ABSTRACT

STUDIES ON THE CULTIVATION AND WEEDINESS POTENTIAL OF EDIBLE AMARANTH, AMARANTHUS HYBRIDUS L. IN SOUTHERN ONTARIO

Geoff Farintosh
Advisor:
University of Guelph, 2018

Amaranthus hybridus L. is a leafy vegetable grown primarily in tropical regions. Similarities to other amaranths in Ontario suggest it could grow efficiently as a crop, but certain characteristics of this species raise the concern of introducing a new weed. Various harvest techniques were implemented to mimic cultural preferences in combination with different cutting frequencies. Germination trials at various depths and in plots with varying levels of disturbance examined the ability of seeds to establish and persist. The highest yields and quality measures were found in plants harvested every 2-3 weeks, cutting the thicker stems 15cm above ground level. Germination was highest when seeds were planted close to the surface but seeds lacked the ability to establish in untilled surfaces. Results suggest Amaranthus hybridus has the potential to become a successful vegetable crop in southern Ontario and that there limited ability for the edible cultivar to become a problematic weed.
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CHAPTER 1 – INTRODUCTION

*Amaranthus hybridus* L. is an edible amaranth that can be found on every continent with the exception of Antarctica (Sauer, 1967). *A. hybridus* is generally considered a weed in North America, commonly known as smooth amaranth, but is consumed as a staple food in other areas of the world such as Africa, Asia, the Caribbean and part of Europe (Abbasi et al., 2013; Schwerzel, 1986). With an increasing immigrant population in Canada, the demand for *A. hybridus* has grown (Filson & Adekulne, 2017). In 2016, Statistics Canada estimated the population of Canada to be 35.15 million people, with 13.45 million in Ontario. The population of Ontario has grown 10.6% from 2006 to 2016 with a large portion of growth coming as a result of immigration. A census released from Statistics Canada in 2016 estimated there are 3.85 million immigrants currently living in Ontario, with 463,115 arriving in the 5 year span from 2011 to 2016.

This constantly growing immigrant population means there is increasing demand for ethnic vegetables. In the Greater Toronto Area alone there is thought to be a 61 million dollar market opportunity to grow ethnic vegetables rather than importing them from abroad (Adekunle et al., 2011). Adekunle et al. (2011) listed edible amaranth as number 3 in the top 10 list of vegetables demanded by Afro-Caribbean immigrants, and this does not account for demand for this vegetable by other immigrant groups. In 2007, Statistics Canada suggested Ontario had nearly 350,000 people of Caribbean origin, and that immigration from the Caribbean was steadily increasing. In 2001, 55% of Caribbean Canadians were born outside of Canada and most had immigrated in recent years, with only 2% immigrating before 1961.
While some small farms are already growing edible amaranth in southern Ontario, they are all selling on a small-scale, often using a pick your own model or selling these plants in small bunches. There seems to be a variety of growing strategies also, with some farmers growing in the field while others produce plants in greenhouses or high tunnels (personal observation). Harvest techniques also vary depending on consumer preferences. In general, it appears that Afro-Caribbean consumers desire entire stems with the leaves, African consumers only value the leaves, and Europeans only harvest the tender leaves at the growing tips (personal observation). This variation leads farmers to question how to optimize harvestable yield via harvesting approaches.

While there may be a lack of information on edible amaranth as a crop in Ontario, there is a wealth of information in regards to weedy amaranths in Ontario. Edible amaranth strongly resembles the weedy amaranths found in Ontario, and in some cases the weedy amaranths such as redroot pigweed, *(Amaranthus retroflexus)* have been sold as edible amaranth. These similarities raise concern that edible amaranth production may introduce a new weed to southern Ontario or outcross with similar amaranths to create new weedy hybrids.

This study aims to examine harvest approaches for *A. hybridus* including cutting frequency and length of cutting in order to optimize marketable yield. In addition we will also explore the weediness potential of edible amaranth by looking at germination rate of seeds exposed to different variables and the ability of seeds to establish seedlings in different environments.
CHAPTER 2 – LITERATURE REVIEW

2.1 BACKGROUND INFORMATION

2.1.1 Taxonomy

The ubiquitous nature of amaranths has created a host of taxonomical issues. Even the most common name for edible amaranth used in Southern Ontario, callaloo, can be confusing. In Jamaica the name callaloo is used to describe both the Caribbean stew which utilizes A. hybridus as the main ingredient, and A. hybridus itself. The common names are extremely variable and hard to track, for example in Trinidad, and island close to Jamaica habitants refer to the plant as bhaji. There are over 50 different common names for edible Amaranth around the world (National Department of Agriculture – South Africa, 2000).

Even within the scientific community there are naming differences for this crop. This becomes apparent when one tries to link the common names to the scientific names. Searching for callaloo will highlight Amaranthus cruentus L., Amaranthus spinosus L., Amaranthus viridis L., and Amaranthus hypochondriacus L. For this study, a couple of samples taken from an edible amaranth field in Ontario were sent to Dr. Mihai Costea at Wilfrid Laurier University and he identified them as Amaranthus hybridus L.

The species complex Amaranthus hybridus itself is under taxonomic scrutiny. M. Costea worked with A. Sanders and G. Waines from the University of California in 2001 to publish a paper highlighting preliminary evidence for splitting the complex into A. hybridus subsp. quitensis and A. powellii subsp. bouchonii. This change is based on anatomical and morphological differences that raise the possibility of further subgenera division. The A.
hybridus aggregate is both the most studied group of the Amaranthus genus and the source of most of the taxonomic questions (Costea et al., 2001).

This taxonomic uncertainty for this species can make it difficult to find relevant literature as the amaranth in question may be different than the name implies or under an entirely different name due to different nomenclature practices. This can also create issues related to external validity as the edible amaranth used in our study could be different from the edible amaranth grown in other countries or produced by different seed producers, even if it is identified as A. hybridus. For this study we will work under the assumption that we are working with A. hybridus L. as per the characterisation by Dr. Costea.

2.1.2 Description

A. hybridus is an erect annual from the Amaranthaceae family (Omosun et al., 2007). This cultivated biotype is thought to be native to southern Mexico or Guatemala, but could also have been native to eastern North America, Central America, or northern South America before expanding its range (Sauer, 1955; Weaver and McWilliams, 1980). It is extremely vigorous in part because it is a C₄ plant which confers an ability to efficiently utilize high light levels and temperatures while tolerating drought (Arntz et al., 1998). The plant’s growth rate is associated with cumulative growing degree days with a base temperature of 10°C (Shrestha and Swanton, 2007).

A. hybridus is monoecious and self-pollinates. Pollen is primarily transported by wind although in some cases insects may also aid in pollination (Arntz et al., 1998). When the seedlings emerge they sport a pair of long, thin cotyledons approximately 2.5mm wide and 12.5mm long (Weaver and McWilliams, 1980). The first true leaves are much larger and more oval in
comparision to the leaves of a mature plant. As the plant grows the branching taproot becomes moderately deep and reddish in colour. The red tinge can also be found on the underside of leaves and lower portion of the stem. Some species will keep this colouration but in edible *Amaranthus hybridus* the red disappears as the plants mature, becoming a bright green colour instead.

Figure 2.1: *Amaranthus hybridus* seedling at Farintosh Farms, Stouffville, Ontario

*Amaranthus hybridus* has simple or branched ovate to rhombic-ovate leaves arranged alternatively on the stem. These leaves are dull, green, thick, smooth, and can grow up to 20cm long. The entire plant can grow extremely tall, easily reaching 3m in height (Weaver and McWilliams, 1980).
Both male and female flowers can be found on the same plant, appearing as soon as 6 weeks after emergence. These flowers are small and green, forming at leaf axils and at branched spikes at the top of major stems. Small round seeds develop, that change from a dark reddish-brown to black as they mature. The seeds are approximately 1mm in diameter and a single gram can contain over 3,000 seeds. A mature plant can produce 100,000 to 600,000 seeds if given space and time (Massinga et al., 2001), but in a conventional density with multiple plants per square meter seed production ranges from 100,000 to 500,000 seeds per square meter based on planting density (Sellers et al., 2003). Studies have shown that it takes 1-6 weeks for the seeds to mature after pollination (Shrestha and Swanton, 2007), although species similar to A. hybridus fall on the longer end of this spectrum. Brainard et al. (2007) reported that if the seed has been pollinated it will continue to mature even if the plant is removed from the soil.

Figure 2.2: Female inflorescence and seeds taken from mature Amaranthus hybridus plant at Farintosh Farms, Stouffville, Ontario
The seeds of *A. hybridus* are generally dispersed through water or soil displacement, often in the form of irrigation, floods and tillage practices, but they can also cling to clothing and machinery (Weaver and McWilliams, 1980). For some amaranths, the seed head will break off when mature and form tumbleweed aiding is seed dispersal, but this is very uncommon for *A. hybridus* (personal observation).

Weaver and McWilliams (1980) provided a summary of the germination behaviour of weedy *A. hybridus*. They found that seeds are most likely to germinate if they reside within the top 1-2.5 cm of soil. An increase in moisture, temperature and light can promote germination. They suspected that multiple dormancy mechanisms act in this species to promote germination at different timings over the course of several years, and in turn increase long-term persistence. Mechanical tillage can bring up dormant seeds from past years to that upper 2.5 cm of soil, but no-till practices seem to favour weedy amaranths in the field. *A. hybridus* tends to germinate better in higher temperatures, with optimal germination between 30 to 40°C (Bibbey, 1935). This temperature requirement means that seeds of this species do not normally germinate in southern Ontario until late May to early June (Baskin and Baskin, 1977).

### 2.1.3 History of use as a Crop

Edible amaranth usage dates back to the 15th century, when Aztecs grew amaranths as a staple crop. The seeds were used not just as a grain but also to form dough which was sculpted to form religious idols (Sauer, 1950). Amaranth seeds have also been found in a diverse range of excavated archaeological cultural sites in the Americas and Europe (Apogino, 1957). *A. hybridus* is thought to have descended from *A. cruentus* which has been grown in Central America and southern Mexico for decades, first as a grain crop and later used for dye and as an
ornamental as well. There has likely been introgression between *A. cruentus* and *A. hybridus* (Sauer, 1967).

### 2.1.4 Range

*A. hybridus* was first seen growing as a native riverbank pioneer in eastern North America, Central America, and northern South America but its range is continuing to expand north and west (McWilliams, 1966). McWilliams (1996) reported that *A. hybridus* has been found as far north as Iowa and Illinois, and Frost (1971) reported specimens were found in the Toronto area. Some specimens of *A. hybridus* have been recorded in Canada as early as 1892, but all specimens prior to Frost’s reporting in 1971 were found in private gardens either grown as an ornamental or as a crop, often mixed in with other amaranths.

In Canada, *A. hybridus* occurs in south western Ontario and is seldom seen north of Toronto (Weaver et al., 1980). In 1967, Sauer collected samples in Algeria, the Bahamas, Bermuda, Brazil, China, Dominican Republic, Japan, Mexico and Morocco and since then this species has been found all over the world. While *A. hybridus* appears in all these locations there are many biotypes, often specific to location and these can be visibly very different from one another.

### 2.1.5 Use as a Vegetable

There has been a significant increase in interest in vegetable amaranth in North America recently due to how easily it grows in home gardens with very little management (Billey, 2000). It grows more vigorously than most leafy vegetables in semi-arid areas where lack of water prevents growth of more traditional vegetables (Allemann et al., 1996). It is grown as an edible green around the world in places such as the Caribbean, China, South Africa, Zimbabwe, and
India (Holm et al., 1977). It also has the potential to be a valuable forage crop (Mugerwa and Bwabye, 1974).

Studies in Africa point to the main use of *Amaranthus hybridus* as a leafy nutritious vegetable. (Omosun et al., 2008). When compared to spinach, *A. hybridus* contains considerably higher levels of vitamin A and C, calcium, iron, phosphorous, fibre and niacin (Watt and Merril, 1975; Mnzava, 1997). *A. hybridus* contains a considerable amount of protein which is high in lysine (Mallory et al., 1990). Due to its health benefits, amaranth is considered a staple in many developing countries and is said to substantially reduce malnutrition. (Schwerzel, 1986).

### 2.1.6 Use as a Grain

Sauer (1967) reported *A. hybridus* seeds have higher protein and fat content than most common cereal crops with similar carbohydrates and that it could be a viable pseudo-cereal crop in some regions. While over a decade of cultivar research on grain amaranth has been conducted, the demand for the grain is low and seemingly limited to a small portion of multigrain products (Myers, 1996).

### 2.1.7 Hybridization

*A. hybridus* has been found to naturally hybridize. Field studies have found female tall waterhemp (*Amaranthus tuberculatus* Moq.) hybridizing with *A. hybridus* (Trucco et al., 2005). A single tall waterhemp plant was capable of producing more than 200,000 hybrids, suggesting little if any gametic incompatibility. *A. hybridus* seems to be especially prone to hybridization compared to other amaranths, although the F1 generation is often sterile, creating very few F2 generation plants (Murray, 1940). This ability to readily hybridize may explain the variation of
A. hybridus biotypes around the world. This variation may also be a result of introgression with A. retroflexus (Sauer, 1950).

2.1.8 Potential use as a Medicine

A. hybridus is an important source of minerals and phytochemicals (Akubugwo et al., 2008). It can be used to create an astringent tea which is reported to help with indigestion, diarrhea, intestinal bleeding, and excessive menstruation (Tanaka, 1976). A. hybridus seeds have also been found to be a source of squalene, an isoprenoid compound which acts as an intermediate metabolite in the synthesis of cholesterol (He et al., 2002).

2.1.9 Toxicity

Amaranths can accumulate nitrates, sometimes to levels harmful to livestock depending on the environment and the stage of development (Kingsbury, 1964, Stuart et al., 1975). The nitrates are found in highest concentration within the stems and branches, increasing in concentration as the plant matures, reaching peak concentration right before flowering (Campbell, 1924). The Canadian Biodiversity Information Facility (CBIF) lists A. hybridus as a poisonous plant due to its ability to accumulate nitrates to toxic levels.

2.2 AGRONOMY

2.2.1 Cropping Practices

Many species of Amaranthus weeds grow well in Ontario, which suggests A. hybridus has potential as a crop in southern Ontario. Some farmers are already successfully growing this crop. Plants are generally started in a greenhouse because they require high temperatures for seed germination and plant growth. The trays are planted around mid-April so the plants can be
transplanted at the start of June, often with a 20-20-20 fertilizer mix. Once planted in the field, it is important to control weeds, often wild amaranths such as *A. retroflexus* and *A. powellii* S. Wats. Weed control is typically mechanical, usually with a mechanized weeder/scuffler or simply with a hoe. At the end June, plants benefit from being clipped or cut near the base to help promote suckering (adventitious growth). A 46-0-0 fertilizer can also be applied around this time to boost regrowth. Irrigation may be required in a dry year. Drip-tape irrigation is sometimes used to water this crop but the irrigation tubes are at risk of being cut when the plants are harvested. Towards the end of July the plants are usually ready for harvest. The field is often sectioned off so one section can be harvested while other areas are left to regrow. Into August, reproductive structures may start to emerge on plants remaining in the field. It is important to remove these seed heads as they can limit vegetative growth and potentially lead to volunteer plants in the following year. 46-0-0 fertilizer may be reapplied around the end of August if required. After a frost, the plants are undesirable to most consumers although some will still pick them. The plants are surprisingly tolerant to frost; in fact the word *amaranth* is derived from the Greek word for unwilting, “*amaranton*”. By October there is seldom any value left so the plants are mowed down and the fields are ploughed (personal observation).
2.2.2 Weediness Potential

In southern Ontario, there are multiple weedy amaranths such as *A. retroflexus* and *A. powellii* so it is possible that the species being grown as edible amaranth (*A. hybridus*) may also be weedy. In fact, *A. hybridus* is already recognized as a weed in southern Ontario, although the weedy biotype of *A. hybridus* is noticeably different than the edible cultivated type (M. Costea, personal communication). The weedy biotype has been found to substantially reduce the yield of corn and soybeans (Moolani et al., 1964). Weaver et al. (1980) found that *Amaranthus hybridus*...
seeds took longer to germinate and the plants took 3 weeks longer to mature than *A. retroflexus* or *A. powellii*, but it produced more seeds than either of those species.

*A. hybridus* can quickly create a canopy over shorter vegetables but also competes with taller crops. Massinga et al. (2001) reported that just 1-3 *A. hybridus* plants in 3 m of a corn or soybean row could cause significant yield loss. Amaranths can be especially problematic in warm climates. A study by Chu et al. (1978) found that *Chenopodium album* L. had greater competitive ability than *A. retroflexus* at 13/7°C, but at 24/29°C *A. retroflexus* had the advantage displaying faster growth and more successful establishment.

With the ability to produce so many seeds, *A. hybridus* plants have a high potential rate of increase under optimal conditions. It is even possible to have two generations of amaranths in a single growing season because of how fast the plants mature and the lack of primary dormancy (Frost, 1971). In an unpublished study by Susan Weaver (1980), 1000 *A. hybridus* seeds in a 0.25m² plot produced an average of 30 plants and 196,300 seeds per plot. The study found, however, that *A. powellii* and *A. retroflexus* produced more plants and seeds. Larger and heavier seeds tend to sprout into plants that will have a higher dry weight of leaves, stems and roots (Schreiber, 1967).

*A. hybridus* seedlings are easily controlled and slow to grow early in the season, but as they mature they are much harder to control as they can often regrow after being physically injured by cultivation (Feltner, 1970). Most edible amaranths are able to be controlled by herbicide use although hybridization could lead to the development of herbicide resistant weedy biotypes (Feltner, 1970).
2.2.4 Herbicide Resistance

Herbicide resistance in amaranths is not a new phenomenon, with triazine-resistant *Amaranthus powellii* first identified in 1968 in Washington State in the United States (Birschbach et al., 1993). The first case in Canada was recorded in 1979, again triazine-resistant *Amaranthus powellii*, near Montrose, Ontario. There are currently eight different amaranth species that have displayed triazine resistance, including *Amaranthus hybridus* (Birschbach et al., 1993). There have also been cases of resistance to acetolactate synthase (ALS)-inhibiting herbicides including imidazolinone and halosulfuron (Whaley et al., 2006; Trader et al., 2009). The ability of *A. hybridus* to resist triazines seems to come at a cost of decreased electron transport efficiency, which impacts the ability of plants to tolerate physical damage such as leaf removal (Gassmann, 2004). More recently *A. tuberculatus* has been found to resist group 4 herbicides such as 2,4-D and dicamba (Bernards et al., 2012).

2.2.5 Need for and Response to Fertilizer Application

*Amaranthus hybridus* is very responsive to the nitrate form of nitrogen, creating more biomass and seeds, along with increased seed germination (Alonge et al, 2007; Egley, 1986; Blackshaw and Brandt, 2008). This response to nitrogen means that amaranths benefit from fields which have had a legume cover crop.

Materechera et al. (2006) carried out a study in South Africa which looked at the effects of nitrogen on *A. hybridus*. The plants received 40 kg of actual N ha$^{-1}$ in the form of ammonium nitrate (13% N), cattle manure, or an equal mixture of both. The fertilizer treatments were applied prior to planting along with 20 kg P ha$^{-1}$ using single super phosphate (10.5% P). All three treatments showed a significant increase in plant height and stem diameter versus the
control, with the mixture treatment showing the largest increase, followed by the ammonium nitrate treatment. The soil for this study was taken from uncultivated land in a semi-arid area of South Africa. The study did not look at varying rates of fertilizer or subsequent applications.

2.2.6 Harvest Methods

Around the world, edible A. hybridus is harvested differently as an edible crop. In the western hemisphere, thicker stems or shoots are selected and cut where they meet the main stem near the base of the plant. These stems are cut with the leaves on and then grouped and tied into bundles so they can be easily sold at market. In many African countries, only the leaves are harvested and sold (Materechera et al., 2006), while in Greece just the top 5-10 cm of each stem is sold, including the tender growing point (Gordon, 2016).

Materechera et al. (2006) studied the effect of harvest frequency on yield of A. hybridus. The study was done in South Africa so only the leaves were considered for marketable yield. They found that more leaves were produced with weekly harvest treatments but they had very little yield in terms of weight. Yield increased with longer periods between cuttings but this also lead to leaves becoming coarse and thick which is not desirable for customers. The study came to the conclusion that in the South African summers the optimal harvest frequency to achieve higher yield while maintaining acceptable quality is 2 weeks.

In southern Ontario most farms harvest stems daily until the field is exhausted and needs to be left to regrow for a couple weeks (personal observation). This method takes a considerable amount of time in terms of harvesting, because stems need to be carefully selected.
2.2.7 Insect Pressures

Black cutworm larvae, *Agroti ipsilon* Hufnagel, have been known to attack *A. hybridus* (Busching and Turpin, 1977) and can eat right through the stems of young plants causing the entire plant to die (person observation). Japanese beetles, *Popillia japonica* Newman, have been found eating the leaves of *A. hybridus* in southern Ontario (personal observation). In 2013 some type of insect larvae was found boring into the stems of *A. hybridus* plants (personal observation). The larvae were unable to be identified by entomologists at the University of Guelph but there was speculation that it was a leaf-miner fly from the *Agromyzidae* family (M. Filotas, personal communication, September 19, 2013). While the larvae did not appear to stunt plant growth the infested stems were not suitable for consumers.

**Figure 2.4:** *Amaranthus hybridus* damage from unidentified leaf-miner larvae (left) and black cutworm larvae, *Agroti ipsilon* (right) at Farintosh Farms, Stouffville, Ontario.
2.3 THESIS OBJECTIVES

The ability to grow edible amaranth in southern Ontario could help meet growing demand for ethno-cultural vegetables in this province and reduce imports. Unfortunately, while a significant amount of research has been done on weedy amaranths there is a lack of research on edible amaranth, not just in southern Ontario, but globally. This includes little work on how harvesting methods affect marketable yield. The one study that was done on harvest approaches and impact on marketable yield only considered harvesting the leaves and was conducted in South Africa which has a very different climate than southern Ontario. In order to support an expansion of edible amaranth production in Ontario it is important to evaluate the growth of this crop in southern Ontario and determine how various harvest approaches will influence marketable yield and quality.

If edible amaranth is going to be grown in southern Ontario it is also important to know if it has the potential to be a weed. While *A. hybridus* has been studied as a weed in southern Ontario, the edible biotype appears very different than weedy biotypes, and is likely to perform differently as a weed. There is well documented research on weedy *A. hybridus* and other weedy amaranths. These provide clear examples to compare to edible *A. hybridus* and in turn highlight noticeable differences and similarities. One of the factors the makes amaranths such a troublesome weed is their ability to produce large amounts of viable persistent seeds and establish in high disturbance fields. Knowing if the seed of edible amaranth displays these same persistence and seedling establishment characteristics as weedy amaranth would help to assess the risk of edible amaranth becoming a weed in southern Ontario.
In this respect, this study aims to provide initial information on:

1) The most suitable harvest approaches to maximize marketable yield and quality of edible amaranth in southern Ontario. More general management decisions will also be recorded to help identify what conditions and timings benefit growth in general. Marketable yield, total yield, and regrowth will be measured using fresh and dry weights (kg/m$^2$). We hypothesize that longer time periods between cuttings will produce more yield, but lower quality. We also hypothesize that harvest approaches that cut the stems lower on the plant will result in higher yields (generally).

2) The potential weediness of edible *A. hybridus* in southern Ontario. Seed germination and seedling establishment experiments with a variety of factors will be conducted to assess whether edible amaranth poses a threat of becoming a volunteer and an invasive weed. We hypothesize that seeds taken from edible amaranths in the field will have higher germination levels and demonstrate less seed dormancy and potential persistence than weedy amaranths. In addition, we hypothesize that unlike weedy amaranths, seeds of edible *A. hybridus* will have a limited ability to produce viable seedlings when planted at depth in soil and that these seeds will have a limited ability to establish seedlings in undisturbed environments.
CHAPTER 3 – STUDIES ON THE GROWTH AND YIELD OF AMARANTHUS
HYBRIDUS L. AS IMPACTED BY HARVESTING APPROACHES IN SOUTHERN
ONTARIO, CANADA

3.0 INTRODUCTION

While *A. hybridus* and other edible amaranths are a staple food in other parts of the world there is very little grown in southern Ontario. With an increasing immigrant population in Ontario it is unsurprising that demand for ethnic produce is increasing. This demand, coupled with the ability for *A. hybridus* to grow quickly, and the high nutrient content, (Akubugwo et al., 2007) make it a strong candidate for a new crop in southern Ontario (Filson and Adekulne, 2017).

Trials on amaranths have been carried out in Ontario before but with a focus on grain production rather than exploring the potential as a leafy vegetable (R. Riddle, personal communication, April 3, 2017). *A. hybridus* is already being sold in select grocery stores in the United States and some ethnic Caribbean stores are beginning to sell it in Ontario. While a few Caribbean specialty shops sell Ontario grown *A. hybridus* fresh, most of it is grown and canned abroad before being imported and sold (personal observation).

Edible amaranth is harvested differently in different parts of the world based on climate or customer cultural preferences. In southern Ontario there has yet to be a comparison of different cutting methods and their impact on marketable yield. Harvesting too frequently may hinder the plant from re-growing, while waiting for a prolonged period might affect quality if the harvested product is too tough or stringy for consumers (Materechera et al. 2006). In addition to harvest timing, the area cut is also likely to impact marketable yield. While some consumers may
value the tender growing tips, only cutting them will probably limit yield, while cutting the entire stem may boost yield but be less desirable to the consumer.

The primary objective of this study was to test which harvest approaches are the most effective at optimizing both yield and marketable quality of *A. hybridus* in southern Ontario. These results can support the potential for growing more edible amaranth in southern Ontario, and open the door for further studies on this crop.

### 3.1 MATERIALS AND METHODS

#### 3.1.1 Study Site

Field experiments were conducted in 2017 at the Guelph Centre for Urban Organic Farming (GCUOF) located at the University of Guelph, in Guelph, Canada (43° 32’N, 80° 13’W), the Simcoe Horticultural Research Station (SHRS) in Simcoe, Canada (42° 51’N, 80° 16’W) and at Farintosh Farms in Stouffville, Canada (43° 56’N, 79° 21’W). Soil samples were taken from all 3 sites using a metal soil corer to a depth of 8cm. The plot at GCUOF was a loam soil classified as a Luvisol had a pH of 7.6 and organic matter of 5.2%, the sample from SHRS was a very fine sandy loam (VFSL) known as Watford and had a pH of 7.4 and 2.0% organic matter, while Stouffville was a Bookton sandy loam with a pH of 6.3 and 2.7% organic matter (Appendix 7.3).

The Simcoe site was planted with rye before glyphosate was applied at 2L/ha on May 9th. The field was then cultivated on May 31st and 700kg/ha of 15.7-7.2-11.4 (NPK) fertilizer was applied. Prior to planting the land was worked again to incorporate the fertilizer and bury emerging weeds. The Stouffville site was planted with edible amaranth in 2016 and ploughed in the fall, 550kg/ha of 6-24-24 was applied and the field was cultivated three times before
planting. The Guelph site was covered primarily in orchard grass (*Dactylis glomerata L.*) before it was rototilled and raked by hand before planting.

### 3.1.2 Experimental Design

Field plots were arranged in a randomized complete block design. There were six treatments in total and four blocks (replicates) at each site with the exception of GCUOF where there was only room for three blocks (replicates). Three harvest treatments were all cut to 15cm above ground, and there were three different timing intervals: weekly, every two weeks, and every three weeks. In addition to these treatments, two harvest treatments were included to mimic the two most common consumer self-harvesting approaches (pick your own). First, Afro-Caribbean consumers tend to desire the plants to be cut low, where the side shoots meet the main stem, selecting thicker, more mature stalks. Other consumers, including those of European descent, tend to prefer to take just the very tips of each stalk. Both of these “consumer” treatments were applied every two weeks. Finally, a control treatment was included where the plants were not harvested until the final harvest date.

Seeds were planted into 128 cell trays in Stouffville on April 26th and placed into a greenhouse to encourage seed germination and the establishment of seedlings. Approximately eight seeds were planted into each 28.6mm$^2$ cell. As the seeds emerged and the seedlings grew, they were thinned to roughly five seedlings per cell. Once the seedlings were approximately 10cm in height they were transplanted into the field sites. The *A. hybridus* seedlings were transplanted at the Simcoe research station, GCUOF, and Farintosh Farms in Stouffville on June 9th, 12th and 13th respectively. At the Simcoe and Stouffville sites the transplants were planted with 8.5g/L of 20-20-20 fertilizer while at Guelph the plants were planted with water.
Transplants were planted with 45cm spacing in the row, with the rows 1m apart. In early July 85kg/ha of 46-0-0 fertilizer was applied at the Simcoe and Stouffville site whereas Guelph did not receive anything. Once the plants were tall enough, all six treatments were cut to a height of 15cm in early July to encourage adventitious growth. Each plot was comprised of three rows with five plants in each row, for a total of 15 plants per plot. To limit edge effects only the three plants on the inside of the plots were sampled for the experiment. The treatments were applied to all 15 plants within each plot.

3.1.3 Data Collection

Plants were harvested by cutting perpendicular to stems using a sharp knife. Cuttings from the inner three plants in each plot were pooled for a given plot. Fresh weights were immediately measured on site using an ADAM®CPW plus -15 scale (Adam Equipment Inc, Fox Hollow Road, Oxford, CT, USA, 06478) with an accuracy of 5 g and a max weight of 15 kg. Once fresh weights were measured, samples were put in a paper bag, labeled, and moved to a dryer. The dryer maintained a temperature of 48.9 °C. After 2 weeks in the dryer, the dry weight was measured using the same scale. The weight measures were converted to kg/m².

3.1.4 Data Analysis

Statistical analysis software (SAS) version 9.4 (SAS Institute, Cary, NC) was used for all statistical data analysis. An analysis of variance (ANOVA) for mixed models was carried out using PROC GLIMMIX. The different harvest treatments were the fixed effects, while block was treated as the random effect. There was too much variation between the experimental sites for site to be used as a random effect or to pool over sites and so analysis was done on an individual site basis. The data was tested for normality using the Shapiro-Wilk test and Q-Q plots generated
by PROC UNIVARIATE. The PDMIX800 macro on SAS was used in combination with Tukey’s test to convert Fisher's LSD means separation into letter groupings. All analyses were considered significant at $\alpha=0.05$.

### 3.1.5 Data Organization

While data was collected for a total of eight weeks (initial harvest, six weeks of harvest with treatments applied, and a final harvest where plants were cut to ground level) to best display results, the data was placed into three groupings to make relevant comparisons. These groupings were:

A. **Regrowth**: contains only harvest data from the six weeks after the initial harvest. This data is most representative of the treatments as it does not contain the initial harvest before the treatments were implemented and because the treatments that were harvested weekly, every other week, and every three weeks all fall naturally on the sixth week without harvesting any trial prematurely.

B. **Marketable yield**: contains the harvest data from the six weeks in addition to the initial harvest. The final harvest was not included in this group as the plants were cut down to ground level and much of the biomass would not be close to the quality expected by consumers. This grouping provides the most accurate estimate of marketable yield from a seven week period.

C. **Total Biomass**: contains initial harvest, the six weeks treatments where applied and the final harvest where plants were cut down to ground level. With so much focus on what is being harvested it is important to also have a final harvest to account for all plant growth during the experiment period. By combining all of the harvest data together it is easier to
gain a better understanding of how treatments affected biomass production of this species under these conditions.

3.2 RESULTS AND DISCUSSION

These groups were presented individually for each site as there were significant differences between the three sites ($P = <0.0001$). This significant site effect was likely due to differences in weather and soil properties among the sites. The average total biomass of all six treatments shows this difference. Simcoe had an average total biomass (fresh weight) of $5.34\text{ kg/m}^2$, Stouffville yielded $3.91\text{ kg/m}^2$, while Guelph produced an average of $0.91\text{ kg/m}^2$. The field trial at GCUOF in Guelph had a disadvantage right from the start as the site was certified organic so synthetic fertilizer could not be used. Another reason that the Guelph site may have been so far behind was due to a wet start to the growing season. There was 243.6mm of rain in June and July in Guelph, when Stouffville and Simcoe had only 135.2mm and 101.7mm, respectively, in the same period (Appendix 7.2). Guelph was also not as warm as the other two sites throughout the course of the experiment (Appendix 7.1). The differences in yield between Guelph and Stouffville are harder to trace to monthly temperature and precipitation differences or differences in soil properties. Rather, the timing of rainfall may have been a factor, especially in June where Stouffville received heavy rain at the start of the month where as it was more evenly dispersed in Simcoe. These differences in weather seemed to have affected yield greatly over the course of the experiment. While the first harvest was done at the same time across all three sites, the plants were already very different in size at each site and may have responded differently to treatments that did not account for plant size at time of application.
3.2.1 Regrowth

Analysis of plants harvested at the Stouffville site showed significant fresh weight differences between all five harvest treatments (Table 3.1). From highest to lowest yield, the treatments ranked as; the customer method of selecting for large stems and cutting low, then triweekly, biweekly, weekly, and lastly harvesting only the tips. While dry weight measures followed the same treatment order, there was not a significant difference between every treatment with respect to dry weights (Table 3.1). Instead, for dry weight, the customer treatment was significantly higher than the rest of the treatments, while the tips only treatment was still the lowest yield but not significantly different than the weekly harvest treatment. The ratio of fresh to dry weight was greatest for the triweekly treatment, closely followed by the customer treatment. These two treatments both allowed the plant to grow longer and achieve thicker stems, suggesting that the stems may be able to contain more water as a percent than the leaves.

Table 3.1 Mean (plus or minus standard error) edible amaranth (*Amaranthus hybridus* L.) regrowth as affected by various harvest approaches over six weeks at Farintosh Farms in Stouffville, Ontario, Canada for the 2017 season. For explanation of treatments see Materials and Methods.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fresh Weight (kg/m²)</th>
<th>Dry Weight (kg/m²)</th>
<th>Ratio (fresh kg/m² /dry kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weekly</td>
<td>0.59±0.024d</td>
<td>0.18±0.042bc</td>
<td>3.74±0.694b</td>
</tr>
<tr>
<td>Biweekly</td>
<td>0.78±0.052c</td>
<td>0.16±0.012b</td>
<td>4.97±0.399b</td>
</tr>
<tr>
<td>Triweekly</td>
<td>1.26±0.053b</td>
<td>0.18±0.009b</td>
<td>6.89±0.383a</td>
</tr>
<tr>
<td>Customer</td>
<td>1.89±0.117a</td>
<td>0.35±0.021a</td>
<td>5.46±0.453ab</td>
</tr>
<tr>
<td>Tips</td>
<td>0.30±0.026e</td>
<td>0.07±0.008c</td>
<td>4.28±0.242b</td>
</tr>
</tbody>
</table>

*a-e* Means followed by the same letter within a column are not significantly different according to a Tukey’s multiple range test (α=0.05)
At the Simcoe site the results followed a similar pattern to the Stouffville site, with customer and triweekly treatments providing the greatest fresh and dry weights (Table 3.2). The results at the Simcoe site for the tip only treatment also mirrored the results at the Stouffville site with significantly lower fresh and dry weight versus the other treatments. Only the fresh to dry weight ratio of the customer treatment was significantly higher than the tip only treatment. For the Simcoe site, the ratios were higher in general compared to the Stouffville site. This was surprising considering Stouffville received 61.8mm more rain in July and August than did Simcoe. However, both sites received far less rain during the experiment period than the 30 year average (Appendix 7.2). Neither site was irrigated but the Simcoe site received rainfall more regularly, while the Stouffville site had just a few downpours.

Table 3.2 Mean (plus or minus standard error) edible amaranth (*Amaranthus hybridus* L.) regrowth as affected by various harvest approaches over six weeks at the University of Guelph Horticultural Experimental Station in Simcoe, Ontario, Canada for the 2017 season. For explanation of treatments see Materials and Methods.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fresh Weight (kg/m²)</th>
<th>Dry Weight (kg/m²)</th>
<th>Ratio (fresh kg/m² /dry kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weekly</td>
<td>0.96±0.044b</td>
<td>0.15±0.007b</td>
<td>6.35±0.277ab^z</td>
</tr>
<tr>
<td>Biweekly</td>
<td>1.24±0.083ab</td>
<td>0.18±0.008a</td>
<td>6.82±0.400ab</td>
</tr>
<tr>
<td>Triweekly</td>
<td>1.45±0.164ab</td>
<td>0.23±0.013a</td>
<td>6.34±0.391ab</td>
</tr>
<tr>
<td>Customer</td>
<td>1.48±0.140a</td>
<td>0.22±0.022ab</td>
<td>6.78±0.181a</td>
</tr>
<tr>
<td>Tips</td>
<td>0.33±0.019c</td>
<td>0.06±0.003c</td>
<td>5.74±0.214b</td>
</tr>
</tbody>
</table>

^z a-e Means followed by the same letter within a column are not significantly different according to a Tukey’s multiple range test (α=0.05)
The site in Guelph produced very few significant differences between treatments. The dry weight of the weekly treatment was significantly higher than the tips only treatment, the biweekly and the triweekly treatments. The ratio of the tips only treatment was significantly higher than the weekly cutting treatment (Table 3.3). The fresh and dry weights from this site were low compared to the other sites and there was greater variation around the means. This meant that even in cases where the means between treatments were numerically great (e.g. fresh weight for the customer treatment was more than triple the other treatments) the differences were not statistically significant. In addition, the mean separation power was lower for this site than the other two sites because there were only three and not four replicates. As well, the site environment was not consistent in multiple directions with a large greenhouse to the south and a waterway to the north. Overall, the low yields for this site were likely due to multiple factors but the key may have been a possible lack of soil nitrogen at this site because the site was a certified organic site and thus no synthetic fertilizer was applied.
Table 3.3 Mean (plus or minus standard error) edible amaranth (Amaranthus hybridus L.) regrowth as affected by various harvest approaches over six weeks at the University of Guelph Centre for Urban Organic Farming in Guelph, Ontario, Canada for the 2017 season. For explanation of treatments see Materials and Methods.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fresh Weight (kg/m²)</th>
<th>Dry Weight (kg/m²)</th>
<th>Ratio (fresh kg/m²/dry kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weekly</td>
<td>0.12±0.033a</td>
<td>0.05±0.006a</td>
<td>2.99±1.222b</td>
</tr>
<tr>
<td>Biweekly</td>
<td>0.10±0.014a</td>
<td>0.02±0.001b</td>
<td>5.14±0.415ab</td>
</tr>
<tr>
<td>Triweekly</td>
<td>0.10±0.027a</td>
<td>0.02±0.003b</td>
<td>5.05±0.625ab</td>
</tr>
<tr>
<td>Customer</td>
<td>0.34±0.126a</td>
<td>0.08±0.031ab</td>
<td>4.71±0.301ab</td>
</tr>
<tr>
<td>Tips</td>
<td>0.08±0.014a</td>
<td>0.01±0.003b</td>
<td>6.12±0.699a</td>
</tr>
</tbody>
</table>

a-e Means followed by the same letter within a column are not significantly different according to a Tukey’s multiple range test (α=0.05)

Across all three sites, the customer harvest treatment tended to provide the highest fresh weight yield, closely followed by the triweekly treatment. This result is valuable not just because it highlights how to maximize yield through harvest approach but also because two very different harvest approaches provided similar results. The customer method is very time consuming as each stem has to be evaluated and cut individually based on thickness, while the triweekly cutting method is very time efficient with just a single swipe of the knife required for harvesting plants every three weeks. The tips only treatment tended to provide the lowest fresh weight yield. One of the more obvious reasons for this is that such a small part of the plant is being harvested. It is worth noting that the fresh weight yield from the weekly treatment tended to be close to the tips only treatment, suggesting that two weeks was too long of a harvest interval for the tips only treatment or that the weekly cuttings allowed the plants to sprout more adventitious growth. A similar example of cutting to increase adventitious growth can be found in eucalyptus plantations.
where shining gum (*Eucalyptus nitens* Deane & Maiden) are cut to produce greater total leaf than unpruned trees (Pinkard & Beadle, 1998)

### 3.2.2 Marketable Yield

The marketable yield results were very similar to the regrowth results given that the only difference between these groups was the addition of the initial harvest. Before the initial harvest was done, none of the treatments had been applied, meaning that (within a site but among treatments) approximately the same amount of biomass was present on each plant. By adding the initial harvest the differences between treatments were diluted and in some cases the statistical significance between treatments was lost compared to the regrowth results. Notable from the marketable yield results was how much the initial harvest differed between sites. The Simcoe site had the largest initial harvest, averaging 1.97kg/m$^2$, Guelph had the smallest with 0.28kg/m$^2$, and Stouffville was in the middle with 0.89kg/m$^2$. It is important to highlight these initial harvest weights given that plant size at initial harvest impacts the extent to which the plant is able to branch and regrow (Harper, 1977). For example, at the Simcoe and Stouffville sites, the initial harvest 15cm above ground level was relatively low in relation to the height of the plant, falling just above the first break in the stem. This could promote growth of new shoots and higher yield. This was not the case at the Guelph site, however, given that the plants were quite small at first harvest and the cut at 15cm was near the top of most plants. At this site, therefore, this initial harvest would have been similar to a tips only treatment which does not necessarily promote as much branching.

Generally, the results for marketable yield were similar to the results for regrowth, with the customer and triweekly treatments generating the greatest fresh weights at all three sites,
however, this difference among treatments was only significant for the Stouffville site (Table 3.4). The tips only treatment also generally produced the lowest fresh and dry weights but in the case of marketable yield versus regrowth, the differences from other treatments were much less often statistically significant. Differences between treatments for the ratios were less often significant as well, with most significant differences coming from a lower ratio for the tips only treatment at the Stouffville and Simcoe sites. By adding the first harvest the effect of the treatments on the ratio between fresh and dry weight becomes less significant.

Table 3.4 Mean (plus or minus standard error) marketable edible amaranth (*Amaranthus hybridus* L.) yield as affected by various harvest approaches over seven weeks at Farintosh Farms in Stouffville, Ontario, Canada for the 2017 season. For explanation of treatments see Materials and Methods.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fresh Weight (kg/m²)</th>
<th>Dry Weight (kg/m²)</th>
<th>Ratio (fresh kg/m² /dry kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weekly</td>
<td>1.75±0.102b</td>
<td>0.30±0.042ab</td>
<td>6.07±0.876ab⁴</td>
</tr>
<tr>
<td>Biweekly</td>
<td>1.85±0.114b</td>
<td>0.36±0.092abc</td>
<td>5.94±1.043ab</td>
</tr>
<tr>
<td>Triweekly</td>
<td>2.60±0.131a</td>
<td>0.33±0.010b</td>
<td>7.96±0.253a</td>
</tr>
<tr>
<td>Customer</td>
<td>2.56±0.143a</td>
<td>0.42±0.030a</td>
<td>6.05±0.398b</td>
</tr>
<tr>
<td>Tips</td>
<td>0.50±0.019c</td>
<td>0.10±0.009c</td>
<td>5.36±0.308b</td>
</tr>
</tbody>
</table>

⁴ a-e Means followed by the same letter within a column are not significantly different according to a Tukey’s multiple range test (α=0.05)
Table 3.5 Mean (plus or minus standard error) marketable edible amaranth (*Amaranthus hybridus* L.) yield as affected by various harvest approaches over seven weeks at the University of Guelph Horticultural Experimental Station in Simcoe, Ontario, Canada for the 2017 season. For explanation of treatments see Materials and Methods.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fresh Weight (kg/m²)</th>
<th>Dry Weight (kg/m²)</th>
<th>Ratio (fresh kg/m² /dry kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weekly</td>
<td>3.46±0.242a</td>
<td>0.40±0.042a</td>
<td>8.74±0.811a²</td>
</tr>
<tr>
<td>Biweekly</td>
<td>3.60±0.379a</td>
<td>0.45±0.058a</td>
<td>8.08±0.269a</td>
</tr>
<tr>
<td>Triweekly</td>
<td>4.02±0.340a</td>
<td>0.50±0.030a</td>
<td>8.01±0.679a</td>
</tr>
<tr>
<td>Customer</td>
<td>3.77±0.265a</td>
<td>0.47±0.032a</td>
<td>8.08±0.107a</td>
</tr>
<tr>
<td>Tips</td>
<td>0.48±0.009b</td>
<td>0.08±0.002b</td>
<td>5.91±0.0417b</td>
</tr>
</tbody>
</table>

²a-e Means followed by the same letter within a column are not significantly different according to a Tukey’s multiple range test (α=0.05)

Table 3.6 Mean (plus or minus standard error) marketable edible amaranth (*Amaranthus hybridus* L.) yield as affected by various harvest approaches over seven weeks at the University of Guelph Centre for Urban Organic Farming in Guelph, Ontario, Canada for the 2017 season. For explanation of treatments see Materials and Methods.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fresh Weight (kg/m²)</th>
<th>Dry Weight (kg/m²)</th>
<th>Ratio (fresh kg/m² /dry kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weekly</td>
<td>0.36±0.117ab</td>
<td>0.08±0.009a</td>
<td>3.74±0.694b²</td>
</tr>
<tr>
<td>Biweekly</td>
<td>0.41±0.059a</td>
<td>0.07±0.015ab</td>
<td>4.97±0.399b</td>
</tr>
<tr>
<td>Triweekly</td>
<td>0.50±0.216ab</td>
<td>0.09±0.044ab</td>
<td>6.89±0.383a</td>
</tr>
<tr>
<td>Customer</td>
<td>0.74±0.267ab</td>
<td>0.14±0.048ab</td>
<td>5.46±0.453ab</td>
</tr>
<tr>
<td>Tips</td>
<td>0.15±0.010b</td>
<td>0.02±0.004b</td>
<td>4.28±0.242b</td>
</tr>
</tbody>
</table>

²a-e Means followed by the same letter within a column are not significantly different according to a Tukey’s multiple range test (α=0.05)
The marketable yield and regrowth results provided yield measures from only a relatively short seven week harvest season. These results did not include the final harvest which represented further harvest potential in an open fall season.

### 3.2.3 Total Biomass

The total biomass results were very different compared to the regrowth and marketable yield results. The control treatment produced significantly more fresh weight than any of the other treatments in Stouffville (Table 3.7), but this was not the case at the other two sites where none of the six treatments were significantly different from one another (Table 3.8, Table 3.9). The tips only treatment was no longer the lowest yielding treatment but one of the highest yielding because while the small growing tips were being harvested regularly the plant continued to grow thicker, longer stems and produce reproductive structures. When it comes to edible amaranth though, yield is only valuable if quality is acceptable for the consumer, and for the total biomass results, the control and tips only treatments contained very little quality yield (tender leaves and stems) as a proportion of the total biomass harvested (personal observation).

However, the measure of total biomass allowed us to explore whether the ratio between fresh and dry weight was an effective measure of quality by applying it to extreme examples, such as the control treatment where, for the most part, the plant material was far too tough to be acceptable to consumers. While the control treatment had one of the lowest ratios at the Simcoe and Guelph sites, it has the highest ratio in Stouffville. This difference between sites showed that the ratio was determined not just by the treatment but also by site factors such as rainfall and soil quality. The best measure of quality was a simple visual inspection, making sure leaves were not wilting and that stems were tender rather than tough.
Table 3.7 Mean (plus or minus standard error) total edible amaranth (*Amaranthus hybridus* L.) biomass as affected by various harvest approaches at Farintosh Farms in Stouffville, Ontario, Canada for the 2017 season. For explanation of treatments see Materials and Methods.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fresh Weight (kg/m²)</th>
<th>Dry Weight (kg/m²)</th>
<th>Ratio (fresh kg/m²/dry kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weekly</td>
<td>2.74±0.181c</td>
<td>0.59±0.0280d</td>
<td>4.65±0.348ab^z</td>
</tr>
<tr>
<td>Biweekly</td>
<td>2.91±0.104c</td>
<td>0.67±0.090bcd</td>
<td>4.50±0.491ab</td>
</tr>
<tr>
<td>Triweekly</td>
<td>3.94±0.201b</td>
<td>0.77±0.031c</td>
<td>5.10±0.107b</td>
</tr>
<tr>
<td>Customer</td>
<td>3.64±0.454bc</td>
<td>0.77±0.103abcd</td>
<td>4.78±0.1.91b</td>
</tr>
<tr>
<td>Tips</td>
<td>4.61±0.224b</td>
<td>0.94±0.033ab</td>
<td>4.89±0.137b</td>
</tr>
<tr>
<td>Control</td>
<td>5.60±0.147a</td>
<td>0.99±0.021a</td>
<td>5.64±0.084a</td>
</tr>
</tbody>
</table>

^z a-e Means followed by the same letter within a column are not significantly different according to a Tukey’s multiple range test (α=0.05)

Table 3.8 Mean (plus or minus standard error) total edible amaranth (*Amaranthus hybridus* L.) biomass as affected by various harvest approaches at the University of Guelph Horticultural Experimental Station in Simcoe, Ontario, Canada for the 2017 season. For explanation of treatments see Materials and Methods.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fresh Weight (kg/m²)</th>
<th>Dry Weight (kg/m²)</th>
<th>Ratio (fresh kg/m²/dry kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weekly</td>
<td>4.78±0.246a</td>
<td>0.58±0.042b</td>
<td>8.35±0.479a^z</td>
</tr>
<tr>
<td>Biweekly</td>
<td>5.03±0.313a</td>
<td>0.62±0.066b</td>
<td>8.10±0.2079a</td>
</tr>
<tr>
<td>Triweekly</td>
<td>5.48±0.507a</td>
<td>0.69±0.015b</td>
<td>7.91±0.469ab</td>
</tr>
<tr>
<td>Customer</td>
<td>5.66±0.602a</td>
<td>0.74±0.040b</td>
<td>7.71±0.164a</td>
</tr>
<tr>
<td>Tips</td>
<td>5.48±0.433a</td>
<td>0.89±0.100ab</td>
<td>6.15±0.095c</td>
</tr>
<tr>
<td>Control</td>
<td>5.58±0.361a</td>
<td>0.86±0.019a</td>
<td>6.50±0.297bc</td>
</tr>
</tbody>
</table>

^z a-e Means followed by the same letter within a column are not significantly different according to a Tukey’s multiple range test (α=0.05)
Table 3.9 Mean (plus or minus standard error) total edible amaranth (*Amaranthus hybridus* L.) biomass as affected by various harvest approaches at the University of Guelph Centre for Urban Organic Farming in Guelph, Ontario, Canada for the 2017 season. For explanation of treatments see Materials and Methods.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fresh Weight (kg/m²)</th>
<th>Dry Weight (kg/m²)</th>
<th>Ratio (fresh kg/m² /dry kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weekly</td>
<td>0.61±0.203a</td>
<td>0.14±0.043a</td>
<td>3.98±0.729abc°</td>
</tr>
<tr>
<td>Biweekly</td>
<td>0.64±0.068a</td>
<td>0.13±0.011a</td>
<td>4.83±0.313a</td>
</tr>
<tr>
<td>Triweekly</td>
<td>0.92±0.384a</td>
<td>0.23±0.167a</td>
<td>4.14±0.244ab</td>
</tr>
<tr>
<td>Customer</td>
<td>1.47±0.514a</td>
<td>0.42±0.274a</td>
<td>3.66±0.198bc</td>
</tr>
<tr>
<td>Tips</td>
<td>0.80±0.114a</td>
<td>0.24±0.085a</td>
<td>3.39±0.492abc</td>
</tr>
<tr>
<td>Control</td>
<td>1.00±0.244a</td>
<td>0.39±0.265a</td>
<td>2.81±0.378c</td>
</tr>
</tbody>
</table>

a-e Means followed by the same letter within a column are not significantly different according to a Tukey’s multiple range test (α=0.05)

The total biomass results are important across all three sites because they show that *A. hybridus* will produce just as much or more biomass when left untouched or when just the growing tips are harvested compared to the treatments that have outperformed the others in the other two groupings (regrowth and marketable yield). This means that when applying cutting treatments, total yield will not increase in most scenarios, but rather decrease compared to leaving the plants to grow untouched. This means the only advantage to cutting treatments compared to a control is the quality of the yield, as it is unlikely for a consumer to value a plant which was left to grow fibrous and tough. These results are especially pertinent to the treatment where just the growing tips were taken, as the treatment went from the lowest yielding to one of the highest when you consider total biomass. This suggests that there is still room for improving this treatment, as the plant is still producing a lot of biomass in the stems rather than producing more growing tips as in the weekly treatment. By cutting more frequently than every two weeks...
the plant would likely produce more tips rather than the thick stems which lead to such high total biomass.

3.3 CONCLUSIONS

The results of this experiment followed the trends hypothesized on the basis of the study in South African by Materechera et al. (2006) which studied the effect of harvest frequency on yield of A. hybridus, but there were some important differences. Both studies showed yield increased the longer the period between cuttings, but the South African study found a decrease in quality after two weeks while in our trials quality did not diminish in the treatment where the plants were harvested every three weeks. This difference is likely because Materechera et al. only harvested the leaves rather than cutting the entire stem down low. By only harvesting the leaves the plant had less biomass to regrow and allowing three or more weeks may have been more than required, especially in the African heat.

The research in southern Ontario, supported the hypothesis that longer time periods between cuttings will produce more yield but lower quality and less marketability. The quality did diminish when there was three weeks between cuttings if the plants are cut at the 15cm above ground level height. The stems and leaves harvested from the control were far from market quality indicating that it is unlikely the plants could go for much longer than three weeks between cuttings and continue to maintain quality. Cutting frequency also appears to be tied to the harvest method. If only the leaves or growing tips are being harvested a shorter cutting period of one to two weeks may increase both yield and quality, while if the plants are cut lower and the stems are harvested, the period can be extended to three weeks or possibly more to maximize yield without sacrificing quality.
CHAPTER 4 – STUDIES ON THE WEEDINESS POTENTIAL OF EDIBLE

AMARANTHUS HYBRIDUS L.

4.0 INTRODUCTION

With numerous amaranths already acting as major weeds in Ontario it is important to understand the risk of introducing a new crop to Ontario from the Amaranthaceae family. One reason amaranths are such effective weeds is their ability to produce enormous amounts of viable persistent seed. If the seeds manage to germinate in favourable conditions the seedlings are extremely competitive (Lin, 2015). Considering the viability of seeds produced in the field and their ability to establish in various conditions is key to understanding the weediness potential of a species (Van Acker, 2009). As no studies have been done to-date on the weediness potential of edible A. hybridus in Ontario this research is required.

The purpose of this study is to investigate seed germination characteristics and potential persistence and the seedling establishment potential of edible A. hybridus under Ontario conditions. This information will provide an initial understanding of the potential weediness of edible A. hybridus and what precautions need to be taken before it can be widely grown as a commercial crop in southern Ontario.
4.1 MATERIALS AND METHODS

4.1.1 Study Site

4.1.1.1 Germination and Depth Trials

Indoor germination trials were conducted in a growth room in the Crop Science building at the University of Guelph, in Guelph, Canada (43° 32’N, 80° 13’W) to establish a baseline for the germinability and possible dormancy status of A. hybridus seeds from the seedlots we were working with and to see how planting depth affected germination and seedling establishment of this species. For all trials in this study, the growth room was set to 25°C days and 20°C nights at 70% relative humidity. There was a 16 hour photoperiod (16 hours of light, 8 hours of darkness) each day.

4.1.1.2 Establishment Trials

Seedling establishment experiments were conducted in 2017 at the Simcoe Horticultural Research Station (SHRS) in Simcoe, Canada (42° 51’N, 80° 16’W) and at Farintosh Farms in Stouffville, Canada (43° 56’N, 79° 21’W). At each site, plots were set up on an uncut heterogeneous sward containing primarily quackgrass (Elymus repens L. Gould) and some dandelion (Taraxacum officinale Weber in Wiggers). These grassy areas were chosen as they resembled relatively common field margin and roadside areas in Ontario where species escapes can occur (Chakraborty et al. 2016).
4.1.2 Experimental Design

4.1.2.1 Germination Trials

The germination trials were laid out in a randomized complete block design. There were four treatments and four blocks in each trial. The four lots of A. hybridus seeds tested were: 1) seeds taken from a plant that was not harvested and allowed to reach sexual maturity at Farintosh Farms, Stouffville, Ontario in October of 2016, 2) seeds taken from the same field in Stouffville but from plants that were harvested throughout the season, 3) seeds acquired from AgroGrace in Portmore, Jamaica in 2017, and 4) seeds from the same supplier that were acquired in 2016.

The seeds were placed on Ahlstrom Grade 642 filter paper within a 9cm petri dish to germinate. Each petri dish had 50 seeds from a single seedlot placed within it. The dishes remained covered by a thin clear plastic lid with the exception of when the seeds were watered using a spray bottle filled with de-ionized distilled water. Every two days the petri dishes were monitored to make sure there was adequate moisture for the seeds to germinate. Both the blocks and petri dishes within the blocks were shifted in a random fashion every two days in an attempt to reduce variation within the growth room. The growth room was set to a 16 hour photoperiod with 25°C days, 20°C nights, and 70% relative humidity.

4.1.2.2 Depth Trials

A randomized complete block design was utilized with four blocks and three seeding depth treatments. Samples of 50 seeds were planted within each individual pot at a depth of 5cm, 2cm, or at the surface level within the growth room. The soil was a fine sandy loam taken from a farm in Kitchener to mimic a realistic growing medium. All of the seeds were harvested from a single mature A. hybridus plant which was grown at Farintosh Farms, Stouffville, ON. The pots
were watered every other day for a span of 14 days. This experiment was carried out twice, first beginning on February 16, 2017 and then again beginning on April 7, 2017.

At the same time, a nearly identical version of this experiment was run except the seeds were placed within cotton packets. This allowed for the packets and seeds to be exhumed after the 14 day period. The seeds that did not germinate were removed from the packets and placed in a petri dish (as per the conditions described above for the germination trials) to see if they were still viable germinable. The seeds which did not initially germinate in the petri dishes were monitored for another 14 days and watered as necessary to encourage germination. Throughout the experiment, the blocks along with the petri dishes and the pots within each block were moved randomly every two days.

4.1.2.3 Establishment Trials

The plots were set up in a randomized complete block design with three disturbance treatments replicated across four blocks. The three disturbance treatments were an undisturbed grassy sward, a mowed treatment where the area was cut down to 10cm above ground level using a motorized rotary push mower, and a tilled treatment created by digging up the soil with a spade and then raking it smooth. The plots were first prepared and then sown with A. hybridus seed on August 27th in Stouffville and on August 28th in Simcoe. Three hundred seeds (taken from the same single mature A. hybridus plant used in the germination trials) were scattered evenly by hand in each 0.5m by 0.5m plots. These plots were maintained on a weekly basis to keep the treatments in their desired level of disturbance.

4.1.3 Data Collection

4.1.3.1 Germination Trials
Over the course of 14 days the seeds were monitored every two days for germination. If a seed had germinated it was recorded and then removed from the petri dish to avoid counting errors.

4.1.3.2 Depth Trials

Every two days the pots were examined and the number of emerged seedlings was recorded. The seedlings were not removed from the pots until the end of the 14 days as none seemed to die off and it made it easier to get accurate numbers when it came time to exhume the packets. For the pots planted with the packets, the number of seeds that germinated but did not reach the soil surface (emerge) were also recorded. The number of seeds that did not germinate within the packet but did germinate within the petri dish in the following 14 days was also recorded. In the petri dish, once a seed germinated it was recorded and removed to avoid counting errors.

4.1.3.3 Establishment Trials

The plots at Simcoe and Stouffville were monitored weekly to see how many seedlings had emerged. During the eight weeks after the experiments were established, emerged seedlings were counted but not removed in order to see if they would survive and continue to grow or if they would die off. The plots were then monitored after the 8 week period to determine the longer term fate of seedlings that had emerged and were still living. This was done until killing frosts occurred in mid-October.
4.1.4 Data Analysis

Statistical Analysis Software (SAS) version 9.4 (SAS Institute, Cary, NC) was used to conduct all statistical analyses. An analysis of variance (ANOVA) for mixed models (PROC GLIMMIX) was used for analyzing the different dependent variables in the germination, depth and establishment trials. For all experiments, block (and run if applicable) was treated as the random effect while *A. hybridus* seeds of different origins, seeding depths, disturbance levels and sites were treated as fixed effects. Analysis of variance model assumptions tests were conducted to check if the residuals followed a normal distribution were homogeneous, random and had a mean of zero. The PROC UNIVARIATE statement was used to request a Shapiro-Wilk test and a Q-Q plot to check for normal distribution of residuals. The studentized residuals were also plotted to determine if there were any non-random patterns. Tukey’s test was used to find significant pairwise means comparisons, and then the PDMIX800 macro was used to group treatments into significantly different letter groups. All analyses were considered significant at $\alpha=0.05$.

4.2 RESULTS AND DISCUSSION

4.2.1 Germination Trial

All four seed sources had significantly different germination rates (Table 4.1). Seed taken from the mature plant growing in the field at Farintosh Farms in Stouffville had the highest germination rate at 87.5%, while the seed taken from the immature plants had only a 62.0% germination rate. The seed bought from the seed supplier in 2017 had a 72.8% germination rate, while the seed bought from the same supplier a year earlier (2016) had only a 0.8% germination rate.
The very high germination rate for the freshly harvested seed from the mature plant suggests that the seeds of edible *A. hybridus* have little to no primary dormancy. The store bought seeds also appeared to lose germinability quickly, with the seeds from 2016 barely germinating compared to seeds from the same supplier in 2017. The seeds purchased in 2016 were stored in a cool (~10°C) and dark indoor storage room so the reduction in germination is different from seeds of *A. retroflexus* which can last for 30 months in dry storage without a significant decrease in viability (Egley and Chandler, 1978). The differences between the mature and immature seeds in terms of germinability also has real world implications because if plants intended to be a seed source are harvested early the seed will not be mature and it will not germinate. Even the plants that were only harvested once every three weeks in the harvest trial were harvested frequently enough to prevent seeds from maturing or even coming close to the maturity of the immature seeds in this germination trial. This is important to know because it means that regularly harvested plants may not be a source of volunteer seed.

### Table 4.1

Mean (plus or minus standard error) total germination (%) of edible amaranth (*Amaranthus hybridus* L.) seed from a variety of sources germinated in a petri dish within a growth room at the University of Guelph, Ontario, Canada. For explanation of treatments see Materials and Methods.

<table>
<thead>
<tr>
<th>Seed Source</th>
<th>Germination (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mature field plant</td>
<td>87.5±2.06a²</td>
</tr>
<tr>
<td>Immature field plant</td>
<td>62.0±2.42c</td>
</tr>
<tr>
<td>New store-bought seed (2017)</td>
<td>72.8±2.87b</td>
</tr>
<tr>
<td>Old store-bought seed (2016)</td>
<td>0.8±0.53d</td>
</tr>
</tbody>
</table>

²a-d Means followed by the same letter are not significantly different according to a Tukey’s multiple range test (α=0.05)
4.2.2 Depth Trials

The germination of the seeds within the packets were all significantly different at each depth (Table 4.2). When exhumed, the packets placed 1cm below the soil surface had a 77.8% germination rate, followed by the 2cm depth with a 57.9% germination rate and finally the 5cm depth with only a 31.2% germination rate. The seeds that were free from the packets emerged at a very similar rate to the germination of the seeds within the packets at the 1cm and 2cm depths. For seeds free from packets, 79.2% germinated and produced seedlings that emerged from the 1cm depth while only 56.6% germinated and produced seedlings that emerged from the 2cm depth. The differences in seedling emergence between these depths were not statistically significant however due to high variability between replicates for the 2cm depth treatment. The germination rate results for the free seeds differed greatly from the packeted seeds when it came to the 5cm depth. While the packeted seeds showed a 31.2% germination rate, for the free seeds, only 11.1% of the seeds germinated and produced seedlings that emerged from the 5cm depth. This large difference could be due to fatal germination which causes the seedling to die before it reaches the soil surface, which is often a result of the seed being planted too deep (Davis & Renner, 2007). The inability to emerge when planted at depth could lessen the weediness potential as tillage practices would drastically weaken the seedbank. This is similar to another plant in the Amaranthaceae family, Kochia scoparia L. A study by Schwinghamer and Van Acker (2008) found the warm weather annual had small, fragile, non-dormant seeds and was unable to produce a threatening seed bank, with only 7% emergence at 40mm. It is also possible that the 14 day time period was not long enough for the seedlings to reach the surface from that depth, although the emergence rate for the 5cm depth seemed to plateau at a similar rate to the other treatments.
Table 4.2 Mean (plus or minus standard error) total emergence (%) of edible amaranth (*Amaranthus hybridus* L.) from seed planted in a range of depths in a growth room at the University of Guelph, Ontario, Canada. Seeds were planted in packets in February, 2017 and April, 2017 and exhumed 14 days after planting. For explanation of treatments see Materials and Methods.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>In Packet (Germination %)</th>
<th>Free (Emergence %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>77.8±3.49a</td>
<td>79.2±2.75az</td>
</tr>
<tr>
<td>2</td>
<td>57.9±2.64b</td>
<td>56.6±12.44a</td>
</tr>
<tr>
<td>5</td>
<td>31.2±3.67c</td>
<td>11.1±4.27b</td>
</tr>
</tbody>
</table>

<sup>z</sup> a-c Means followed by the same letter are not significantly different according to a Tukey’s multiple range test (α=0.05)

4.2.3 Establishment Trials

Seedlings were able to emerge at both sites when planted into the tilled treatment, although at the Simcoe site there was significantly higher seedling emergence at 61.59% compared to the Stouffville site at 18.83% (Table 4.3). The cut grass treatment was significantly different from the tilled treatment at both sites where emergence was less than 1% in Simcoe and Stouffville. No seedlings emerged at either site when seeds were spread in the longer, uncut grassy swards. The difference between sites in emergence levels for the tilled treatment may have been due to differences in weather, given that the Simcoe site received 47.3mm more rain than the Stouffville site in October (Appendix 7.2) and no additional water was provided to either site. Of the seedlings that emerged none of them lived for longer than four weeks after emergence. This may have been due to a lack of water, although temperature (too low) may also have played a part despite the warmer than average October (Appendix 7.1). A study by Steckel et al. (2003) tested the effect of temperature on nine different amaranths and found that *A. hybridus* germinated best at 30°C, attaining complete germination on the first day after seeding. With such high base germination temperatures edible amaranths may not be able to germinate in
the spring when temperatures are cooler, making them less competitive. It is also possible that by the time seeds do germinate there will not be enough time in the season here in Ontario for these plants to produce viable seed before frost kills them.

Table 4.3 Mean (plus or minus standard error) total emergence (%) of edible amaranth (*Amaranthus hybridus* L.) from seed in a range of field environments at Farintosh farms in Stouffville, Ontario, Canada and at the University of Guelph Horticultural Experimental Station in Simcoe Ontario, Canada. Seed was spread in August, 2017 and emergence was monitored for the period from August to October of 2017. For explanation of treatments see Materials and Methods.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Stouffville (% establishment)</th>
<th>Simcoe (% establishment)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tilled</td>
<td>18.83±4.227a</td>
<td>61.59±7.349a^z^</td>
</tr>
<tr>
<td>Cut</td>
<td>0.17±0.170b</td>
<td>0.67±0.360b</td>
</tr>
<tr>
<td>Long</td>
<td>0.00±0.00b</td>
<td>0.00±0.00c</td>
</tr>
</tbody>
</table>

^z^ a-e Means followed by the same letter within a column are not significantly different according to a Tukey’s multiple range test (α=0.05)

4.3 CONCLUSIONS

Weedy amaranths have a reputation for being aggressive in agricultural fields and costly to farmers in southern Ontario. The experiments exploring the weediness potential of edible *A. hybridus* showed that it may share some of the same weedy traits as weedy amaranths including high seed production potential and high germination levels for mature seed. Personal communications with farmers in Ontario who have grown edible amaranth for over 30 years suggests that this species is not invasive and rarely returns volunteer plants in fields the following year. The volunteer plants that have emerged were described by farmers as small and not aggressive compared to weedy amaranths. While the lack of volunteer plants may arise from the inability of seed to germinate and seedlings to establish, it may also be due to the fact that farmers are continuously harvesting the plants until frost, preventing the plants from producing
mature seed. Farmers reported that they saw a higher frequency of volunteer plants when they did not have enough time or labour to harvest all of the plants the previous season.

Aside from seed maturity, it should be noted that the germination and establishment experiments were all carried out in warm conditions, with peak temperatures greater than 25°C on most days. These conditions are much warmer than typical spring temperatures in Ontario and more comparable to the tropical Caribbean or Central America where this species originates. It may be that seeds from edible amaranth rot or are predated in the spring before temperatures are warm enough for germination.

As hypothesized the seeds taken from the edible amaranths in the field had high germination rate and low seed dormancy, although it is hard to know how these factors would affect persistence. The seeds were able to emerge at depths of 5cm but at a much lower percent compared to those planted near the surface. Seeds had barely any establishment in undisturbed environments, while the seedlings that did establish in the disturbed environment did not survive for long. These findings provide a basic understanding on some of the factors that might contribute to edible amaranth becoming a volunteer or an invasive weed, but there are still many interactions that need to be investigated. To gain a better understanding of the mechanisms at play and their effect on the weediness potential of edible amaranth more experiments examining overwintering, germination and establishment should be done over a longer time period in more realistic conditions.
CHAPTER 5 – GENERAL DISCUSSION

Ontario is a diverse and culturally rich province with people from all over the globe bringing their preferences along with them when they immigrate. In the Greater Toronto Area more than half of the population surveyed recently were born outside of Canada (Filson & Adekulne, 2017) so it comes as no surprise that demand in Ontario for ethno-cultural food is steadily increasing. While many of these foods must be imported, the potential to grow some of them in Ontario is an exciting prospect for both consumers and farmers. Growing locally can help keep money within the community rather than bleeding it out through all the processes that go along with supermarkets, transportation, taxes, etc. If farmers in Ontario are able to grow a new crop with relative efficiency compared to nonlocal competitors then it is possible to keep costs down and avoid a deadweight loss; and this can help to boost the provincial economy. Depending on the demand for the new crop, more farmers will have an opportunity to make top dollar on a niche product rather than trying to compete in saturated commodity markets.

While there can be great potential benefits and opportunities to introducing a new crop there are also risks and challenges. To gain a better understanding of a crop, substantial monetary investment is required to fund research. From basic agronomic practices and pest management to market research and post-harvest methodology a new crop can pose a daunting challenge and deter investments. Often the investment into research does not pay off, at least not immediately, and crops such as grain amaranth end up sidelined to small specialty operations and the outcome does not match initial promotion and expectations. Edible leafy amaranth has an advantage as a new crop though, because instead of having to build a whole new market there is an opportunity to replace canned product and sell to customers who used to eat it in their country of birth but no longer have access to it. North Americans once deemed amaranths as only suitable for pigs,
hence the name “pigweed”, but today we’re seeing this stereotype degrade as people base their dietary choices on cultural preferences and experiences rather than social class (Laclau, 1977). With more and more people emigrating from countries familiar with edible amaranth to Ontario the future looks promising for this new crop.

The field trials for this project showed some interesting results in terms of how various harvest approaches influence total yield, marketable yield and quality. Personal communication with Ontario farmers led to our initial hypothesis that the “customer” treatment based on the typical method of cutting the larger stems low to the ground would encourage adventitious shoot growth and outperform the other treatments. While this treatment did spur new grow growth and resulted in the highest yields, cutting straight across the entire plant at a set height of 15cm above ground level every three weeks yielded an amount which was not significantly different. This finding has promising real world implications for larger operations as the same amount can be harvested with far less labour (and perhaps even automated) while maintaining quality.

There are certain cultural groups that prefer just the growing tips of edible amaranth but the harvest treatment we explored, of only selecting these tips every two weeks stunted marketable yields compared to the other treatments. A significantly better approach to harvesting what appears to be the same portion of the plant was the weekly harvest treatment. By cutting more frequently the plants appeared to create far more growing tips to be harvested instead of investing in fewer. While the yield is still low compared to other treatments it is worth keeping in mind that if the amaranth is being growing specifically for a consumer base that favours the tender growing tip.
The cutting treatments likely still have room for improvement and could be optimized by harvesting based around weather and other factors rather than being held to a set interval. We chose a set interval so that we could standardize treatments and to serve scientific methodology. Regardless, the amount harvested in the field trials is already more than promising and if the demand holds up, edible amaranth has the potential to be a viable crop for farmers in southern Ontario. Before committing to growing edible amaranth though, it is important to gain a better understanding of the potential for the amaranth to become a weed and what costs it could incur in a farming system.

Until concerns around the weediness potential of edible amaranth have been addressed there may remain some risk of edible amaranth becoming a problematic weed, although if the plant is being harvested at all, this seems very unlikely based on how long the plants need to be left unharvested in order for seeds to even come close to maturing sufficiently to be viable, let alone, persistent.

Edible amaranth has proven to be able to yield enough to make it profitable in southern Ontario given warm weather, well-drained soil and sufficient nutrient. To maximize yield and quality growers should be aiming to harvest between two to three weeks, cutting the plants no higher than 15cm above ground level. The biggest limitations and unknowns to my knowledge are the extent of the demand, post-harvest management, and the true weediness potential.
6.0 LITERATURE CITED


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Lin, Y. A. 2015. Interactions of onion (Allium cepa) and yellow wax bean (Phaseolus vulgaris) in monoculture and intercropping with weeds, Chenopodium album and Amaranthus hybridus. Brock University, 95.


McWilliams, E. L. 1966. Ecotypic differentiation within Amaranthus retroflexus L., Amaranthus hybridus L. and Amaranthus powellii Wats. Iowa State University, 179.


# 7.0 APPENDICES

## Appendix 7.1 Data on monthly average for 2017 and 30 year average temperature (°C) for Guelph, ON, Stouffville, ON and Simcoe, ON.

<table>
<thead>
<tr>
<th>Month</th>
<th>Guelph&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Stouffville</th>
<th>Simcoe&lt;sup&gt;b&lt;/sup&gt;</th>
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<tbody>
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<td>2017</td>
<td>30 year average</td>
<td>2017</td>
</tr>
<tr>
<td>Jan</td>
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<td>-7.4</td>
<td>-1.6</td>
</tr>
<tr>
<td>Feb</td>
<td>-1.8</td>
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<td>-0.2</td>
</tr>
<tr>
<td>Mar</td>
<td>-2.0</td>
<td>-1.9</td>
<td>-0.5</td>
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<tr>
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<td>8.1</td>
<td>5.7</td>
<td>9.4</td>
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<td>12.6</td>
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<sup>a</sup> Fergus, Ontario was used as a proxy for 30 year average temperature by month in Guelph, ON

<sup>b</sup> Delhi, Ontario was used as a proxy for Simcoe, ON

## Appendix 7.2 Data on monthly average for 2017 and 30 year average precipitation (mm) for Guelph, ON, Stouffville, ON and Simcoe, ON.

<table>
<thead>
<tr>
<th>Month</th>
<th>Guelph&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Stouffville</th>
<th>Simcoe&lt;sup&gt;b&lt;/sup&gt;</th>
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<tbody>
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<sup>a</sup> Fergus, Ontario was used as a proxy for Guelph, ON

<sup>b</sup> Delhi, Ontario was used as a proxy for Simcoe, ON
Appendix 7.3 Soil test results from samples taken from Guelph Centre for Urban Organic Farming (GCUOF) in Guelph, ON, Farintosh Farms in Stouffville, ON, and the Horticultural Experimental Station in Simcoe, ON, Canada.

<table>
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<th>Organic Matter (%)</th>
<th>Phosphorous P (ppm)</th>
<th>Potassium K (ppm)</th>
<th>Magnesium Mg (ppm)</th>
<th>Calcium Ca (ppm)</th>
<th>Cation Exchange MEQ/100g</th>
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<tr>
<td>Simcoe</td>
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<td>135G</td>
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