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# Exploring the Nutritional Value of Carrots and Determining Attributes that are Favored by Consumers

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# Exploring the Nutritional Value of Carrots and Determining Attributes that are Favored by Consumers

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**Dedication**

I would like to dedicate this Honors Thesis to my grandfather, Pop Pop.
October 1, 1931- December 18, 2016

## Abstract

This study explored 24 varieties of carrots, the most popular vegetable of the Apiaceae family. Carrots are one of the most widely consumed vegetables. They are a cool season vegetable crop, which comes in many different varieties and colors, each having its distinct aroma, content of volatiles and nutritional compounds that influence the harshness or eating quality of the carrot. In the US, 3.5 billion pounds of carrots are grown each year, showing the importance that carrots have in United States agricultural economic systems. Carrots are an important vegetable due to their characteristic flavor and the many health benefits, such as: reducing the risk of cancer and heart disease and improving vision. The taste and health benefits of carrots are related to the levels of phenolic compounds, volatiles, and sugar. Data was collected from 24 carrot varieties at harvest and after a 3-month cold storage to determine effects storage has on the quality and taste of the carrot. During storage, biochemical changes happen to the carrot, decay, respiration and the breakdown of sugars. These post-harvest changes influence the development of volatiles that leads to the formation of harsh bitter flavors. Some carrot varieties are bred to be able to withstand storage conditions. This study found that three carrot varieties: Bolero (C7), Navarino (C8), and Bermuda (C23) fared the best under cold storage conditions. It is important to understand how storage affects the taste profile of carrots; this information will inform farmers on which carrot varieties are the best to grow, store, and sell to consumers.

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# 1. Introduction

## Background

Carrots (Daucus Carota L.) are in the top 10 of vegetables favored by consumers throughout the world. In 2010, the world's production of carrots was 33.7 million tons; this demonstrates the horticultural and economic importance of the carrot crop [1]. Carrots are not only an important vegetable for agriculture, but also for a healthy diet. The earliest known mention of domesticated carrots dates back to the 10th century in Persia and Asia Minor. These first carrots were purple and white with a thin root. Over time, a mutation occurred removing the purple pigmentation. This mutation created a new breed of yellow carrots. These yellow carrots then evolved into the orange rooted carrots that are now the most popular type of carrot. The earlier forms of domesticated carrots were used as an herb for medicinal purposes before they were used as a root vegetable in the diet. Orange carrots became more popular in the 16th century when they were depicted in market scenes in Dutch and Spanish paintings. The word "carrot" was first recorded in the English language around the year 1530. This name was borrowed from the Middle French word, carotte [2]. The continued domestication of these earlier carrots transformed them from small, thin, white, sharply flavored taproots into the large, orange storage root vegetable we have today. Color is an important attribute of carrots, it adds to the visual appearance, which is the main driving factor when consumers are choosing a product.

There are two types of cultivated carrots: Eastern/Asiatic carrots, and Western/Carotene carrots. The Eastern/Asiatic carrots are often referred to as

anthocyanin carrots due to their purple appearance. This type of carrot has pubescent leaves that give it a gray-green color, and they bolt up out of the ground quickly. Asiatic carrots are still cultivated in Asia. The Western/Carotene carrots from the 16th/17th century first originated in Turkey, having orange, red or white roots. These carrots were most likely derived from the Asiatic carrots as well as hybrid progenies of yellow Eastern carrots and white carrots grown in the Mediterranean [3] Orange rooted. Western/Carotene carrots are rapidly replacing the Eastern/Asiatic carrots in the market.

Carrots can be grown in many regions of the world and have become an important root vegetable in the diet. According to the National Agricultural Statistics Service, over the last 15 years, carrot production has remained consistent, but carrot sales have seen a dramatic increase of 115%. Carrots are grown on 1,972 U.S farms, which produce an annual average of 3.5 billion pounds, three-fourths of which is sold into the fresh market, making the United States the leading carrot producer in the world [3].

## Growing Requirements

Carrots can be a complicated vegetable to grow properly to produce an ideal product for market. For a carrot crop to produce a marketable product, it needs to be grown in a cool environment (50 to 77ºF). Temperature affects the rate of chemical reactions that occur in carrots and the usage of photosynthetic products, all of which have impacts on the growth of the carrot crop [4]. Moderate day temperatures and relatively low night temperatures are preferred during the taproot formation. Increasing temperatures during the day have been shown to improve the carbohydrate accumulation in carrots [5]. Warm weather is only acceptable in the earlier stages of the growing process. If temperatures fall below 50ºF, this will cause the growth of the carrot to be

stunted, negatively affecting the growth of the foliage on the carrot crop. If temperatures rise to mid-80ºF, the development of undesirable flavors in the carrots can occur. Currently, studies are being conducted to formulate a new breed of carrot cultivar that will support growth in warmer climates and at higher temperature. This is important to allow for crop changes in the face of climate change [4].

Another variable that impacts the quality of a carrot crop is the type of soil. The ideal soils for carrot growth are sandy and silt loam soils. This kind of soil allows for water to flow smoothly through the ground, allowing even water dispersal to the whole carrot crop as well as allowing the roots to quickly and efficiently push through the ground. It is important not to waterlog the ground during carrot growth. Heavy clay soils cause the carrot crop to become miss-shaped and have stunted growth [5]. When adding fertilizer to the soil it is only necessary to fertilize during the early stages of carrot growth, soils that are too high in nitrogen will cause the carrot to become forked, an undesirable visual and production aspect.

Carrots require a regular watering routine to prevent irregular growth and disease [5]. Too much water in the soil can suffocate the plant by stopping the air supply to the plant. Excess water can also cause the crop to have root rot, leading to a diseased plant. Lack of water in the soil also negatively affects the growth of the taproot. Drought conditions put high stress on the crop, which adversely affects the growth of the carrot during different developmental stages. If the carrot plant is subjected to dry growing conditions in the beginning stages of growth, there may be an increased risk of the crop developing infections. Drought not only affects the health and the quality of the carrot crop, but it also affects the yield [5]. Increased drought stress on a carrot plant

significantly decreases the yield. The quality of a carrot crop is greatly influenced by the environment in which it is grown. Carrots will have the best growth and taproot production when they are grown in silted, loam soils, with a regular watering pattern.

## Nutrition

Carrots are a popular vegetable due to the many nutritional benefits they provide. Carrots are ranked 10th for their nutritional value among 39 fruits and vegetables [1]. Carrots contain carotenoids, flavonoids, polyacetylenes, vitamins, minerals, and the trace mineral molybdenum. Molybdenum is an essential nutritional component of carrots because it is rarely found in vegetables and aids in the metabolism of fats and carbohydrates as well as plays a significant role in iron absorption. Carrots are also an excellent source of dietary fiber. Fiber is a crucial part of a healthy diet. Fiber can be found in many fruits and vegetables and can help maintain a healthy weight and lower risk of heart disease. Carotenoids and vitamins that are found in carrots act as antioxidants, anticarcinogens and immune enhancers [6]. Carotenoids are the yellow, orange, and red colored phytochemicals found in most carrots [7].Carotenoids are a major source of dietary vitamin A and provide antioxidant activity. They are beneficial for the prevention of major health problems, such as cancer and cardiovascular diseases [8]. The consumer recognition of the many health benefits of carrots has contributed to the rapid rise in popularity of carrots in the diet.

Carrots contain a wide variety of compounds that work together to improve the overall health of an individual by providing preventative and protective factors. The vitamins and minerals that are provided by carrots promote longevity; decrease the risk of chronic disease, cancer, heart disease and stroke [9]. Carrots have also been linked to

providing mental health benefits. People who consume greater amounts of fruits and vegetable are less depressed, happier, and more satisfied with their lives. Carrots are a good source of antioxidants which help scavenge free radicals and prevent cancer; they are full of vitamins and minerals that help promote good eye health, bone development, energy production, and lower risk the of developing heart disease. Carrots provide an all-encompassing plethora of health benefits. These health benefits are one of the leading reasons why the popularity of carrots in the diet has increased so significantly over the last 15 years.

Carrots contain a broad range of vitamins, including, vitamin C, K, thiamin (B1) riboflavin (B2), pyridoxine (B6), and folate (B9) [7]. All of these vitamins are beneficial to a person's overall health. Vitamin C promotes the absorption of non-heme iron and is also required for fighting off infections. Vitamin K is essential for promoting blood coagulation. Thiamin (B1) in the diet has beneficial effects on the nervous system. Riboflavin (B2) is needed for cellular respirations and the formation of red blood cells. Pyridoxine (B6) inhibits the formation of homocysteine and reduces the risk of heart disease. Folate (B9) also lowers homocysteine levels, which lowers the risk of heart attacks. B6 and B9's role in reducing homocysteine levels is beneficial to a person’s health as high levels of homocysteine have been linked to the increased risk of hardening arteries caused by the accumulation of fatty plaques [7].

The carotenoids and anthocyanins found in purple carrots are the primary antioxidant pigments. Carotenoid levels in carrots have significantly increased over the past four decades due to modern and improved breeding methods [6]. The antioxidants also referred to as anthocyanins, are a group of natural phytopigments that belong to the

flavonoid group of polyphenols. Anthocyanins found in purple carrots can neutralize the effects of free radicals, have the ability to reduce oxidative stress, can restore redox homeostasis in the human body, and can exert anti-carcinogenic activity [6]. Each of these protective properties found in the anthocyanins can help to reduce the risk of developing cancer and decreasing inflammation in the body. The antioxidant ability of the anthocyanins in carrots adds health benefits that make the carrot more desirable to consumers.

Phenolic compounds are antioxidants that can be found in carrots. These phenolic compounds have the ability to scavenge reactive oxygen species and electrophiles, allowing them to inhibit nitrosation and chelate metal ions. The majority of antioxidant activity in carrots comes from these phenolic compounds [10]. Antioxidant assays have determined that the highest amount of phenolic compounds can be found in the carrot peel when compared to the phloem and xylem tissues [10]. The carrot peel provides 54.1% of the total phenolics present in a carrot, phloem tissue provides 39.5%, and the xylem tissue contains 6.4% of phenolic activity [10]. Most carrots are eaten without the peel because during the preparation of carrots for salads or for packaging in stores the manufacturers consider the peel to be a waste product due to its harsh, bitter taste. Utilization of the peel, or keeping the skin on the carrot during processing, could be regarded as a value-added use in the processing industry. The introduction of the “Baby Carrot” caused an upsurge in popularity of carrots in the supermarket in 1997 [11]. To make a baby carrot, carrots are harvested when the carrot is still small, then shaped and cut into bite size pieces using machines. Initially, the peel of the baby carrot was removed causing a decrease in nutrients; a new breed of baby carrot was developed allowing for

the retention of more nutrients. This new carrot is designed to be more slender and tender; it also does not have the coarse outside peel. Baby carrots allow for greater consumer convenience, but with that added convenience comes a loss of nutrients. Baby carrots have the same sugar content as full-sized carrots, but they have less iron, phosphorus, magnesium, vitamins A and C, and significantly less folate when compared to full-sized carrots [11]. Eating raw, full-sized carrots will provide higher levels of phenolic compounds per serving in the diet when compared to baby carrots.

Yellow, orange and red carrots contain carotenoids and are high in provitamin A and β carotene. Vitamin A and β carotene are beneficial for restoring eye health and they have high bioavailability in carrots [12]. β carotene is converted into vitamin A, which helps to protect the corneas of the eyes. The high bioavailability of β carotene and vitamin A in carrots allows for better utilization of these nutrients in the body [12]. The yellow carrot contains lutein, which plays a significant role in the prevention of macular degeneration [7]. Macular degeneration is a leading cause of vision loss in individuals 50 years of age or older. Macular degeneration is caused by the deterioration of the central portion of the retina [13]. Lutein is an antioxidant that is found in the eye, it prevents or delays the progression of chronic eye diseases by filtering out high-energy blue wavelengths of light and is responsible for maintaining healthy cells in the eyes [14]. Most Western diets are deficient in lutein. Adding yellow carrots to the diet will help provide missing nutrients and will help promote good eye health, and reduce the risk of developing eye diseases that can lead to loss of vision.

Scientists have been able to determine that consumers prefer sweet carrots to carrots with a bitter soapy taste through sensory evaluations [15]. The flavor profile of

carrots is derived from the levels of volatile terpenoids [16]. Elevated levels of terpenoids, namely α pinene, β -pinene, γ -terpinene, and terpinolene, and reduced sugar content are responsible for the harsh and oily flavor that can be found in carrots [17]. These volatile compounds are present in the leaves and roots of carrots and are determined by gas chromatography [1]. There are more than 90 volatile compounds found in carrots that give them their characteristic flavors [16]. Volatile compounds are the most important parameters used for consumer acceptance [18]. The complex flavor found in carrots is due to a large number of monoterpenes and sesquiterpenes. These compounds make up 98% of the total volatile mass [16-18]. Overall preference of carrots can be related to high sugar concentrations and reduced levels of terpenoids. Volatile compounds are influenced by genotype, soil, climate, and post-harvest storage and processing. Understanding the volatile compounds in carrots is an important factor in determining the flavor makeup of each carrot cultivar. Information regarding volatiles is helpful for determining which carrot varieties have a higher concentration of volatiles that lead to a sweet, citrus flavor and which cultivars have higher levels of volatiles that create a harsh, bitter flavor.

In the Kjeldsen et al evaluated carrots for their volatile makeup during 4 months of refrigerated storage. This study found that volatiles in the carrots significantly increased. The most prominent class of volatiles that they observed in the carrot samples was terpenoids. The terpenoids accounted for more than 99% of the carrot volatile mass [17]. Monoterpenes, sequiterpenes, and irregular terpenes are volatile compounds that were identified. The major monoterpenes that were observed were: α-pinene, sabinene, β-myrcene, limonene, γ-terpinene, ρ-cymene and terpinolene. The major sesquiterpenes

observed were: β-caryophyllene, α-humulene and (E)- and (Z)- γ-bisabolene. The most abundant irregular monoterpenes were: 6-mthyl-5-hepten-2-one, β-ionone and its 3-oxo derivative [17]. The compounds found were divided into three distinct odor groups based on their GC-O descriptions: “carrot top”, “fruity”, and “spicy-woody”. Volatile terpenoids can be related to the harsh, bitter flavor in carrots. During storage terpene biosynthesis is stimulated causing the increase of terpenoids, therefore also increasing the formation of off-flavor compounds [17]. Kjeldsen et al concluded that the formation of terpenoid volatiles during refrigerated storage causes an off, bitter flavor that is not accepted by consumers. The study also concluded that the formation of some volatiles during storage, like the ones that cause a “sweet, citrus, fruity” flavor, positively affect the acceptability of the carrot. [17].

Storage

During storage, the overall quality of carrots decreases significantly. Refrigerated storage of carrots causes a loss of moisture, physiological breakdown, decay, and the development of unwanted flavor compounds. Canning or freezing carrots may stabilize the quality of the carrot for longer than refrigeration storage [17]. The preservation methods, freezing and canning help to preserve the quality of the carrot crop by inactivating the enzymes that cause the plant to undergo chemical changes after harvest. This inactivation of enzymes helps to protect the carrot crop from experiencing the loss of color, loss of nutrients, and flavor changes [19]. During long-term storage, an off-flavor may develop in the carrots; this flavor is described as soapy and stearin (fatty). Many biological processes that take place in the vegetative tissue during postharvest storage cause the development of an off-flavor. During long-term storage, the reserve

substances in the root of the carrot are used for respiration and other biochemical processes, like the decomposition of sucrose to glucose, fructose, isocoumarins and phenolic acids. These chemical and biological changes that occur in the carrot during storage alter the flavor profile, creating an off, unpleasant flavor. The decomposition of these sugars primarily affects the sweetness, bitterness, and harshness of the carrot flavor [17].

The amount of phenolic activity also decreases throughout the storage of the carrot; dehydrated carrots lose most of their phenolic quality during three-month storage while the freezing of the carrots shows little difference in the phenolic quality during three-month storage. Different methods of preservation that are used are dehydration, blanching, and freezing. The carrots are dehydrated to reduce water activity decreasing the chances of spoilage or decay. Blanching is a form of preservation that inactivates enzymes and softens tissues to help ensure that the product remains in good quality during frozen storage. When the carrots are blanched, it causes an increase in the phenolic activity during storage [20]. When comparing blanched carrots to fresh carrots, blanched carrots had higher levels of phenolic activity; this is related to the softening of the tissues that allow for the release of phenolics from the carrot's matrix. Blanching of carrots is the best way to maintain or to improve the phenolic activity during storage. The maintenance or the increase of phenolic compounds in the carrot will help to increase the antioxidant properties of the carrot, better preserving the nutritional benefits.

During prolonged storage, the sugar content of carrots is negatively affected. While carrots are in storage, it has been confirmed that the sugar content slightly decrease after two weeks and continue to decrease even more after four weeks [8]. The decline in

the sweetness of a carrot during storage has been related to the reduction of glucose and fructose, where the breakdown of glucose and fructose is a normal occurrence. When a carrot crop is harvested and placed in storage, they are "living" plants and continue to break down sugars due to cellular respiration that is occurring in the carrot [21]. Also, there is the development of polyacetylenes, which are highly bioactive compounds that negatively affecting the sensory properties of Apiaceous plants (carrots and parsnips) [22]. The increase of polyacetylenes causes the reduction of soluble sugars in stored carrots [23]. Falcarindiol (FaDOH) is the most prominent polyacetylene that is found in carrots. The amount of polyacetylenes found in carrots are related to the cultivar of the carrot crop that is being grown, the location where the carrot was planted, the storage of the carrot and any water stress the plant was subjected to during growth [23]. While a carrot is still developing, the levels of FaDOH in the roots has been found to be high, there is a 53% decrease in the amount of FaDOH found in carrots when they are picked at maturity [23]. Carrots that are stored for 3 to 6 months in cold storage show a significant increase in polyacetylenes. The increase of polyacetylenes causes the decrease of sweetness that can be found in carrots after prolonged storage. Extended storage of a carrot crop can negatively affect the flavor. The flavor is influenced by the development and increase of polyacetylene levels.

Flavor

Sweetness is an important attribute that consumers look for. The sweetness of a carrot contributes to the pleasant flavor that is preferred by most users [8]. The main sugar that is found in carrots is sucrose, which amounts to about 90% of the total sugar content [8]. Many variables can affect the sweetness, or the ºBrix, these include variety

selection, crop maturity, crop physiology or metabolism, and the abiotic conditions of the growing environment, including, fertility, light, and temperature [24]. Crop maturity, metabolism, and water status are the factors that have the most immediate effect on ºBrix levels. The ideal range of ºBrix for carrot plants according to consumer testing is 8.0-10.0 on the ºBrix scale.

Development of sugars in carrots can be hard to develop and make consistent, as most of the factors that influence the sweetness of a carrot are hard to monitor and are uncontrollable. Environmental conditions that affect crop quality and ºBrix mostly include sunlight, temperature, and moisture [24]. All of these environmental factors influence the soluble solids that are produced in the plant during its growth period. Some soluble solids in a carrot plant or any vegetable crop will tend to increase during the ripening process [24]. The sugar content in carrots tends to be higher during their agricultural season compared to carrots that are not grown in season (the season for growing carrots is 10-12 weeks before first fall frost) [23]. Studies have shown that the purple carrot contains more sugar than the orange carrot; the purple carrot's sugar content was 70mg/g and the orange carrot's sugar content 60mg/g (weight of sugar per weight of fresh carrot) [8]. The sugar content of carrots is dependent on many factors including environmental conditions, sunlight, temperature, and moisture. Sugar content can also be related to the breed and color of the carrot cultivar. These factors can affect the amount of soluble solids, causing either an increase or decrease in sugar content.

Carrots are popular root vegetables that have been cultivated and incorporated into the diet for centuries. They are popular with consumers due to their characteristic flavor and the many health benefits they provide. Consumption of carrots has been linked

to decreased incidence of diseases, including reduced risk of cancer, vision disorders, and heart disease [7]. Carrots have compounds like carotenoids, polyphenols, and antioxidants and are loaded with valuable vitamins and minerals. All of these compounds provide carrots with their numerous health benefits and make then a very popular vegetable for consumers. Carrots can be readily incorporated into the diet with grains and meats to add variety to meals, and carrots are relatively inexpensive when compared to other vegetables [6]. Root vegetables are not limited by the season, as they can be grown outside during the growing season and can also be easily grown inside of greenhouses out of season, which makes it easier for consumers to access these plant-based antioxidants.

The goal of this research project was to investigate the various changes that occurred in carrots during cold storage. These changes included factors that impact the taste profile to help determine which cultivar or cultivars of carrots could best withstand cold storage while still meeting consumer and grower needs. In this research project results were gathered from 24 carrot varieties. Color, ºBrix, volatile compounds, and total phenolic were determined, all of which affect the taste profile of a carrot. The data that was collected at harvest and again after a 3-month cold storage to provide a comparison from “farm fresh” to commercial sales. The data from this research will be utilized via UMaine Cooperative Extension to provide information to Maine Farmers to help them plant carrot varieties that are well accepted by consumers.

## 2. Materials and Methods

### 2.1 Physical Characteristics

Twenty-four varieties were received from Highmoor Farm, in Monmouth Maine. Carrots were obtained at two different time points, harvest and after 3-month cold storage. During cold storage, the carrot samples were stored at Highmoor Farm in a cooler that was 32ºF, high humidity of 80-90% and stored in perforated poly bags to allow for airflow.

Carrots were evaluated for the following attributes: color, size, shape, length, and weight. The visual color was assessed, and carrots were assigned a color code such as orange, white, yellow or purple to help group the carrot varieties. Data for size, shape, and length were collected through visual measurements; they were indicated as small, medium or large in size and shape. These observations were taken for indicators of a difficult growing season.

The weight for each sample of carrots was determined. Each carrot sample was weighted as a group and weighted in the plastic bag they were delivered in. Carrots could not be weighted individually due to the small number of carrots received and their small size. Carrots were weighed using a top loading balance.

## 2.2 Juicing

Materials used:

- Juicer (Hamilton Beach, Glen Allen, VA)
- Ziploc bags
- 50mL aliquots (3 per each carrot sample) (Fisher Scientific, Waltham, MA)
- 5mL aliquots (3 per each carrot sample) (Fisher Scientific, Waltham, MA)

Preparation of carrots for juicing:

Each of the carrot samples was washed to remove excess dirt and then patted dry. The large roots were removed before juicing. For each carrot sample, 150mL of juice was collected and separated into three 50mL aliquots. Three 5mL samples of juice were also collected from each sample to be used later for total phenolic testing. All samples were stored in the -80ºC freezer until analysis. The carrot pulp was collected after each juicing and placed into a Ziploc bag and put into the -80ºC freezer for storage. The juice collected from each carrot was analyzed for color, pH, ºBrix, total phenolics and titratable acidity.

## 2.3 Total Phenolics

Materials used:

- ELx 808 visual spectrophotometer (BioTek,Winooski, VT)
- Volumetric flasks
- Beakers
- Eppendorf pipettes (Fisher Scientific, Waltham, MA)
- 50mL aliquots (7) (Fisher Scientific. Waltham, MA)
- ALF204 Analytical Balance (Fisher Scientific, Waltham, MA)

Chemicals used:

- Folin-Ciocalteu reagent (Sigma-Aldrich, St. Louis, MO)
- Sodium bicarbonate (Fisher Scientific, Waltham, MA)
- Gallic acid (Sigma-Aldrich, St. Louis, MO)
- Milli-Q Double deionized water (Sigma-Aldrich, St. Louis, MO)

Reagent preparation:

A sodium bicarbonate (6g/100mL) solution was prepared by dissolving 6 g $NaHCO_3$ with DD water, and volume was brought up to 100mL using a volumetric flask. The Folin-Ciocalteu (1:9, v:v) solution was prepared by 2mL Folin-Ciocalteu dispensed into a beaker then 18mL of distilled water was added, liquid was mixed thoroughly. Folin-Ciocalteu is a light sensitive chemical and the solution in the beaker was covered with parafilm and completely covered in aluminum foil to prevent penetration of light.

Standard solutions preparation:

Gallic acid is used as the standard for the stock solution because it is the most stable phenolic compound and gallic acid is most commonly used standard in other studies. Standard Stock (1mg/mL): 0.01g gallic acid was dissolved with double deionized water and the volume was brought up to 10mL in a volumetric flask. This standard stock was used to make the working standards.

STD1: 0ug/mL: only water.

STD2: 25ug/mL: stock brought up to 10mL with water.

STD3: 50ug/mL: 0.50mL stock brought up to 10mL with water.

STD4: 100ug/mL: 1.00mL stock brought up to 10mL with water.

STD5: 150ug/mL: 1.50mL stock brought up to 10mL with water.

STD6: 200 ug/mL: 2.00 mL stock brought up to 10mL with water

STD7: 250ug/mL: 2.50mL stock brought up to 10mL with water

Carrot juices were serial diluted to determine dilution factor. 20µL of diluted standards/samples were dispensed into the micro-plate. 90µl diluted Folin-Ciocalteu reagent (1:9) was dispensed into each well (excluding the blank wells). The micro-plate was covered with parafilm and aluminum and incubated for 5 minutes in the dark at room temperature. 90µL sodium bicarbonate (6g/100mL) was added to each well, the micro-plate was covered and incubated for 90 minutes at room temperature. Double deionized water was used as the blank. After the 90 minutes the plate was read at 750nm.

Plate Layout:

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | Blank | Blank | Blank | C1 | C1 | C1 | | | | | | |
| B | STD1 | STD1’ | STD1’ | C2 | C2 | C2 | | | | | | |
| C | STD2 | STD2’ | STD2’ | C3 | C3 | C3 | | | | | | |
| D | STD3 | STD3’ | STD3’ | etc. | | | | | | | | |
| E | STD4 | STD4’ | STD4’ | | | | | | | | | |
| F | STD5 | STD5’ | STD5’ | | | | | | | | | |
| G | STD6 | STD6’ | STD6’ | | | | | | | | | |
| H | STD7 | STD7’ | STD7’ | | | | | | | | | |

STD: standard stock solution

C1, C2, C3, etc: carrot sample

After the micro-plate was read, a standard curve (regression curve) was drawn by Excel software with concentrations (x) and absorbance (y) of the above working standards. A regression equation was determined and expressed as: $y= a + bx$. Total phenolic concentrations of test sample solutions were calculated by $x = (y – a) / b (y)$. Total phenolics were measured in triplicate for each carrot sample.

## 2.4 Titratable Acidity/pH

Equipment used for titratable acidity:

- Hanna Automated Titrator (Hanna Instruments, Loveland, Colorado)
- Small stir bars (Scienceware, Philadelphia, PA)
- Milli-Q water (Sigma-Aldrich, St. Louis, MO)
- 5mL pipette and tips (Fisher Scientific, Waltham, MA)

Chemicals used:

- Hanna Low Range titrant- HI 84532-50 (Hanna Instruments, Loveland, CO)
- Hanna Calibration Standard- HI 84532-50 (Hanna Instruments, Loveland, CO)

Before beginning titration, the 50mL juice samples were thawed in a room temperature water bath.

First the Hanna tirator was calibrated by setting the range to low range (0.10-2.09% MA). The pH electrode was calibrated, and the dosing pump was primed and calibrated. A clean pipette was used to precisely measure out 5mL of carrot juice and placed into the clean beaker then filled up to the 50mL mark with deionized water. Beaker with the juice sample and stir bar was placed into the titrator and the electrode was placed into the calibration beaker. The dispensing tip should not be placed into the calibration beaker, tip must be placed over a waste beaker due to a small amount of titrant being dispensed when the pump resets. After this occurred the tip was placed back into the calibration beaker. After this was completed the titration was started, the first pH reading on the screen was recorded. After completion of the titration result were recorded as malic acid equivalents (percentage of malic acid). Titratable acidity was measured in triplicate for each carrot juice sample.

## 2.5 Colorimeter

Materials used:

- Labscan XE colorimeter (Hunter Lab, Reston, VA)
- Kimwipes (Kimberly-Clark, Irving, TX)
- Optical glass measuring cup

Tests for color were done using the fresh carrot juice, 50mL aliquots of carrot juice were collected and color was measured immediately after juicing.

### Sample Preparation

Optical glass was filled with 25mL of carrot juice sample. A kimwipe was used to wipe the outside of the optical glass to remove any debris or fingerprints. The optical glass was placed over the 17mm porthole on the colorimeter and covered with a black cylinder to block light from the room. After sample was covered the colorimeter test was run. Once sample was read sample ID was input into the window that appeared. These steps were repeated three times for each carrot sample. Carrot juice was stirred between each test and glass beaker was wiped with a Kimwipe to prevent any particulates from affecting the next reading. There were a total of 72 readings. After all the data had been collected the results were copied and pasted into an excel spreadsheet.

Each value represents a distinct numerical value on the Hunter L, a, b color space. The color space is organized in a cube form; the L axis runs from top to bottom with a maximum value of 100 and minimum value of 0. The a and b axes do not have a specific numerical limit. Positive a is red, negative a is green, positive b is yellow and negative b is blue. The combination of L, a, and b values determine the color of the sample.

## 2.6 ºBrix

Materials used:

- PAL-3 Refractometer (ATAGO, Bellevue, WA)
- Carrot juice samples
- Transfer pipets (Fisher Scientific, Waltham, MA)
- Milli-Q water (Sigma-Aldrich, St. Louis, MO)
- Kimwipes (Kimberly-Clark, Irving, TX)

ºBrix was measured immediately after the carrots were juiced. The refractometer was calibrated to zero using deionized water (calibration was performed before every test). 5-10 drops of juice were placed onto the lens of the refractometer, the degree of ºBrix was recorded. This procedure was performed in triplicate for each sample of carrot juice.

## 2.7 Capillary Gas Chromatography-Mass Spectrometry (GC-MS)

Materials used:

- Carrot samples
- Solid phase micro extraction (SPME) vials
- Capillary Gas Chromatography-Mass Spectrometry
- Scale
- Vacuum oven

Stored carrot samples (3-month) were tested for volatile compounds. The weight of the whole carrot was recorded. The weight of each carrot was recorded after 1cm was removed from the top and the bottom of the carrot. The carrots were cut in half, length

wise, and one half was ground while the other half was weighed. The non-ground carrot sample was placed into a vacuum oven for 24hours at 70ºC under a vacuum of 20-25 psi. Moisture content of each carrot sample was determined. The ground half of the carrot sample was transferred to two different SPME vials (1g vial). The sample was absorbed onto the fiber for 15 minutes at 40ºC. The sample was desorbed for 1minute in the injection port set at 250ºC, to calculate oven temperature to pressure profile. Volatile measures were taken in triplicate.

*The development of the volatile method is still an ongoing process by Melissa Chisholm in the Cole Lab in the Department of Chemistry at The University of Maine.

# 3. Results

## 3.1 Carrot Codes, Color, and Variety Names:

To determine the cultivar of each of the carrot samples a list was provided from Highmoor Farm with the corresponding carrot name.

Table 1

| Carrot Code | Color | Cultivar |
|---|---|---|
| C1 | Orange | Crofton |
| C2 | Orange | YaYa |
| C3 | Orange | Sugarsnax 54 |
| C4 | Purple | Purple Haze |
| C5 | Orange | Newhall |
| C6 | Orange | Norwalk |
| C7 | Orange | Bolero |
| C8 | Orange | Navarino |
| C9 | Orange | Unknown |
| C10 | Red | Nutri-Red |
| C11 | White | Snow man |
| C12 | Orange | Morelia |
| C13 | Orange | Nelson |
| C14 | Orange | Napoli |
| C15 | Orange | Candance |
| C16 | Orange | Nectar |
| C17 | Orange | Naval |
| C18 | Orange | Romance |
| C19 | Purple | Purplesnax |
| C20 | Orange | Fidra |
| C21 | Purple | Deep Purple |
| C22 | White | Creampak |
| C23 | Orange | Bermuda |
| C24 | Yellow | Yellowbunch |

3.2 Observational carrot data:

Twenty-four carrot varieties that were received from Highmoor Farm, of the carrots received 70.8% (17 out of 24) of the carrots received were orange. 12.5% (3 out of 24) of the carrots were yellow or creamy white in color, 8.3% (2 out of 24) of the carrots were purple and 8.3% (2 out of 24) were orange with small sections of either purple or red color. (Table 2& Figure 1)

The weight of each carrot type was collected from each variety separately, as a bunch. The weights recorded for this research were significantly lower than expected due to dry growing season.

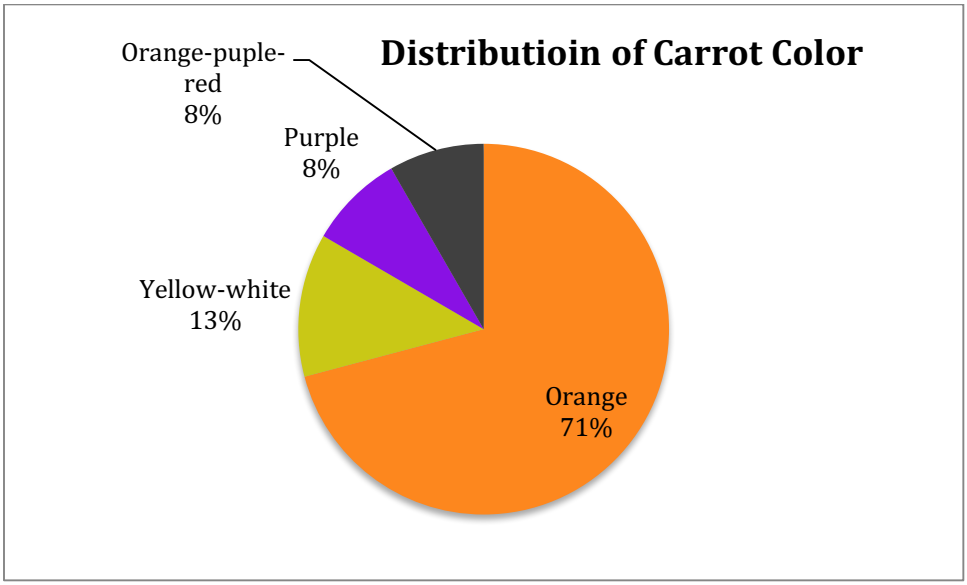



Figure.1.
Distribution of carrot color was determined

Table 2

Carrot Code, Weight, and Description

| Carrot Code | Weight (in bag) | Description |
|---|---|---|
| C1 | 543 g | orange |
| C2 | 540 g | orange |
| C3 | 306 g | orange |
| C4 | 505 g | mostly orange w/some purple spots |
| C5 | 578 g | orange |
| C6 | 533 g | orange |
| C7 | 737 g | orange |
| C8 | 680 g | orange |
| C9 | 256 g | orange |
| C10 | 316 g | washed out red-ish orange tops, white orange bottoms |
| C11 | 417 g | creamy white/yellow |
| C12 | 430 g | orange |
| C13 | 644 g | orange |
| C14 | 876 g | orange |
| C15 | 410 g | orange |
| C16 | 633 g | orange |
| C17 | 609 g | orange |
| C18 | 426 g | orange |
| C19 | 758 g | dark purple |
| C20 | 728 g | orange |
| C21 | 416 g | dark purple |
| C22 | 627 g | creamy white/yellow |
| C23 | 365 g | orange |
| C24 | 799 g | yellow |

3.3 Sugar Content

At harvest the highest mean ºBrix was 10.2, the lowest mean ºBrix was 8.3. After 3-month cold storage the highest mean ºBrix was 8.9 and the lowest mean ºBrix was 7.0 (Table 4). The average ºBrix of all the fresh harvest carrots was 9.22 while the ºBrix for

all the 3-month cold storage carrots was 8.18. During cold storage the sweetness (ºBrix) of all the carrot varieties decreased. The change of ºBrix from fresh harvest to cold storage is more noticeable when it is compared to the changes from the same carrot variety.

Figure 2 shows an overall decrease in ºBrix from fresh harvest to 3-month cold storage. The carrots that showed the greatest change from fresh harvest to storage were, C3 (Sugarsnax 54), C4 (purple haze), C10 (Nutri-Red), C14 (Napoli), C21 (Deep Purple), C22 (Creampak), and C24 (Yellowbunch). C7, (Bolero) and C8 (Navarino) showed the least amount of change. Commercial seed companies consider the Bolero carrot a storage carrot, this means that this type of carrot does well maintaining sweetness during prolonged storage.

Figure 3 shows the ºBrix to acid ratio from fresh harvest to 3-month cold storage. The carrots that experienced the greatest change were, C4, C10, C21, C22, and C24. The carrot variety that remained the most stable after storage was C8

Table 3

Fresh Harvest carrots ºBrix

| Carrot Code | Test 1 | Test 2 | Test 3 | Mean Brix |
|---|---|---|---|---|
| C1 | 9.3 | 9.3 | 9.3 | 9.3 |
| C2 | 9.4 | 9.1 | 9.1 | 9.2 |
| C3 | 9.3 | 9 | 8.9 | 9.1 |
| C4 | 9.8 | 9.6 | 9.8 | 9.7 |
| C5 | 9.1 | 8.9 | 9 | 9.0 |
| C6 | 9.1 | 9.1 | 9.3 | 9.2 |
| C7 | 9 | 8.8 | 8.7 | 8.8 |
| C8 | 8.7 | 8.7 | 8.5 | 8.6 |
| C9 | 8.3 | 8.4 | 8.3 | 8.3 |
| C10 | 9.2 | 9.1 | 9.1 | 9.1 |
| C11 | 9.1 | 9.1 | 9.2 | 9.1 |
| C12 | 9.5 | 9.5 | 9.5 | 9.5 |
| C13 | 8.7 | 8.7 | 8.8 | 8.7 |
| C14 | 8.9 | 8.9 | 8.9 | 8.9 |
| C15 | 9.6 | 9.5 | 9.4 | 9.5 |
| C16 | 9.4 | 9.3 | 9.3 | 9.3 |
| C17 | 9.5 | 9.5 | 9.4 | 9.5 |
| C18 | 9.3 | 9.1 | 9.2 | 9.2 |
| C19 | 8.8 | 8.7 | 8.6 | 8.7 |
| C20 | 8.7 | 8.8 | 8.6 | 8.7 |
| C21 | 10.2 | 10.2 | 10.2 | 10.2 |
| C22 | 10.3 | 10.2 | 10.2 | 10.2 |
| C23 | 9.1 | 9.2 | 9.1 | 9.1 |
| C24 | 10.2 | 10.2 | 10.2 | 10.2 |

Table 4

3-Month Cold Storage Carrots ºBrix

| Carrot Code | Test 1 | Test 2 | Test 3 | Mean Brix |
|---|---|---|---|---|
| C1 | 8.4 | 8.4 | 8.4 | 8.4 |
| C2 | 8.6 | 8.9 | 9 | 8.8 |
| C3 | 8 | 7.7 | 7.7 | 7.8 |
| C4 | 8.2 | 8.3 | 8.1 | 8.2 |
| C5 | 8.3 | 8.1 | 8.3 | 8.2 |
| C6 | 8.2 | 8 | 8.1 | 8.1 |
| C7 | 8.4 | 8.3 | 8.3 | 8.3 |
| C8 | 8 | 8.1 | 9.1 | 8.4 |
| C9 | 7.5 | 7.4 | 7.3 | 7.4 |
| C10 | 7 | 7 | 7.1 | 7.0 |
| C11 | 7.6 | 7.8 | 7.7 | 7.7 |
| C12 | 8.9 | 8.8 | 8.8 | 8.8 |
| C13 | 8.1 | 8.1 | 8.1 | 8.1 |
| C14 | 7.6 | 7.6 | 7.4 | 7.5 |
| C15 | 8.3 | 8.2 | 8.4 | 8.3 |
| C16 | 8.4 | 8.3 | 8.3 | 8.3 |
| C17 | 7.9 | 7.9 | 8 | 7.9 |
| C18 | 8.4 | 8.2 | 8.2 | 8.3 |
| C19 | 7.6 | 7.7 | 7.8 | 7.7 |
| C20 | 7.8 | 7.8 | 7.7 | 7.8 |
| C21 | 8.8 | 8.8 | 8.7 | 8.8 |
| C22 | 8.9 | 9 | 9 | 9.0 |
| C23 | 8.5 | 8.7 | 8.8 | 8.7 |
| C24 | 8.7 | 8.8 | 8.8 | 8.8 |

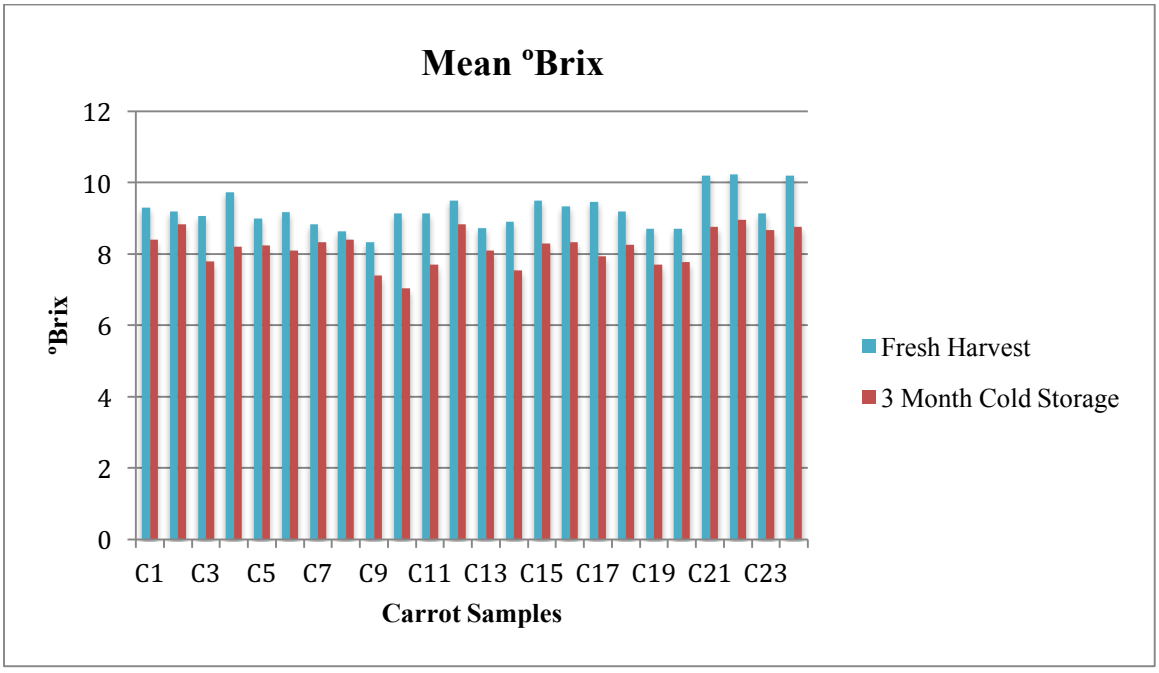



Figure.2.

ºBrix found in each carrot variety at harvest and then again after 3-month cold storage.

Testing was done in triplicate for both harvest and 3-month cold storage

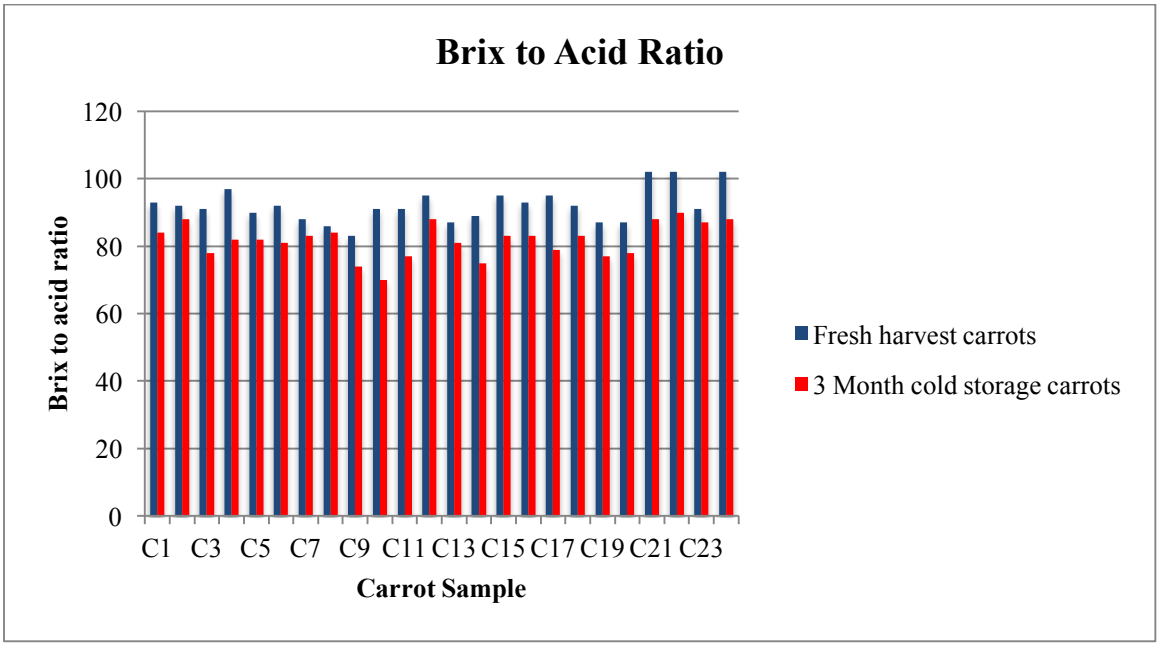



Figure.3.

Brix to acid ratio calculated for each of the 24 carrot varieties. The data reported is the mean of 3 replicates.

3.4 Titratable Acidity

After comparing the data from table 5 and table 6, there was no percent change in the malic acid that was found in carrots at harvest and 3-month cold storage carrots. The mean pH at harvest for carrots was 6.33 while the mean pH for cold storage carrots was 6.26. From fresh harvest to storage there is little to no change in the pH of the carrots.

Table 5

pH and Percentage of Malic Acid in Carrots at Harvest

| Carrot Code | pH1 | MA 1 | pH2 | MA2 | pH3 | MA3 |
|---|---|---|---|---|---|---|
| C1 | 6.6 | 0.10% | 6.4 | 0.10% | 6.5 | 0.10% |
| C2 | 6.4 | 0.10% | 6.5 | 0.10% | 6.5 | 0.10% |
| C3 | 6.5 | 0.10% | 6.5 | 0.10% | 6.4 | 0.10% |
| C4 | 6.5 | 0.10% | 6.5 | 0.10% | 6.5 | 0.10% |
| C5 | 6.2 | 0.10% | 6.2 | 0.10% | 6.3 | 0.10% |
| C6 | 6.4 | 0.10% | 6.4 | 0.10% | 6.3 | 0.10% |
| C7 | 6.3 | 0.10% | 6.2 | 0.10% | 6.2 | 0.10% |
| C8 | 6.3 | 0.10% | 6.3 | 0.10% | 6.4 | 0.10% |
| C9 | 6.3 | 0.10% | 6.3 | 0.10% | 6.4 | 0.10% |
| C10 | 6.3 | 0.10% | 6.2 | 0.10% | 6.2 | 0.10% |
| C11 | 6.2 | 0.10% | 6.2 | 0.10% | 6.2 | 0.10% |
| C12 | 6.3 | 0.10% | 6.3 | 0.10% | 6.3 | 0.10% |
| C13 | 6.4 | 0.10% | 6.3 | 0.10% | 6.4 | 0.10% |
| C14 | 6.2 | 0.10% | 6.3 | 0.10% | 6.3 | 0.10% |
| C15 | 6.3 | 0.10% | 6.3 | 0.10% | 6.3 | 0.10% |
| C16 | 6.3 | 0.10% | 6.3 | 0.10% | 6.3 | 0.10% |
| C17 | 6.2 | 0.10% | 6.2 | 0.10% | 6.3 | 0.10% |
| C18 | 6.2 | 0.10% | 6.2 | 0.10% | 6.3 | 0.10% |
| C19 | 6.3 | 0.10% | 6.3 | 0.10% | 6.3 | 0.10% |
| C20 | 6.3 | 0.10% | 6.4 | 0.10% | 6.4 | 0.10% |
| C21 | 6.4 | 0.10% | 6.4 | 0.10% | 6.4 | 0.10% |
| C22 | 6.2 | 0.10% | 6.3 | 0.10% | 6.3 | 0.10% |
| C23 | 6.4 | 0.10% | 6.4 | 0.10% | 6.5 | 0.10% |
| C24** | | | | | | |

Table 6

pH and Percentage of Malic Acid in Carrots After 3-Month Cold Storage

| Carrot Code | pH1 | MA 1 | pH2 | MA2 | pH3 | MA3 |
|---|---|---|---|---|---|---|
| C1* | 6.7 | 0.10% | 6.5 | 0.10% | 6.6 | 0.10% |
| C2* | 6 | 0.10% | 6.1 | 0.10% | 6.1 | 0.10% |
| C3* | 6.3 | 0.10% | 6.3 | 0.10% | 6.4 | 0.10% |
| C4* | 6.1 | 0.10% | 6.1 | 0.10% | 6.1 | 0.10% |
| C5* | 6.4 | 0.10% | 6.3 | 0.10% | 6.4 | 0.10% |
| C6* | 6.2 | 0.10% | 6.1 | 0.10% | 6.2 | 0.10% |
| C7* | 6.3 | 0.10% | 6.2 | 0.10% | 6.2 | 0.10% |
| C8* | 6.2 | 0.10% | 6.1 | 0.10% | 6.2 | 0.10% |
| C9* | 6.2 | 0.10% | 6.2 | 0.10% | 6.1 | 0.10% |
| C10* | 6.1 | 0.10% | 6 | 0.10% | 6.1 | 0.10% |
| C11* | 6 | 0.10% | 6.1 | 0.10% | 6.1 | 0.10% |
| C12* | 6.3 | 0.10% | 6.1 | 0.10% | 6.2 | 0.10% |
| C13* | 6.2 | 0.10% | 6.2 | 0.10% | 6.2 | 0.10% |
| C14 | 6.6 | 0.10% | 6.5 | 0.10% | 6.5 | 0.10% |
| C15 | 6.2 | 0.10% | 6.3 | 0.10% | 6.4 | 0.10% |
| C16 | 6.3 | 0.10% | 6.2 | 0.10% | 6.2 | 0.10% |
| C17 | 6.2 | 0.10% | 6.1 | 0.10% | 6.1 | 0.10% |
| C18 | 6.4 | 0.10% | 6.4 | 0.10% | 6.4 | 0.10% |
| C19 | 6.1 | 0.10% | 6.1 | 0.10% | 6.2 | 0.10% |
| C20 | 6.4 | 0.10% | 6.4 | 0.10% | 6.4 | 0.10% |
| C21 | 6.3 | 0.10% | 6.4 | 0.10% | 6.3 | 0.10% |
| C22 | 6.3 | 0.10% | 6.4 | 0.10% | 6.2 | 0.10% |
| C23 | 6.3 | 0.10% | 6.3 | 0.10% | 6.4 | 0.10% |
| C24 | 6.5 | 0.10% | 6.4 | 0.10% | 6.4 | 0.10% |

*(Juice from color testing was used for titratable acidity)

**(Juice sample was discarded before tiratable acidity testing could be done)

MA(#) = Malic acid and test number

3.5 Total Phenolic Content

Data from Figure 4 can conclude that during 3-month cold storage the concentration of total phenolics significantly decreases in all of the carrot varieties tested. The carrots that experienced the largest drop in phenolic concentration were, C8, C9, C10, C13, and C17. Carrot C4 was the only carrot sample that experienced the least amount of decrease in phenolic concentration during the storage period.

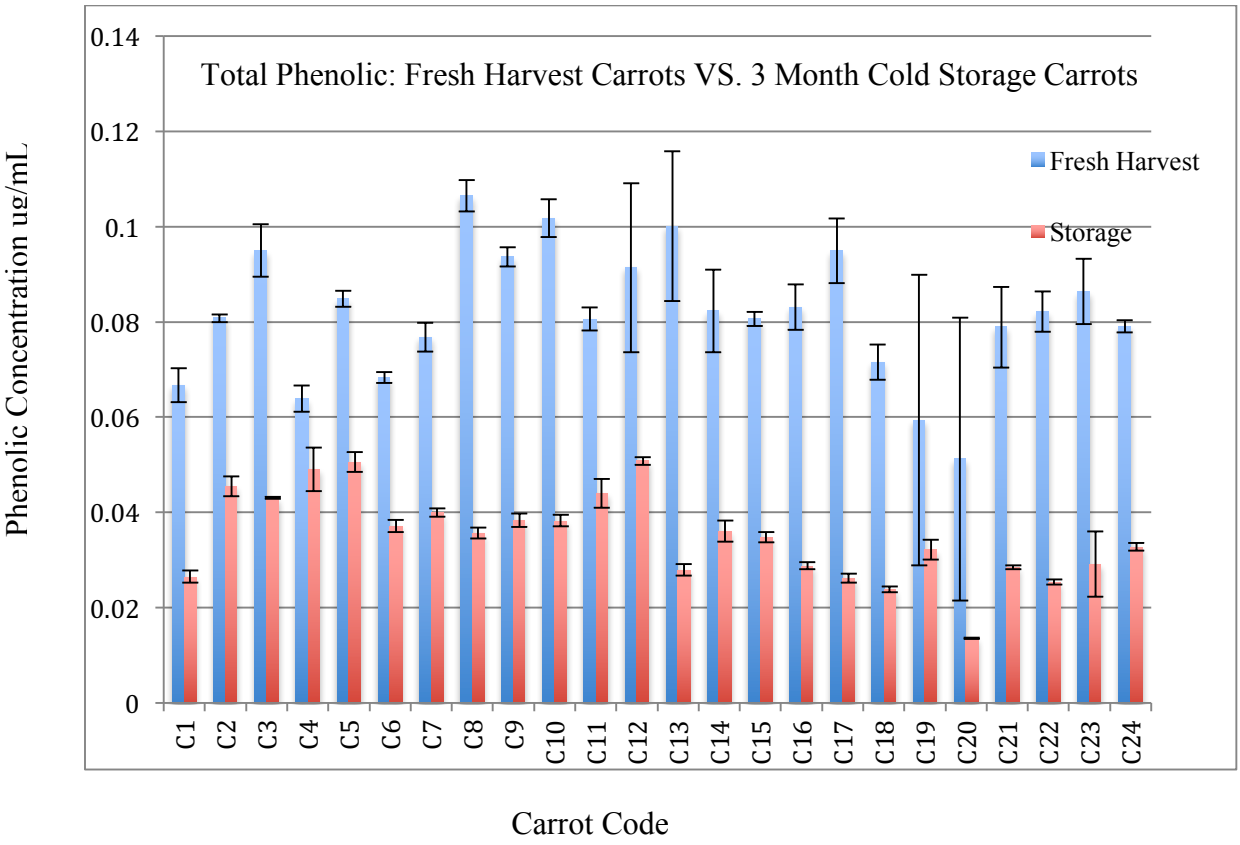



Figure.4.

Total phenolic content of carrots at harvest compared to total phenolic content of carrots after 3-month cold storage. Phenolic tests were done in triplicate. Data are shown as means plus standard deviation.

3.6 Colorimeter Test

The results from the colorimeter (Table 7) help translate visual color into a numerical value. Purple juice is darker and has a lower L value than yellow, the purple carrot (C21) in this research had a mean L value of 4.7, the yellow carrot (C22), had a mean L value of 28.7.

Table 7

Carrot Color Resting, Average L, A, B Values

| Carrot Code | Average L | Average A | Average B | Observed Color |
|---|---|---|---|---|
| C1 | 35.7 | 18.4 | 35.1 | Orange |
| C2 | 37.4 | 21.8 | 38.4 | Orange |
| C3 | 38.2 | 23.6 | 39.3 | Orange |
| C4 | 32.3 | 15.2 | 29.7 | Purple |
| C5 | 33.5 | 19.2 | 34.2 | Orange |
| C6 | 36.2 | 21.5 | 36.9 | Orange |
| C7 | 32.5 | 15.9 | 31.4 | Orange |
| C8 | 34.4 | 19.5 | 34.9 | Orange |
| C9 | 39.2 | 24.7 | 40.6 | Orange |
| C10 | 31.3 | 22.8 | 27.4 | Red |
| C11 | 45.0 | 6.9 | 33.7 | White |
| C12 | 36.7 | 20.3 | 36.5 | Orange |
| C13 | 35.4 | 20.2 | 35.8 | Orange |
| C14 | 32.9 | 18.5 | 33.3 | Orange |
| C15 | 37.4 | 21.2 | 37.6 | Orange |
| C16 | 36.2 | 22.1 | 37.2 | Orange |
| C17 | 34.9 | 18.6 | 34.8 | Orange |
| C18 | 34.9 | 20.2 | 35.2 | Orange |
| C19 | 7.9 | 3.7 | 1.1 | Purple |
| C20 | 33.1 | 18.3 | 34.5 | Orange |
| C21 | 4.7 | 4.5 | -1.2 | Purple |
| C22 | 38.7 | 10.3 | 34.9 | White |
| C23 | 36.6 | 18.8 | 34.2 | Orange |
| C24 | 34.1 | 8.2 | 35.2 | Yellow |

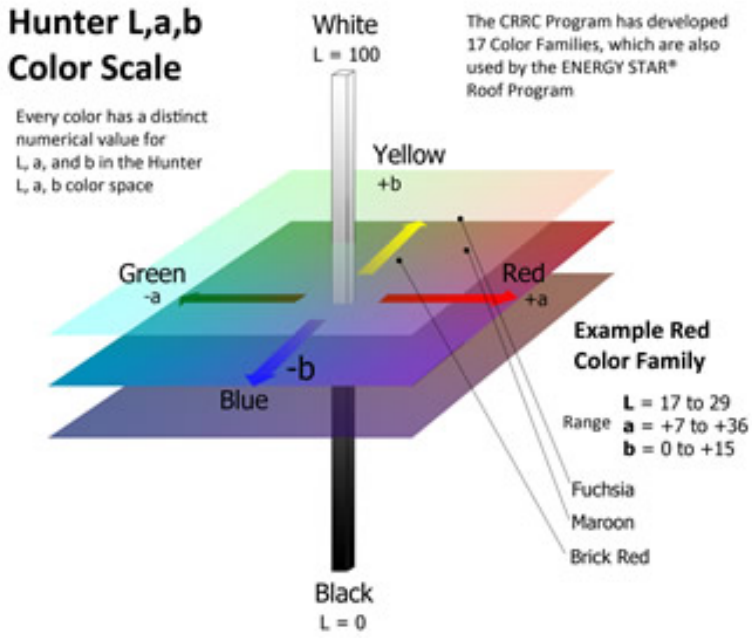
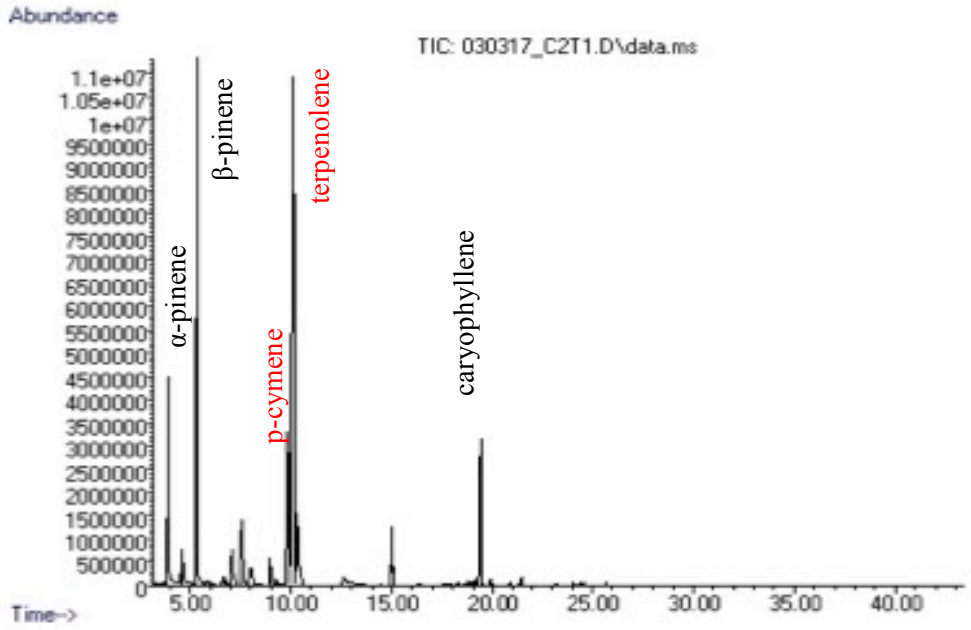



Image from: hunterlab.com

3.7. Volatile Test

Figure.5.

Volatile Compounds in Carrot Sample C2




Red=Major volatiles found in samples

Figure.5. Graph showing volatile compounds found in carrot sample C2 with major volatiles found in the carrot samples highlighted.

Figure 5 shows the levels of 5 volatile compounds that were found in the YaYa (C2) carrot sample. No quantitative results have been determined from volatile tests at this time. This research is still ongoing and is being conducted by Melissa Chrisholm in the Cole Lab in the Department of Chemistry at The University of Maine.

# 4. Discussion

## 4.1 Effects of Storage on ºBrix

ºBrix is a measure of the soluble solids in an aqueous solution and is also an important determinant of consumer acceptability in regards to a carrot's taste (sweetness). According to Agriculture-USA (AG-USA) research, the average consumer acceptability of Brix for carrots is a rating of 6, where 12 is considered good, and a rating of 18 is excellent [24]. All of the carrots in this study fell between average and good (6-12) on the Brix consumer acceptability scale.

In this research project, the carrot varieties that were found to have the highest ºBrix were the purple and the yellow carrot cultivars. These carrot cultivars all had a ºBrix rating around a 10 on the ºBrix scale (refer to Table 3). This data is consistent with findings from other studies, Lee et al. and Kjellenberg et al. regarding ºBrix and cold storage. The studies in reference have determined that purple carrots have a higher when compared to orange carrots [23]. In this study the Brix to acid ratio was evaluated, and it was determined that the purple and yellow carrots in this study had a higher ºBrix to acid ratio (see Figure 2). This ratio represents the sweetness of the carrot; a higher ratio is correlated to the carrot having a sweeter taste. The ºBrix to acid ratio is also a representation of the ripeness of a carrot, a higher ºBrix is associated with a riper carrot and a lower ºBrix rating is associated with a less ripe carrot.

According to the results found in this research, during a 3-month cold storage, each of the 24 carrot cultivars that were tested showed a decrease in ºBrix after storage. This research found that some of the carrot cultivars had a greater decline in ºBrix after storage while certain cultivars (C7, C8, and C23, all orange varieties) had little to no

change (refer to Figure 2). The small decrease in ºBrix that occurred in the Bolero (C7), Navarino (C8) and Bermuda (C23) carrot cultivars during storage indicates that these three varieties tested have the best ability to maintain a quality product during cold storage.

The Bolero (C7) carrot cultivar is considered to be a storage carrot according to commercial seed companies. This variety of carrot is designed and grown to be able to maintain a consistent flavor and firmness during storage. The results gathered from this research support this claim. At harvest, the mean ºBrix of the Bolero (C7) carrot was 8.8 and after the 3-month cold storage the mean ºBrix of 8.3 (refer to Table 3 & 4). The other two cultivars, Navarino (C8) and Bermuda (C23) are not considered storage carrots by commercial seed companies but are known in the seed industry for their sweet taste. This research showed that the Navarino (C8) had a mean ºBrix of 8.6 at harvest and a mean ºBrix of 8.4 after storage. The Bermuda (C23) had a mean ºBrix of 9.1 at harvest and a mean ºBrix of 8.6 after storage. Thus proving both are sweet and can maintain the sugar content over a 3-month cold storage period. After reviewing the ºBrix of the different carrot cultivars at harvest and after storage it can be concluded that the Bolero (C7), Navarino (C8), and Bermuda (C23) carrot cultivars maintain their sugar contents the best under storage conditions.

## 4.2 Volatile Compounds

During storage, carrots undergo many changes, where some may affect the flavor of the carrot. The changes that can occur in the carrot during storage can significantly impact the volatile compounds-the compounds that give carrots their characteristic flavor.

Carrots are made up of more than 90 volatile compounds [16]. The carrot utilizes sucrose during storage as an energy source to carry out respiration and biochemical processes. Sucrose is decomposed to glucose and fructose; this decomposition causes a change in the flavor profile of the carrot in regards to their sweetness [17].

In this research 24 carrot varieties were evaluated for volatile compounds after 3-month cold storage. The most prominent volatiles that were detected in the 24 carrot varieties were: p-cymene, terpinolene, χ-pinene, β-pinene, and caryophyllene. Each of these compounds corresponds to a different flavor that can be found in a carrot: p-cymene is the carrot top taste: terpinolene is the sweet, fruity, and citrus flavor: χ-pinene is the sharp, pine, carrot top, β -pinene is the carrot like, fresh green taste, and caryophyllene, is the terpene-like, spicy, woody taste. When these are found in different levels in the carrots, it causes the carrot to express different flavors. The sweet flavor of carrots is associated with increased levels of sugars and decreased levels of terpenoids, while the harsh flavors that can be found in carrots are related to an increase in the levels of terpenoids and the decline of sugars [17]. The results of this research supported the results of Kjeldsen et al. research.

The volatile compounds were not tested at harvest in this study; the carrots were only tested after the 3-month storage. Protocol testing the volatile compounds was still under development at the time of the carrot harvest. Due to this, we are unable to compare what changes occurred from harvest to 3-month storage. The data that we did gather after the 3-month storage is comparable to data found in the Kjeldsen et al. study, meaning that this data shows a good representation of what does occur to volatiles during storage.

## 4.3 Effects of Storage on Total Phenolic Compounds

Antioxidants found in phenolic compounds can scavenge reactive oxygen species and electrophiles, which helps to reduce the risk of developing cancer [10]. Carrots are an excellent source of phenolic compounds. Phenolic compounds are affected by biological changes, preservation methods, and how long the carrot is in storage.

In the American diet, many raw vegetables are processed and preserved using a variety of methods, such as freezing, blanching, dehydration, and canning. These different forms of preservation are used to extend the shelf life and availability of the vegetable. There has been an increase in the consumption of carrots in both the raw and cooked state due to the many different cooking uses of carrots, the carrot's high nutritional value, and antioxidant content. Processing of raw vegetables helps to give vegetables their characteristic texture, flavor, and aroma, but processing can also cause a decrease of nutrients and antioxidants found in the vegetable [20].

Preservation and cooking of carrots can have positive effects on the texture by softening the cell walls, but it can also have negative impacts on the phenolic content, causing it to decrease. The degree of decrease in phenolic content during processing is dependent on which form of processing is used. In the Al-Dabbas et al. study it was found that the use of blanching increased the phenolic content when compared to the phenolic content in fresh carrots. This phenomenon can be due to the softening of the cells caused by blanching. This softening of the cells allows for a more efficient release of phenolics from the carrot's matrix. The increase of phenolic content has also been noted in other vegetables after blanching, such as peppers, broccoli, green beans, and corn [20]. The Al-Dabbas et al. study concluded that blanching was the best method for

processing carrots to improve the phenolic content, while dehydration had the greatest decline in phenolic content. This study also concluded that the amount of phenolics found in each carrot after processing was greatly affected by the amount of time it was held in storage, the longer the product was kept in storage, the greater the decline in phenolic content.

The results that were gathered from this research supported the results found in the Al-Dabbas et al. study. From this analysis, we concluded that during 3-month cold storage the phenolic content in each of the carrot varieties greatly decreased. The four carrot varieties that experienced the greatest decline in phenolic content were, Navarino (C8), Nutri-Red (C10), Nelson (C13), and Naval (C17), all of which were orange. The one carrot purple variety that had the least decline in phenolic content was Purple-Haze (C4). More research needs to be done to determine what effect the color of the carrot has on the phenolic content during different storage and processing methods. Overall, all the data collected from both of the studies supported that the phenolic content in carrots decreases during processing and storage, as well as during increased storage time.

## 5. Conclusion

Carrots are a complex vegetable with many factors that influence their overall taste profile. The quality of carrot taste is related to ideal growing conditions, proper harvest times, the amount of water used, cultivar variety, the storage and method of processing. All of these aspects of growing and treatment of carrots significantly influence the overall flavor of a carrot. These conditions affect the volatile compound make up of a carrot, its sugar content and phenolic compounds. Volatile compounds are the most influential parameter on the consumer acceptance of carrots [18]. The carrot

volatiles are influenced by genotype, soil climate, and postharvest storage and processing; they are mostly made up of monoterpenes and sesquiterpenes. Elevated levels of terpenes and decreased sugar content are linked to the development of harsh, and oily flavor in carrots during prolonged storage [17]. The physiological breakdown is also associated with the development of off flavors post-harvest. Refrigeration slows down the physiological breakdown and decay but does not stop it. The reduction of sugar can also cause the formation of unpleasant flavors. Carrots have the highest amount of sugar during their peak harvest time [24]. During storage, there is a decrease of glucose and fructose and a development of polyacetylenes, which causes a reduction of soluble sugars [23]. More research is needed to determine the effects of phenolic activity of different carrot varieties and compare the volatile compounds that are found in fresh harvest carrots and cold storage carrots to determine the actual effects that storage has on the flavor make-up of carrots, especially related to consumer acceptance.

One way to improve this research would be to include a sensory analysis of the carrot varieties. By performing sensory evaluations, it will provide stronger evidence of which cultivar of carrot is preferred by consumers. Visual appearance is the primary driving factor that consumers use when picking a product, but the taste is a factor that encourages consumers to buy the product again. This information will be helpful for farmers, by providing them with information about which carrot cultivars are the most beneficial to be grown for market.

The collected data showed which cultivars performed better after cold storage and still be favorable market carrots, these varieties include, C7, C8, C20, C21, and C23. This information will enable growers to invest their resources into the best carrot variety that

have the highest sweetness and which ones hold up the best during cold storage. This data provides valuable information about the effects cold storage has on flavor and sweetness of carrots during prolonged storage.

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## 7. Author's Bibliography

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Upon graduation in August 2017, Hannah will be attending the University of New Hampshire where she will complete her dietetic internship. After completion of the dietetic internship Hannah plans on pursuing a career working as a Dietitian.