>Random</td>
<td>28</td>
<td>0.78</td>
<td>0.782</td>
<td>0.53</td>
<td>0.975</td>
<td>1.18</td>
</tr>
<tr>
<td>Error</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source</th>
<th>Type</th>
<th>DF</th>
<th>sweet</th>
<th>acidic</th>
<th>bitter</th>
<th>astringent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>F</td>
<td>Pr &gt; F</td>
<td>F</td>
<td>Pr &gt; F</td>
</tr>
<tr>
<td>Assessor (A)</td>
<td>Random</td>
<td>14</td>
<td>22.02</td>
<td>&lt; 0.0001</td>
<td>11.19</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Product (P)</td>
<td>Fixed</td>
<td>13</td>
<td>2.56</td>
<td>0.012</td>
<td>2.35</td>
<td>0.027</td>
</tr>
<tr>
<td>Replica (R)</td>
<td>Random</td>
<td>2</td>
<td>0.03</td>
<td>0.973</td>
<td>0.23</td>
<td>0.801</td>
</tr>
<tr>
<td>P*A</td>
<td>Random</td>
<td>101</td>
<td>1.71</td>
<td>0.001</td>
<td>1.29</td>
<td>0.064</td>
</tr>
<tr>
<td>P*R</td>
<td>Random</td>
<td>26</td>
<td>0.85</td>
<td>0.676</td>
<td>1.22</td>
<td>0.223</td>
</tr>
<tr>
<td>A*R</td>
<td>Random</td>
<td>28</td>
<td>0.67</td>
<td>0.897</td>
<td>0.88</td>
<td>0.648</td>
</tr>
<tr>
<td>Error</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source</th>
<th>Type</th>
<th>DF</th>
<th>firmness</th>
<th>juicy</th>
<th>chewy</th>
<th>smoothness of flesh</th>
<th>mealy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>F</td>
<td>Pr &gt; F</td>
<td>F</td>
<td>Pr &gt; F</td>
<td>F</td>
</tr>
<tr>
<td>Assessor (A)</td>
<td>Random</td>
<td>14</td>
<td>15.75</td>
<td>&lt; 0.0001</td>
<td>15.354</td>
<td>&lt; 0.0001</td>
<td>10.067</td>
</tr>
<tr>
<td>Product (P)</td>
<td>Fixed</td>
<td>13</td>
<td>16.01</td>
<td>&lt; 0.0001</td>
<td>14.47</td>
<td>&lt; 0.0001</td>
<td>15.98</td>
</tr>
<tr>
<td>Replica (R)</td>
<td>Random</td>
<td>2</td>
<td>0.23</td>
<td>0.801</td>
<td>0.48</td>
<td>0.639</td>
<td>0.04</td>
</tr>
<tr>
<td>P*A</td>
<td>Random</td>
<td>101</td>
<td>1.47</td>
<td>0.012</td>
<td>1.94</td>
<td>&lt; 0.0001</td>
<td>1.47</td>
</tr>
<tr>
<td>P*R</td>
<td>Random</td>
<td>26</td>
<td>0.73</td>
<td>0.824</td>
<td>0.86</td>
<td>0.666</td>
<td>0.73</td>
</tr>
<tr>
<td>A*R</td>
<td>Random</td>
<td>28</td>
<td>1.53</td>
<td>0.052</td>
<td>0.76</td>
<td>0.800</td>
<td>0.98</td>
</tr>
<tr>
<td>Error</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)Attribute evaluated using Kruskal-Wallis non-parametric test of means with K-value observed and p-value being reported for product effect.
B.2. PCA generated to include 8 significant sensory attributes (red vectors) identified in Year 2. The overall variance accounted for by the PCA was 90.2 %, with Factor 1 accounting for 74.6 %. Seven physicochemical variables (blue vectors) and 3 sensory attributes that didn’t contribute to the variance of the model (grey vectors) are overlaid as supplementary variables.
B.3. Two-way mixed model ANOVA analyzing the effect of pre-cooling treatment applied to commercially mature peaches in Year 2 (p ≤ 0.1)

<table>
<thead>
<tr>
<th>Source</th>
<th>Type</th>
<th>DF</th>
<th>OAI-smell F</th>
<th>OAI-smell Pr &gt; F</th>
<th>citrus F</th>
<th>citrus Pr &gt; F</th>
<th>tropical fruit F</th>
<th>tropical fruit Pr &gt; F</th>
<th>vegetal F</th>
<th>vegetal Pr &gt; F</th>
<th>OAI-taste F</th>
<th>OAI-taste Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessor (A)</td>
<td>Random</td>
<td>14</td>
<td>6.417</td>
<td>&lt; 0.0001</td>
<td>7.404</td>
<td>&lt; 0.0001</td>
<td>4.087</td>
<td>0.001</td>
<td>4.903</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>Fixed</td>
<td>3</td>
<td>0.764</td>
<td>0.560</td>
<td>25.570</td>
<td>0.064</td>
<td>7.799</td>
<td>0.039</td>
<td>18.280</td>
<td>0.147</td>
<td>3.562</td>
<td>0.093</td>
</tr>
<tr>
<td>Day (D)</td>
<td>Fixed</td>
<td>2</td>
<td>0.733</td>
<td>0.524</td>
<td>5.686</td>
<td>0.040</td>
<td>0.690</td>
<td>0.519</td>
<td>7.109</td>
<td>0.018</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Replica (R)</td>
<td>Random</td>
<td>2</td>
<td>1.996</td>
<td>0.212</td>
<td>3.630</td>
<td>0.405</td>
<td>0.053</td>
<td>0.948</td>
<td>1.095</td>
<td>0.382</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A*T</td>
<td>Random</td>
<td>33</td>
<td>1.052</td>
<td>0.397</td>
<td>0.899</td>
<td>0.630</td>
<td>0.971</td>
<td>0.517</td>
<td>1.006</td>
<td>0.464</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A*D</td>
<td>Random</td>
<td>19</td>
<td>1.514</td>
<td>0.081</td>
<td>1.725</td>
<td>0.033</td>
<td>3.450</td>
<td>&lt; 0.0001</td>
<td>1.869</td>
<td>0.017</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A*R</td>
<td>Random</td>
<td>28</td>
<td>0.834</td>
<td>0.710</td>
<td>0.465</td>
<td>0.991</td>
<td>1.207</td>
<td>0.224</td>
<td>0.697</td>
<td>0.873</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T*D</td>
<td>Fixed</td>
<td>6</td>
<td>0.614</td>
<td>0.719</td>
<td>0.867</td>
<td>0.520</td>
<td>2.529</td>
<td>0.021</td>
<td>2.222</td>
<td>0.042</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T*R</td>
<td>Random</td>
<td>6</td>
<td>0.849</td>
<td>0.534</td>
<td>0.394</td>
<td>0.882</td>
<td>0.697</td>
<td>0.652</td>
<td>1.501</td>
<td>0.178</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D*R</td>
<td>Random</td>
<td>4</td>
<td>0.445</td>
<td>0.776</td>
<td>0.378</td>
<td>0.824</td>
<td>1.478</td>
<td>0.209</td>
<td>1.236</td>
<td>0.296</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td></td>
<td>254</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source</th>
<th>Type</th>
<th>DF</th>
<th>sweet F</th>
<th>sweet Pr &gt; F</th>
<th>acidic F</th>
<th>acidic Pr &gt; F</th>
<th>bitter F</th>
<th>bitter Pr &gt; F</th>
<th>astringent F</th>
<th>astringent Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessor (A)</td>
<td>Random</td>
<td>14</td>
<td>9.63</td>
<td>&lt; 0.0001</td>
<td>6.03</td>
<td>&lt; 0.0001</td>
<td>7.23</td>
<td>&lt; 0.0001</td>
<td>30.11</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>Fixed</td>
<td>3</td>
<td>0.83</td>
<td>0.510</td>
<td>4.57</td>
<td>0.089</td>
<td>0.49</td>
<td>0.697</td>
<td>1.94</td>
<td>0.210</td>
</tr>
<tr>
<td>Day (D)</td>
<td>Fixed</td>
<td>2</td>
<td>5.05</td>
<td>0.035</td>
<td>3.92</td>
<td>0.092</td>
<td>0.11</td>
<td>0.897</td>
<td>2.43</td>
<td>0.154</td>
</tr>
<tr>
<td>Replica (R)</td>
<td>Random</td>
<td>2</td>
<td>0.01</td>
<td>0.988</td>
<td>0.12</td>
<td>0.887</td>
<td>0.12</td>
<td>0.891</td>
<td>0.95</td>
<td>0.448</td>
</tr>
<tr>
<td>A*T</td>
<td>Random</td>
<td>33</td>
<td>1.40</td>
<td>0.079</td>
<td>0.91</td>
<td>0.615</td>
<td>1.56</td>
<td>0.032</td>
<td>1.24</td>
<td>0.184</td>
</tr>
<tr>
<td>A*D</td>
<td>Random</td>
<td>19</td>
<td>2.03</td>
<td>0.008</td>
<td>1.34</td>
<td>0.158</td>
<td>3.01</td>
<td>&lt; 0.0001</td>
<td>1.75</td>
<td>0.030</td>
</tr>
<tr>
<td>A*R</td>
<td>Random</td>
<td>28</td>
<td>0.56</td>
<td>0.968</td>
<td>0.92</td>
<td>0.581</td>
<td>0.79</td>
<td>0.766</td>
<td>0.37</td>
<td>0.999</td>
</tr>
<tr>
<td>T*D</td>
<td>Fixed</td>
<td>6</td>
<td>2.79</td>
<td>0.012</td>
<td>0.90</td>
<td>0.493</td>
<td>2.19</td>
<td>0.044</td>
<td>1.13</td>
<td>0.345</td>
</tr>
<tr>
<td>T*R</td>
<td>Random</td>
<td>6</td>
<td>0.70</td>
<td>0.647</td>
<td>0.90</td>
<td>0.498</td>
<td>0.93</td>
<td>0.477</td>
<td>1.34</td>
<td>0.238</td>
</tr>
<tr>
<td>D*R</td>
<td>Random</td>
<td>4</td>
<td>0.82</td>
<td>0.512</td>
<td>1.21</td>
<td>0.305</td>
<td>1.89</td>
<td>0.112</td>
<td>0.79</td>
<td>0.530</td>
</tr>
<tr>
<td>Error</td>
<td></td>
<td>254</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Source</td>
<td>Type</td>
<td>DF</td>
<td>F</td>
<td>Pr &gt; F</td>
<td>F</td>
<td>Pr &gt; F</td>
<td>F</td>
<td>Pr &gt; F</td>
<td>F</td>
<td>Pr &gt; F</td>
</tr>
<tr>
<td>-----------------</td>
<td>----------</td>
<td>----</td>
<td>------</td>
<td>--------</td>
<td>------</td>
<td>--------</td>
<td>------</td>
<td>--------</td>
<td>------</td>
<td>--------</td>
</tr>
<tr>
<td>Assessor (A)</td>
<td>Random</td>
<td>14</td>
<td>8.72</td>
<td>&lt; 0.0001</td>
<td>6.20</td>
<td>&lt; 0.0001</td>
<td>4.64</td>
<td>&lt; 0.0001</td>
<td>5.26</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>Fixed</td>
<td>3</td>
<td>42.41</td>
<td>0.002</td>
<td>15.10</td>
<td>0.001</td>
<td>44.47</td>
<td>0.001</td>
<td>2.41</td>
<td>0.110</td>
</tr>
<tr>
<td>Day (D)</td>
<td>Fixed</td>
<td>2</td>
<td>11.37</td>
<td>0.004</td>
<td>30.86</td>
<td>&lt; 0.0001</td>
<td>10.10</td>
<td>0.006</td>
<td>0.94</td>
<td>0.413</td>
</tr>
<tr>
<td>Replica (R)</td>
<td>Random</td>
<td>2</td>
<td>0.010</td>
<td>0.908</td>
<td>0.23</td>
<td>0.799</td>
<td>0.02</td>
<td>0.979</td>
<td>1.31</td>
<td>0.324</td>
</tr>
<tr>
<td>A*T</td>
<td>Random</td>
<td>33</td>
<td>0.98</td>
<td>0.503</td>
<td>1.44</td>
<td>0.066</td>
<td>1.27</td>
<td>0.154</td>
<td>2.02</td>
<td>0.011</td>
</tr>
<tr>
<td>A*D</td>
<td>Random</td>
<td>19</td>
<td>2.25</td>
<td>0.003</td>
<td>2.81</td>
<td>0.000</td>
<td>1.87</td>
<td>0.017</td>
<td>3.93</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>A*R</td>
<td>Random</td>
<td>28</td>
<td>1.56</td>
<td>0.041</td>
<td>0.69</td>
<td>0.877</td>
<td>0.99</td>
<td>0.484</td>
<td>1.34</td>
<td>0.125</td>
</tr>
<tr>
<td>T*D</td>
<td>Fixed</td>
<td>6</td>
<td>10.34</td>
<td>&lt; 0.0001</td>
<td>4.23</td>
<td>0.000</td>
<td>6.57</td>
<td>&lt; 0.0001</td>
<td>5.63</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>T*R</td>
<td>Random</td>
<td>6</td>
<td>0.64</td>
<td>0.697</td>
<td>0.72</td>
<td>0.634</td>
<td>0.26</td>
<td>0.954</td>
<td>0.57</td>
<td>0.753</td>
</tr>
<tr>
<td>D*R</td>
<td>Random</td>
<td>4</td>
<td>1.86</td>
<td>0.118</td>
<td>0.77</td>
<td>0.544</td>
<td>0.90</td>
<td>0.467</td>
<td>1.82</td>
<td>0.126</td>
</tr>
</tbody>
</table>

\(^1\)Attribute evaluated using Kruskal-Wallis non-parametric test of means with K-value observed and p-value being reported for treatment effect
B.4. Summary of 9 variables entered into backwards multiple linear regression (n=230)

<table>
<thead>
<tr>
<th>Number of variables&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Variables</th>
<th>MSE</th>
<th>R&lt;sup&gt;2&lt;/sup&gt;</th>
<th>R&lt;sup&gt;2&lt;/sup&gt; adj</th>
<th>Mallows’ Cp</th>
<th>Akaike’s AIC</th>
<th>Schwarz’s SBC</th>
<th>Amemiya’s PC</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>firm w/o peel&lt;sup&gt;2&lt;/sup&gt;, firm w/ peel&lt;sup&gt;3&lt;/sup&gt;, pH,</td>
<td>125.95</td>
<td>0.296</td>
<td>0.267</td>
<td>10.0</td>
<td>1122.04</td>
<td>1156.42</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>background colour, visual mealiness, force at fracture, slope, AUC&lt;sup&gt;4&lt;/sup&gt;, juice content</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>firm w/o peel, firm w/ peel, pH, visual mealiness, force at fracture, slope, AUC, juice content</td>
<td>125.39</td>
<td>0.296</td>
<td>0.270</td>
<td>8.0</td>
<td>1120.04</td>
<td>1150.98</td>
<td>0.76</td>
</tr>
<tr>
<td>7</td>
<td>firm w/o peel, firm w/ peel, pH, force at fracture, slope, AUC, juice content</td>
<td>124.82</td>
<td>0.296</td>
<td>0.274</td>
<td>6.0</td>
<td>1118.04</td>
<td>1145.54</td>
<td>0.76</td>
</tr>
<tr>
<td>6</td>
<td>firm w/o peel, firm w/ peel, force at fracture, slope, AUC, juice content</td>
<td>124.26</td>
<td>0.296</td>
<td>0.277</td>
<td>4.0</td>
<td>1116.04</td>
<td>1140.10</td>
<td>0.75</td>
</tr>
<tr>
<td>5</td>
<td>firm w/o peel, force at fracture, slope, AUC, juice content</td>
<td>123.71</td>
<td>0.296</td>
<td>0.280</td>
<td>2.0</td>
<td>1114.04</td>
<td>1134.67</td>
<td>0.74</td>
</tr>
<tr>
<td>4</td>
<td>firm w/o peel, slope, AUC, juice content</td>
<td>123.16</td>
<td>0.296</td>
<td>0.283</td>
<td>0.0</td>
<td>1112.04</td>
<td>1129.23</td>
<td>0.74</td>
</tr>
<tr>
<td>3</td>
<td>slope, AUC, juice content</td>
<td>122.61</td>
<td>0.296</td>
<td>0.286</td>
<td>-2.0</td>
<td>1110.04</td>
<td>1123.79</td>
<td>0.73</td>
</tr>
</tbody>
</table>

<sup>1</sup>Number of variables included within the regression model  
<sup>2</sup>Firmness measured using TA.XT plus without peel  
<sup>3</sup>Firmness measured using TA.XT plus with peel  
<sup>4</sup>Area under the compression curve