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Effects of Thermal Processing on Peach Puree of Different Cultivars: Analysis of Biochemical Alteration, Non-enzymatic Browning Reaction, and Color Changes

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Effects of Thermal Processing on Peach Puree of Different Cultivars: Analysis of Biochemical Alteration, Non-enzymatic Browning Reaction, and Color Changes

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EFFECTS OF THERMAL PROCESSING ON PEACH PUREE OF DIFFERENT CULTIVARS: ANALYSIS OF BIOCHEMICAL ALTERATION, NON-ENZYMATIC BROWNING REACTION, AND COLOR CHANGES

A Thesis
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Master of Science
Food Science

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by
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ABSTRACT

The effects of pasteurization temperature and time on the change in seven peach puree variables over a 6-week accelerated shelf-life test (35°C) were evaluated. The variables of interest were three color measures [L^* (lightness), a^* (redness), and b^* (yellowness)]; two brown pigment measures [spectrophotometric absorption at 420 nm (Browning Index) and 443 nm (Hydroxymethylfurfural)]; °Brix; and pH). Puree was collected from three different cultivars (2 freestone and 1 clingstone) and puree samples from each cultivar were subjected to 20 combinations of pasteurization temperatures (70°C, 80°C, 90 °C, 100°C) and same hold times (0 minutes, 1 minute, 3 minutes, 5 minutes, and 10 minutes). This resulted in 60 total combinations of cultivar, temperature, and hold times. The changes in the seven total peach puree variables over the 6-week accelerated shelf-life test were evaluated for all 60 combinations. Resulting data on the effects of increasing temperature and hold time on shelf-life changes in the seven variables varied inconsistently throughout this study; yet some minute trends were detected. Inconsistency in the results may be due to the imitated duration time of testing. This experimentation should be repeated with an increased testing period.

DEDICATION

I dedicate this research to mother and father, Lori and Mark Hayes, and to my aunt Lynn Hicks. I am truly blessed to have had you beside me leading me though the journey of life. Thanks, and much love.

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I would like to acknowledge my family as well as my friends for inspiring and supporting throughout this process. Without you none of this would have been possible and for that I am eternally grateful. Furthermore, I would like to especially acknowledge my aunt, Lynn Hicks. Lynn, you are truly an example of how the Lord wants his people to love and lead, thank you for showing me how to do the same. Mom and Dad, you are creative caring, and would give the shirt-off your back if it meant someone else would be warm, this is a life lesson that I will hold-fast as I navigate through life. Thank you both for loving me and teaching me how to be a true man. Last, but not least, I want to thank my friends, you all are the best and I look forward to making more memories as we age.

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CHAPTER ONE

INTRODUCTION

Consumer perception of a product's quality of freshly harvested produce directly affects the profit margin and overall financial success of a company (Grunert, 2005). Maintaining the quality of freshly harvested produce is one of the top economic concerns in the food industry. Being that all freshly harvested food products are built upon raw, biological materials they are destined to deteriorate or spoil over time affecting the quality of a food product (Singh & Anderson, 2004). Thus, the freshness of a food product is a degradative process perceived through quality, which decreases over time as the food spoils.

Determination of quality of freshly harvested produce can be evaluated by nutrient concentration, texture (firmness), appearance, flavor, and aroma (Francis, Gallone, Nychas, Sofos, Colelli, Amodio, & Spano, 2012). Bellizzi and Hite (1992), note that although all these characteristics regarding quality are important when purchasing freshly harvest produce, none are more important to the consumer than appearance especially the appearance of color. Color is pivotal in the produce industry as many of the fruits and vegetables eaten are vivid in coloration when fresh. However, when no longer fresh, a distinct decrease in color notifies us that it is time to repurpose or discard.

Degradation in the color of freshly harvested produce has two main causes: mechanical or chemical damages. Mechanical damage, such as bruising, is caused by the direct mishandling of any given produce product itself (Elik, Yanik, Istanbullu, Guzelsoy, Yavuz, & Gogus, 2019). When mechanical damage occurs, the color change associated with it results from damage to the cell structure of the outermost layers of the fruit or vegetable (Hussein, Fawole, & Opara, 2020).

On the other hand, chemical damage is driven by the biochemical breakdown of the composition of the produce product. One of the most identified chemical changes that lead to color change in fruits and vegetables is browning. Browning reactions occur over time as the fruit degrades carbohydrates naturally by aerobic respiration (Toivonen & Brummell, 2008). Browning of fruit occurs either enzymatically (EB) or non-enzymatically (NEB) based on the presence of oxygen. EB reactions take place when oxygen is present and readily available enzymatically to react with biochemical compounds in freshly harvested produce including phenolic compounds, anthocyanins, flavonoids, non-flavonoids, minerals, phytochemicals, antioxidants, and carotenoids of a fruit (Terefe, Buckow, & Versteeg, 2014). NEB reactions on the other hand are not catalyzed by oxygen. NEB reactions result from the interaction between free amino acids and a carbonyl group on reducing sugars that are present in freshly harvested fruit (Saura, Vegara, Martí, Valero, & Laencina 2017). Examples of NEB reactions include caramelization, chemical oxidation of phenols, and Maillard browning (Cámara, Matallana, Sánchez-Mata, Lillo Ayué, & Labra, 2003). Regardless of the type of browning reaction, fruit quality will deteriorate over time affecting appearance. Browning reactions can also affect the nutritional and organoleptic properties of freshly harvested fruit and lead to safety concerns for the consumer from its byproducts (Skrypec, 2020). Based on color change resulting from browning, fresh produce products are often perceived by the consumer to spoil or lose quality much quicker than other food products (Bellizzi, & Hite 1992).

Manipulating the quality of freshly harvested produce can be achieved in two timeframes: pre-harvest and post-harvest (Porat, Lichter, Terry, Harker, & Buzby, 2018). As the consumer does not see produce until at the time of purchase, the post-harvest phase has become the focal point of control when attempting to preserve freshly harvested fruits. Post-harvest factors include

temperature and humidity during storage, physical handling, distribution practices, microbial interactions, biochemical aspects of the product itself, and processing techniques. All factors can lead to faster spoilage of the freshly harvested produce which will in turn affect the appearance of quality (Porat, Lichter, Terry, Harker, & Buzby, 2018). Post-harvest factors can be controlled and manipulated to improve fresh produce quality better protecting the bottom line of a company (Porat, Lichter, Terry, Harker, & Buzby, 2018). Manipulating chemical and physical aspects of a produce product or its environment, as well as altering produce processing and packaging techniques have been found adequate when attempting to extend shelf-life and maintain quality (Ramaswamy, 2014). Extending shelf-life by any of these methods may have positive or negative effects on product quality. Thus, balancing these post-harvest manipulation techniques remains a challenging dynamic for the food industry.

One of the more commonly used methods of preservation of freshly harvested produce is by utilizing thermal processing. Thermal processing is the act of using heat for any given time to prolong a product's shelf-life (Patras, Brunton, O'Donnell, & Tiwari, 2010). Thermal processing methods typically used commercially include retorting, aseptic processing, pasteurization, and hot-filling (MacNaughton, 2018). Thermal processing extends a food product's shelf-life by manipulating microbial load or by eliminating microbes (Patras, Brunton, O'Donnell, & Tiwari, 2010). Negative effects of thermal processing on fresh produce include loss or change in texture, taste, aroma, nutritional value, and color (Wang, Chen, Yang, McClements, & Jin, 2021). Both during and after thermal processing, a decline in the quality of a produce product often results from the degradation of biochemical compounds via the acceleration of enzymatic reactions that occur within a product itself as a reaction to heating. Fruits and their many formats such as purees, juices,

jellies, jams, and slices are sensitive to thermal processing (Fellows, 2009a). Thus, they require more mild thermal processing methods, such as hot-fill or pasteurization.

Peaches challenge the food industry because they require a delicate balance of the dynamics between actual product quality and consumer perception of quality. Peaches are diverse in their use and cultivars. They offer a nutritiously rich biochemical composition, are oxygen-sensitive, and are full of color from various pigments (carotenoids, anthocyanins, and polyphenols) (Lill, O'Donoghue, & King, 1989). After harvest, they are readily subjected to deterioration of quality resulting from both browning reactions despite thermal processing. There are two main types of peaches found, free-stone and clingstone, named appropriately for their seed orientation (Hong, Barrett, & Mitchell, 2004). Traditionally, free-stone (larger) peaches are supplied as the fresh supermarket peach, and clingstone (smaller) peaches are the commercial peach used in many different processing methods to create juices, desserts, baby food, puree, and smoothies (Hong, Barrett, & Mitchell, 2004). Researchers in the food industry utilize quantifiable parameters when determining the peach quality and method of processing. These parameters include pH, acidity, Brix, or soluble solids content (SCS) ratio; textural analysis, and color analysis regardless of seed orientation (Gonzalez, Mauromoustakos, Prokakis, & Aselage, 1992). Knowledge of these quantifiable quality attributes allows researchers to measure shelf-shelf manipulation from processing and packaging techniques.

This study aimed to determine the effect of thermal processing by way of pasteurization at varying temperatures and hold-times has on the browning reaction rate of peach puree from three different peach cultivars, two free-stones (Big Red and August Lady), and one clingstone (Venture) peach during six-week accelerated storage. Analysis of visual quality and biochemical properties of the peach puree included colorimetric parameters (L*, a*, b*), °Brix (SSC), pH, and

absorbances by way of spectrophotometry at 443 nm to determine HMF concentration and spectrophotometry at 420 nm to browning index (non-enzymatic browning).

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CHAPTER TWO

LITERATURE REVIEW

2.1 The Peach

Originating in China as early as 3000 BC. the peach or Prunus Persica has long since been domesticated (Cao, Liang, Shi, Shao, Song, Bian, Chen, Yang, 2017). Its ease of domestication has allowed this fruit-bearing crop to be grown worldwide and to have many different varieties and cultivars. Peaches are harvested at varying times depending on geographical location and the cultivar desired. In the United States, the ideal time to harvest peaches is during the summer months from May (early season) to September (late season) (Mari, Spadaro, Casals, Collina, De Cal, & Usall, 2019). Depending on their cultivar peaches express different tolerances to the cold (Mari, Spadaro, Casals, Collina, De Cal, & Usall, 2019). interestingly, some peach cultivars require "chilling hours' to achieve optimal growth. Peaches are abundantly sourced biochemically with high-quality nutrients such as vitamins A, C, E, minerals, phenolic compounds, phytochemicals, flavonols, anthocyanins, antioxidants, carotenoids, potassium, and fiber (Bassi, Mignani, Spinardi, & Tura, 2016). Peaches are said to be "stone fruits". Mari et al. (2019), defines stone fruits as any fruit in which the seed is encapsulated by a hard outer casing known as an endocarp (Mari, Spadaro, Casals, Collina, De Cal, & Usall, 2019). How this "stone" is orientated to the flesh of the fruit allows for a peach to be categorized. Peaches may have one of two stone-to-flesh orientations, clingstone, and freestone (Skrypec, 2020). As the name implies, a peach in which the flesh of the fruit is attached to the stone is known as a clingstone. A peach in which the stone does not attach to the flesh of the fruit is known as a freestone peach (Skrypec, 2020). In some rare cases, semi-freestone peaches have been seen to have a flesh-to-stone orientation in between that of freestone and clingstone (Skrypec, 2020). Peach flesh color can be expressed as

yellow, white, or red and is considered a differential point for separation during sorting. Yet, how a peach is processed and consumed typically depends on stone-to-flesh attachment. Freestone peaches are typically larger, bearing a greater fruit-to-stone ratio. Thus, they are the retail peach commonly seen on shelves in the supermarket. Clingstone peaches on the other hand have a much smaller fruit-to-stone ratio and are much firmer. Thus, they are more often used as the processing peach seen in cans, pouches, cups, and frozen, which you may find in stores (Singh, B., Suri, Shevkani, Kaur, Kaur, & Singh, N., 2018). Like any other fruit, peaches have maturity standards. The produce industry identifies two maturity standards for peaches tree-ripe and well-matured (Teixeira, 2019). Industry identifies these maturity levels based on firmness regardless of cultivar and "stone" orientation. Tree-ripe peaches are softer in texture and generally only have a shelf life of one-to-two weeks (Teixeira, 2019). Well-mature peaches are much firmer and can be held for several weeks depending on environmental conditions during storage. Skrypec et al. (2019), notes that color, size, and concentration of acids and sugars can also be used when identifying maturity as well. It is important to note that all these characteristics are determined by the biochemical properties of a peach (Skrypec, 2020). Like any multicellular organism or food product, peaches are composed of a complex network of cells that make up their biochemical composition creating their quality characteristics (Singh, B., Suri, Shevkani, Kaur, Kaur, & Singh, N., 2018). Peaches are predetermined to deteriorate or spoil over time naturally affecting their quality. Singh et al. (2018), states that there are three methods by which a product can spoil or decrease in quality: physical (bruising, drying out, breaking), microbial spoilage (interaction between the food product and a microorganism), and biochemical spoilage (color change from enzymatic and non-enzymatic browning, pH, temperature, oxygen availability, water activity), all of which must be accounted for when ensuring safety and quality to the consumer (Singh, B., Suri, Shevkani, Kaur, Kaur, &

Singh, N., 2018). The produce industry must account for how these categorical aspects and spoilage methods affect the biochemical compositions of peach before determining how it will be utilized, harvested, sorted, stored, and processed.

2.2. Achieving Shelf Stability: The Importance of Preserving Peaches

In the last decade, as consumer demand for an increased convivence of peach products has risen a challenge has presented itself. So, how does the produce industry ensure safety and mitigate spoilage due to microbes and biochemical degradation to maintain post-harvest quality of all produce products while providing convivence to the consumer post-harvest? The answer lies within understanding the biochemical compounds of any fruits and veggies like the peach and applying that knowledge to select the appropriate processing techniques to obtain a quality shelf-stable product. According to the United States Department of Agriculture Food Safety and Inspection Service, a shelf-stable product is defined as any product that can be stored unopened at room temperature without the risk of product spoilage or illness after ingesting the food. MacNaughton et al. (2008), identifies that shelf-stable foods can be referred to as "non-perishable products". Produce products, especially peaches, are seen in shelf-stable forms. Once a product is considered shelf-stable, it is considered safe from microbes or microbial byproducts that may be harmful upon ingestion, and it will have what is known as a shelf-life. Shelf-life is the period in which it takes for a food product to spoil assuming it has received adequate processing to eliminate spoilage due to microbial interactions with the product (Gonzalez, Mauromoustakos, Prokakis, & Aselage, 1992). Shelf life can vary depending on the product itself and its packaging, as well as whether this product will need to be refrigerated after opening. Giménez et al, (2012). suggests that there are many ways in which the shelf-life of a food product can be increased such as chemical manipulation (ascorbic acid addition, pH, water content, and activity), physical manipulation

(storage conditions, dicing, pureeing, juicing, mincing), packaging manipulation (cans, jars, cups, modified atmosphere packaging, oxygen scavenging pouches), processing treatment condition manipulation to eliminate microbes (thermal processing, cold-processing, pasteurization, and aseptic treatment), or any combination of the aforementioned (Giménez, Ares, F., & Ares, G. (2012). Although, whether combined or individually these methods will provide a shelf-stable product they may influence a product's quality. The quality of a shelf-stable product must be maintained to ensure said given product will be accepted by consumers. To reiterate, consumer perception of a product's quality is a critical point of concern in the produce industry when assumed a product is safe after processing, especially that of the produce industry (Grunert, 2005).

Typically, after harvesting fruits are stored in bins, bags, or baskets by the harvesting company and immediately taken from orchards to cooled storage facilities to be stored, sorted, and processed. During this time before processing fruits are at a critical stage on their post-harvest time scale. Being that during the post-harvest phase fruits are removed from the tree that bore them, they can no longer receive nutrients allowing them to grow and thrive. When fruit is harvested from the "mother tree" or plant it must rely on the nutrients it already has until it runs out and spoils. During this stage carbohydrates within fruits are broken down to glucose to be utilized as a source of energy (Robertson, 2010). The breakdown of carbohydrates into glucose is known as aerobic respiration. Aerobic respiration to produce glucose in fruits is accompanied by two products carbon dioxide and water (Robertson, 2010). There are two classifications of fruits based on rates of aerobic respiration climacteric and non-climacteric (Paul, Pandey, & Srivastava, 2012). Peaches are considered a climacteric fruit, meaning they experience higher rates of aerobic respiration and ethylene discharge post-harvest. The rate of respiration and ethylene discharge in fruits is important. Higher rates of respiration and ethylene emission have been shown to

exponentially increase the degradation of biochemical compounds associated with fruit quality, especially that of color, aroma, and firmness (Minas, Tanou, & Molassiotis, 2018). Storage conditions and physical handling of fruits should be modified to mitigate increased rates of respiration in fruits. Fruits should be stored in cool conditions favorable to eliminate an increased risk of spoilage. Sheng et al. (2021), states that the ideal temperature conditions to store peaches before processing is 0-2 °C. After being stored in cool conditions the next step is to sort said produce item. Sorting is a difficult process for all fruits but especially so for peaches. Peaches are softer when compared to fruits like apples, pears, and oranges meaning they are prone to experience greater physical damage during sorting. Additionally, sorting facilities can handle many cultivars of peaches at one time differing in stone-to-fruit orientation, size, color, and shape at the same time. Thus, sorting any fruit is a process that requires care and attention to detail to avoid or mitigate physical damage to a fruit product. Prasad et al.(n.d), suggest that limiting human interaction during storage and sorting before processing can limit the physical damage to fruits. Physical damage such as bruising, wounding, slicing, and peeling, creates and promotes conditions optimal for fruit to undergo degradative reactions associated with aerobic respiration, spoilage susceptibility, volatile formation, softening, enzymatic browning, non-enzymatic browning, and pigment formation (Toivonen & Brummell, 2008); Black & Barach, 2015). Improper handling of fruits during sorting and minimal product preparations by humans can be directly correlated to increased rates of aerobic respiration and ethylene release in climacteric fruits, which has been documented to have a detrimental effect on the quality of produce products (Sheng, & Zhu, 2021; Robertson, 2010). Thus, proper storage conditions and sorting methods to limit physical damage before processing are important when maintaining the quality of a produce product. Physical damages to produce products are inevitable during storage and sorting. However, when this does

occur wounded or damaged products can be repurposed into new formats or to create shelf-stable products via processing. Peaches that are wounded and repurposed are commonly reformatted into liquids or semi-liquids that will require thermally processing to become a shelf-stable product.

Before processing a peach product, processors will check three critical points of the new product including pH, water activity (Aw), and storage temperature. These critical points are checked to determine what kind of processing treatment the peach product will need to receive to eliminate microbial interactions with the product as well as to limit biochemical degradation post-processing to guarantee a shelf-stable product of high quality (Black & Barach, 2015; Cropotova, Popel, Parshikova, & Colesnicenco, 2016). There are many ways in which peaches can be processed depending on the ultimate purpose including diced, halved, sliced, pureed, jams, jellies, nectars, juices, and smoothies. The processing method or format also depends on achieving shelf-life safety expectations the producer is intending on providing to the consumer. According to Tinello et al. (2018), peaches that are processed into jams, jellies, purees, juices, nectars, cans, or pouches, typically receive some sort of thermal processing method. Utilizing thermal processing, also known as “cooking”, is the implementation of heat to produce shelf-stable products by manipulating microbial load or by eliminating microbes (Patras, Brunton, O'Donnell, & Tiwari, 2010). Despite ensuring a shelf-stable product, thermal processing methods can be extreme and have adverse effects on product quality post-process (during storage), this is especially true for fruits like the peach (Fellows, 2009a). During storage, a decline in the quality of a food product often results from the degradation of biochemical compounds and enzymatic reactions that occur within a food product itself that has been accelerated by thermal processing or as a result of microbial interactions between the food and any microbe that may have remained if thermal processing was not sufficient (Teixeira, 2019).

2.3. pH, Water activity (A_w), and Thermal Processing

The purpose of every type of food processing is to ensure that a safe, high-quality, and shelf-stable food product will be produced (Britt, 2008). One method to manipulate the rate of spoilage of a food product resulting from microbial is to change the type of processing treatment it receives. The type of processing in which a food product receives to be considered shelf-stable depends on two things Water activity (A_w) and pH concentration (Fellows, 2009b). According to Featherstone et al. (2015), A_w is defined as the amount of water in a food product available for microbial, chemical, or enzymatic activity to occur. Water availability is critical as microbial organisms require it to run biological processes related to growth and replication. Research completed by Fennema et al. (1996), found that Aw levels can be linked to the rate of enzymatic reactions within a food product such as non-enzymatic browning, and lipid oxidation. Figure 2.1 displays the rate of reactions regarding A_w (Aqua Lab, 2018).

pH is defined as the measure of the concentration of hydrogen ion(s) in any given solution and is the negative log of the concentration of hydrogen ions in moles per liter (Reineke, Mathys, & Knorr, 2011). When classifying a food product based on pH, there are two classifications: acidic and basic (Reineke, Mathys, & Knorr, 2011). Acidic compounds have a pH level of less than 7 ($pH<7$) and basic compounds have a pH level greater than 7 ($pH>7$) (Fellows 2009c).

Any food product with an A_w less than 0.85 (A_w <0.85) is considered free from pathogenic microbes at any pH level and will not require any additional processing treatments. However, a food product with an A_w greater than 0.85 (A_w <0.85) is not considered shelf-stable and will require a thermal processing treatment depending on pH to be considered shelf-stable (Fellows 2009a). McNaughton et al. (2008), displays the shelf-life using the relationship between

Aw and pH, which can be seen in Figure 2.3.2 In shelf-stable products when A_w is greater than 0.85 a pH level of 4.6 is the cut-off point as anything below this restricts the growth of Clostridium botulinum (C.bot). C. bot is a microorganism of public health concern. This gram-positive microorganism produces a deadly toxin that is unable to grow in acidic environments below a pH less than 4.8 (pH<4.8). Thus, eliminating it in shelf-stable foodstuffs with a pH greater than 4.8 (pH>4.8) is pivotal when ensuring a product is safe as it requires some sort of thermal processing to be eliminated. Fellows (2009a), identifies peaches to have a pH between 3.6 to 4.1. Thus, C.bot is not of importance to this research. It is important to note that Figure 2.3.1 displays another categorical classification via pH level. This calculation will not be discussed in this research based on peaches having a pH between 3.6 to 4.1.

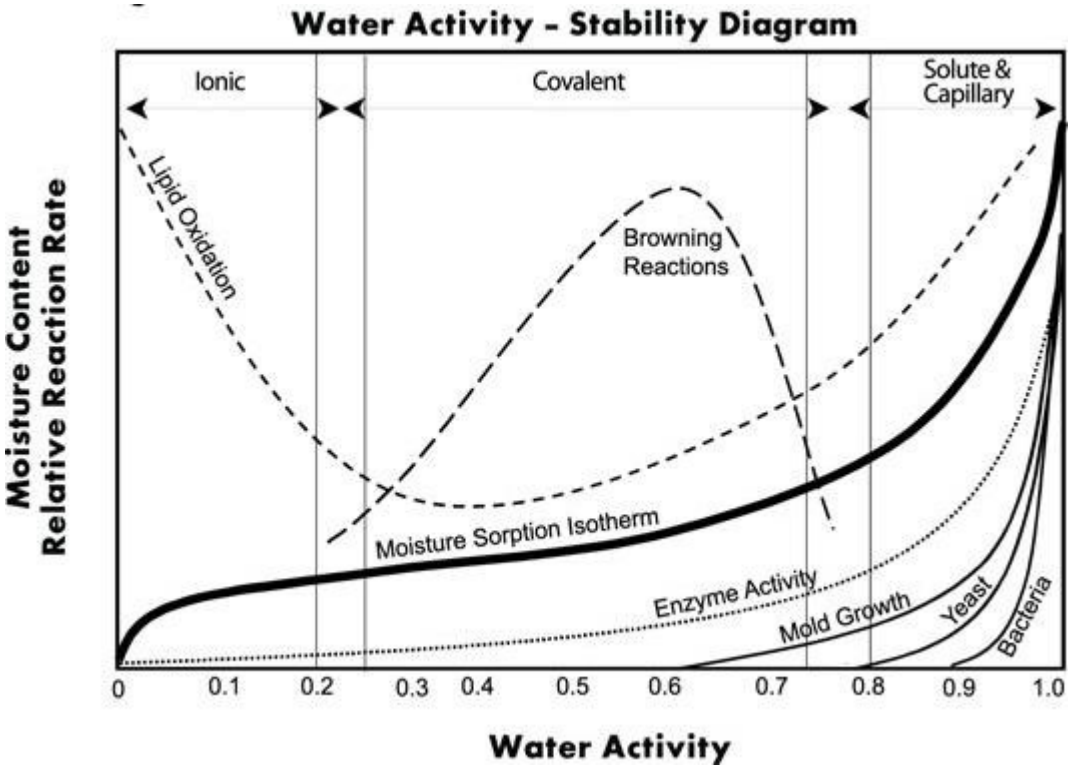


Figure 2.3.1 Water activity and Reaction Rates (Aqua Lab, 2018)

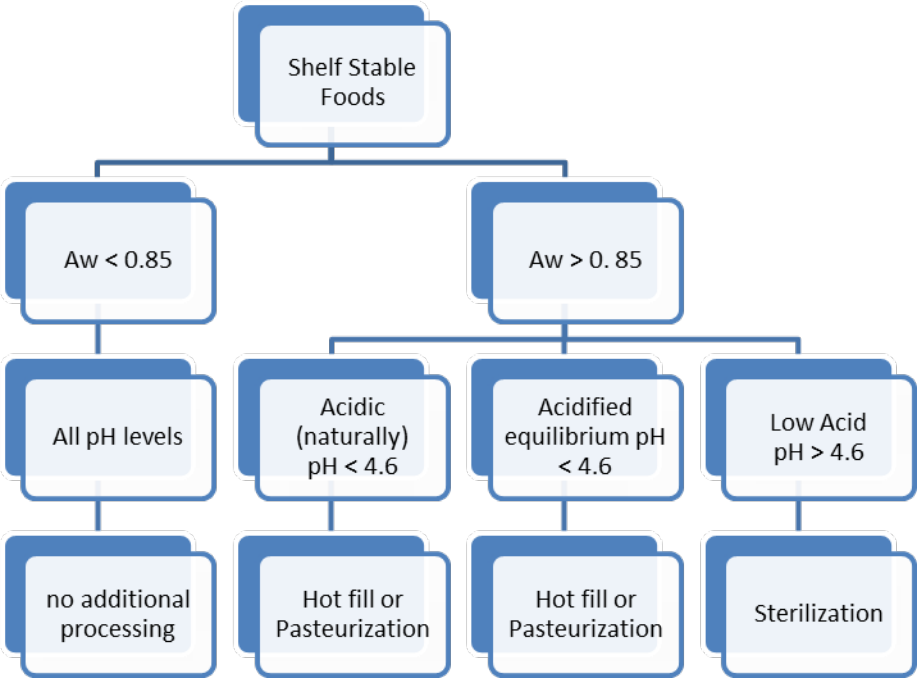


Figure 2.3.2. Categorization of Shelf Stable Foods (MacNaughton, 2008)

Thermal processing is defined as any combination of time and temperature required to produce a food product that is free from microbial organisms and spores that are of health concern, especially C.bot (Tucker & Featherstone, 2011). Selecting the right thermal processing technique is a complicated process as each thermal processing method varies in severity (Awuah, Ramaswamy, & Economides, 2007). Thermal processes or techniques vary in time and temperature depending on the composition of the food product which is set to be processed. The right time and temperature for a thermal process are not only important to ensure a product is safe but also to maintain a product's quality (Awuah, Ramaswamy, & Economides, 2007). Too little processing time or too low of process temperatures may lead to a product that is not considered (MacNaughton, 2008). Awuah et al. (2007), suggest that in contrast, despite ensuring a safe product has been produced, exposure to too high elevations of heat or elongated periods during a process can have detrimental effects on the quality of a product (Awuah, Ramaswamy, & Economides, 2007). Two of the most common thermal processing techniques are pasteurization, which is used on food products with an

A_w > 0.85 and pH < 4.6, and sterilization (Ultra High Temperature (UHT) heating, retorting, or aseptically) on food products with an A_w > 0.85 and pH > 4.6 (Minas, Tanou, & Molassiotis, 2018). Pasteurization is categorized as a mild heat treatment in which the temperature is no greater than 212°F or 100°C for a set period (Tucker & Featherstone, 2011). Pasteurization increases the shelf-life of foodstuffs by reducing microorganisms associated with spoilage, eliminating pathogenic organisms, and by deactivating enzymes (Man, 2015). Predominately pasteurization takes place in-container (Fellows 2009a). Unlike in-container pasteurization, in which the container and the food product are heated at the same time, the hot fill pasteurization method is the act of taking pre-pasteurized, hot food products and injecting them into a container, sealing them immediately, and implementing a hold to ensure the creation of a safe product occurs (Black & Barach, 2015). Using this method, the hot, pasteurized food product, sterilizes the container as it enters and is held. It is important to note that hot filling as a thermal process only destroys vegetative microbes not thermophilic (heat resistant) spores, like that of C.bot. The hot fill method is considered a mild thermal process. Meaning it does not exceed temperatures of 212°F or 100°C during heating, has shorter hold times, and is only able to increase a food-products shelf-life (Black & Barach, 2015). Pasteurization methods result in little quality degradation after processing. Typically, it is utilized when processing liquid products with acidity less than 4.6 including ciders, fruits, fruit juices, and purees (United States Department of Agriculture Food Safety and Inspection Service, 2014). Chutintarasri et al. (2007), identifies peaches, pineapples, nectarines, mangos, and apples, as some of the more common fruits and their formats that are subjected to mild heat treatments, such as pasteurization or hot filling. When exposed to high temperatures biochemical reactions taking place within a fruit accelerate due to an increase in enzymatic activity. Meaning exposure to high heat can affect the color, aroma, texture, and nutritional value of the fruit, which change rapidly

during processing (Black & Barach, 2015). Thus, mild heat treatments are used primarily on liquid, produce products in which quality is the main concern. Unlike the pasteurization and hot fill methods which are mild heat treatments, sterilization using UHT, retorting, or aseptic processes are severe thermal processing methods. When sterilizing using one of these methods, food products are subjected to much higher temperatures for long periods. Retorting is one of the most widely used sterilization techniques globally. This method utilizes pressure and a heating medium such as steam, or water to increase the temperature of products in-container to achieve sterilization of a food product (MacNaughton, 2008). Retorting is conducted in high-pressure vessels to combat the high pressure to which the product and container are exposed. Aseptic thermal processing methods utilize heating mediums similar to that of retorting. During aseptic processing, sterilization of food products and the container in which the product will reside are done separately and combined later in a sterile environment (David, n.d.). Sterilizing using a retort or aseptic process can be severe so this process must be exact carefully studied before performing it to maintain the highest quality product. Regardless of the method of processing chosen, selecting the proper thermal processing method to ensure a product is safe (shelf-stable) and of acceptable quality is dependent upon knowledge of the food product in question, how it is packaged, what is the set schedule of time and temperature the product will be "cooked", and how the product will react during and after heating.

2.4. Browning in Relation to Food Color

The appearance of quality fruits items during shelf-life are subject to degradative change due to potential microbial interactions, physical damage during processing, and nutritional loss as a result of processing. Browning and reactions related to browning are the main limiting factor to the shelf-life of fruit products as consumers see browning to be a negative indication of

quality. Thus, the prevention of browning during processing and storage is of the utmost concern to the produce industry. Browning occurs either enzymatically or non-enzymatically (Terefe, Buckow, & Versteeg, 2014; Wu, 2014). Detection of browning pigments can be measured utilizing spectrometric absorbance at 420 nm to determine a Browning Index and by colorimetric parameters *L*, a*,* and *b** and total color difference (ΔE*) Garza, Ibarz, Pagan, & Giner, 1999; Saura, Vegara, Martí, Valero, & Laencina 2017). Cámara et al. (2003), also determined that intermediates of browning pigments associated with non-enzymatic intermediate molecules can be detected spectrometric absorbance at 443nm.

In 1996, Hunter labs purposed the *L*, a*, b** scale to quantify and measure food color; yet using the CIE *L*a*b*,* or CIELAB color scale to measure and quantify foods is more commercialized since its origin in 1976 (Hunter Lab 2012). Utilizing the Opponent-Color Theory which assumes the human eye sees colors in pairs of opposites or opposing colors, both scales are displayed as one cubic space, composed of four planes on which opposing colors are situated (Krantz, 1975). In the color space created, opposing colors are represented as *L*, a*,* and *b**. *L** represents opposing light and dark colors and has a scale ranging from 0-100, where dark values range from 0 to 50 and light values are 51-100. *a** represents the color range from red to green color and *b** represents the colors yellow to blue. Unlike the *L** value which is only positive numbers, *a** and *b** values may be positive or negative ranging from -100 to +100. The more positive numbers mean more red or less green in coloration for the a* scale and more yellow or less blue on the b* scale. This color space as described by HunterLab can be seen below in Figured 2.4.1 (HunterLab, 2012). Although not calculated and analyzed in this research ΔE* (total color difference), Hue angle (h°), and Chroma can be useful when analyzing the color change in foods. ΔE* (total color difference) is used to analyze variations of colors in food products like fruit pulps

and purees by comparing *L*, a*,* and *b** (Garza, Ibarz, Pagan, & Giner, 1999). Hue angle and Chroma use *a**, and *b** values to quantify saturation indices of a specific color to determine ripeness (Gorny, Hess- Pierce, & Kader, 1998; Cáceres, Díaz, Shinya, & Infante, 2016). According to Gorny et al. (1998), the *L** value (a measure of lightness to darkness) can be indicative of the intensity at which browning has occurred in fruits like peaches and nectarines. Skrypec et al. (2021), studied oxygen scavenging films and how they can affect the rate of browning in peach puree during a twenty-one-week shelf-life period. Utilizing initial colorimetric values *L*, a*,* and *b** versus the final colorimetric values of *L*, a*,* and *b** from samples this study found that the L* value decreased over the shelf-life study and is can an indicative colorimetric value when studying browning (Skrypec, Doh, & Whiteside, 2021. Cáceres et al. (2016), examined the internal flesh browning of peaches when exposed to air and found that there was an increased correlation between ΔL* and browning and that ΔL* greater than or quality of 4.7 can be noticed by the human eye. The research performed by Skrypec et al. (2021), and Gorny et al (1998), agree and further affirms previous research on the *L** value regarding browning.

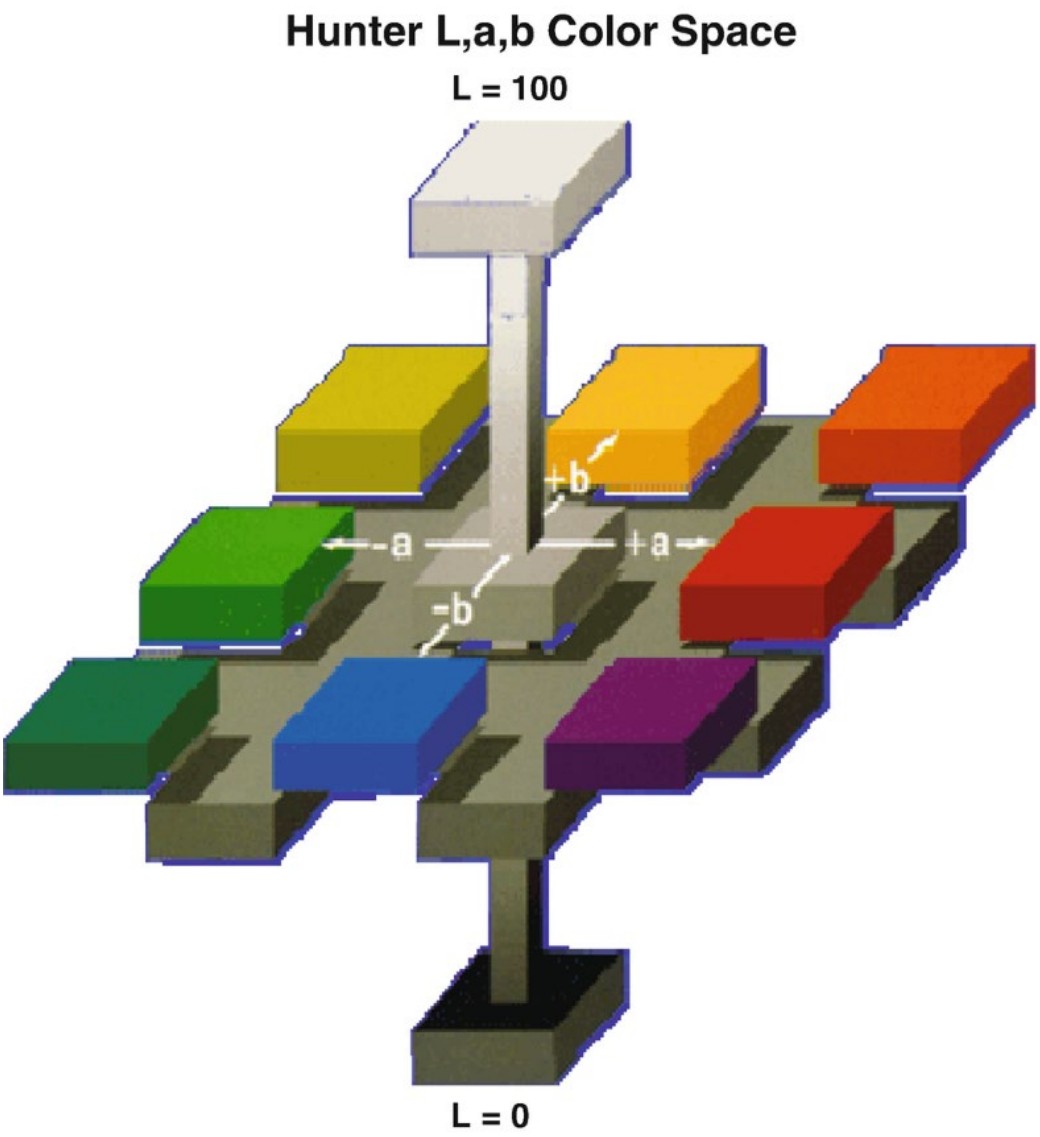


Figure 2.4.1 Representation of the Hunter L, a, b and CIELAB cubic color space (HunterLab, 2012).

Enzymatic browning of fruit is a result of oxidation reactions taking place within its biochemical composition. More specifically, enzymatic browning is caused by oxidation reactions leading to the breakdown of phenols in fruit. In fruits, enzymatic browning can lead to nutritional loss and the loss of organoleptic properties including color, flavor, and aroma (Singh, B., Suri, Shevkani, Kaur, Kaur, & Singh, N., 2018). The loss of organoleptic properties flavor and color has most closely been attributed enzymatic activity of polyphenoloxidase (PPO), peroxidase (POD),

lipase via the oxidation of carotenoids, enzymatic browning, and tyrosinase (Aquino-Bolaños, & Mercado-Silva, 2004). Nutritional loss in fruits can result from interactions involving PPO, POD, Thiaminase, and ascorbic acid oxidization (Skrypec, Doh, & Whiteside, 2021; Terefe, Buckow, & Versteeg, 2014). Post-harvest physical and mechanical damage to the flesh of fruit during storage and processing can increase the rate at which these reactions occur, especially that of enzymatic browning (Tinello & Lante, 2018; Aquino-Bolaños, & Mercado-Silva, 2004). Both physical and mechanical damage will cause cells with a fruit's flesh to separate allowing polyphenol substrates to be released for enzymatic activity. When polyphenol substrates are released enzymes such as PPO or POD will initiate enzymatic (oxidative) browning (Toivonen & Brummell, 2008). It is important to note that oxygen and copper must be present to allow PPO to react and start the enzymatic browning process (Singh, B., Suri, Shevkani, Kaur, Kaur, & Singh, N., 2018). When oxygen is present, enzymatic browning is a two-step reaction initiated by PPO. The first reaction started by the PPO enzyme is the hydroxylation of monophenols to diphenols. Hydroxylation is achieved by adding a hydroxyl (OH) group to any phenol ring present this addition results in the creation of a diphenol which is a colorless product (Whitaker, & Lee, (1995). Zeece, n.d.). The second reaction is the oxidation of diphenols into quinones. The creation of quinones is created via the oxidation of hydroxyl groups to carbonyl groups (C=O) (Zeece, n.d.). Quinones can be further utilized in a cascade of polymerization reactions leading to the formation of melanin (Singh, B., Suri, Shevkani, Kaur, Kaur, & Singh, N., 2018; Al-Amrani, Al-Alawi, & Al-Marhobi, 2020; Qi, Liu, J., Liu, Y., Yan, Wu, Li, & Ren, 2020; & Zeece, n.d.). Figure 2.4.2 displays this reaction. Melanin is a pigment that absorbs light thereby allowing it to reflect dark or brown colors. Accumulation and retention of melanin in fruits are what is known as enzymatic browning (Singh,

B., Suri, Shevkani, Kaur, Kaur, & Singh, N., 2018; Al-Amrani, Al-Alawi, & Al-Marhobi, 2020; Qi, Liu, J., Liu, Y., Yan, Wu, Li, & Ren, 2020; & Zeece, n.d.).

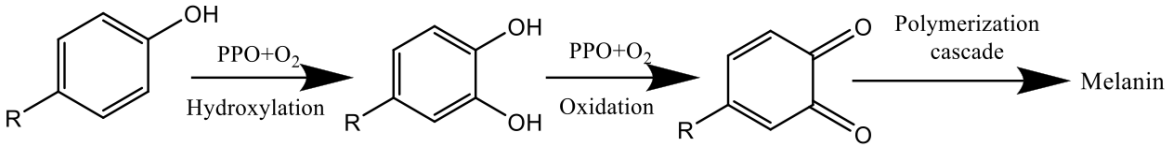


Figure 2.4.2 Representation of the Enzymatic Browning Reaction

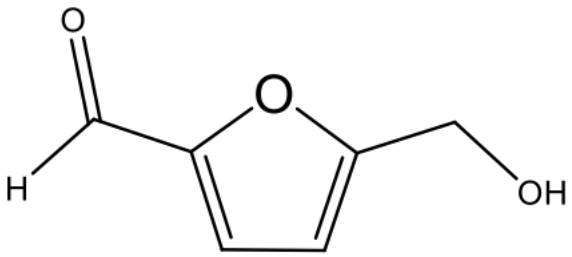
Research suggests that enzymatic browning reactions resulting from reactions involving PPO, POD, and tyrosinase have been seen to be more active at a more neutral pH (McEvily,Iyengar, & Otwell 1992; Rico, Martin-Diana, Frias, Barat, Henehan, & Barry-Ryan, 2007; Zeece n.d.). Utilizing this knowledge, the fruit industry learned that adjusting the pH concentration of pureed, juiced, and sliced fruits to content no greater than 4 will help mitigate enzymatic browning (Rico, Martin-Diana, Frias, Barat, Henehan, & Barry-Ryan, 2007). Lowering pH concentrations of fruit puree or juice is typically done with the addition of acids such as citric acid, ascorbic acid, and fumaric acid (Martinez & Whitaker, 1995). The addition of these acids or acids similar can lead to the removal of the copper ions that are required for PPO, POD, and tyrosinase to react with phenols (Martinez & Whitaker, 1995; Zeece n.d). In addition to pH, controlling a food item's exposure to oxygen, and manipulating the metal ions required to react such as copper can limit enzymatic browning reactions rates (Skrypec, Doh, & Whiteside, 2021; Zeece n.d.). Oxygen exposure can be eliminated or limited by using modified atmospheric packaging (MAP) while the addition of chelating agents or acids can be used to manipulate metal ions associated with enzymatic browning (Zeece n.d.; Skrypec, Doh, & Whiteside, 2021). One of the most widely used MAP techniques to control oxygen and therefore limit the rate of enzymatic

browning is the implementation of an Oxygen scavenging film. Oxygen scavenging films work to provide a barrier between a fruit product from outside oxygen as well as by reducing the amount of free oxygen that may have entered a package during filling. Dey et al. (2019), suggest that oxygen scavenging films in combination with atmospheric manipulation such as nitrogen can reduce the oxygen content in a "filled" film by 0.5 to 2% by volume. Chelating agents such as Ethylenediaminetetraacetic acid (EDTA) help to control enzymatic browning by binding to metal ions pivotal PPO activity (Zeece n.d). Adding acids to a food product not only limits enzymatic activity related to enzymatic browning reactions by lowering the pH but also with its ability to bind (scavenge) to metal ions and oxygen (Zeece n.d). Ascorbate or ascorbic acid (AA) is commonly used as an inhibitor of enzymatic browning as it can lower pH, will bind to oxygen, and chelate metal ions such as copper effectively (Zeece n.d). AA is well known as the universal antioxidant for its effectiveness to reduce oxidation reactions, involvement in changing redox potentials, and the ability to eliminate free radicals ((Skrypec, Doh, & Whiteside, 2021).

Unlike enzymatic browning reactions which utilize oxygen, non-enzymatic browning or NEB reactions do not depend on oxygen to occur. Discoloration resulting from NEB reactions occurs over the life span of a fruit. NEB reactions can occur via many pathways including Maillard browning, caramelization, and chemical oxidation of phenols (Manzocco, Calligaris, Mastrocola, Nicoli, & Lerici, C. R. 2000; Garza, Ibarz, Pagan, & Giner, 1999). The rate at which NEB reactions take place is dependent upon temperature, time, water activity, and the concentration of soluble solutes (sugars or amino acids) within the fruit or a reformatted fruit item itself (Manzocco, Calligaris, Mastrocola, Nicoli, & Lerici, C. R. 2000). Thus, NEB reactions and the ability to manipulate them are critical when creating shelf-stable food items via processing. Maillard browning is widely considered to be of utmost importance when processing fruit. Maillard

browning is initiated when the aldehyde of a reducing sugar interacts with an amine group from a protein or amino acid, both are present in the composition of fruits. The interaction between these two yields a glycosylamine that will rearrange via Amadori rearrangement into an Amadori derivative. The resulting Amadori derivative can be polymerized in a cascade of reactions from pyrroles, pyrazines, and dark (brown) melanoidin pigments. When formed all of these can create a change in nutritional, flavor, aroma, and color compounds with fruit due to the loss of reducing sugars and amines (Garza, Ibarz, Pagan, & Giner, 1999). Color deterioration as a result of NEB reactions, like Maillard browning, have extensively studied to determine how they can be manipulated to improve the creation of shelf-stable fruit items. As previously mentioned, the addition of acids is a method to mitigate the enzymatic browning of food. However, acids such as AA that may already be in or can be added to a shelf-stable fruit product under anaerobic conditions provided by pouches, cans, cups, and jars during processing can spontaneously transform or degrade into 3-deoxypentosulose, furfural, 5-hydroxymethylfurfural (HMF) (Toivonen & Brummell, 2008). 3-deoxypentosulose, furfural, and HMF are intermediates of NEB (Maillard) reactions that have shown the potential to polymerize into melanoidin pigments like those present in the Maillard reaction reducing color (Skrypec, Doh, & Whiteside, 2021). Pham et al. (2019) examined NEB in citrus fruit (orange) juice, from this study it was determined that the spontaneous anaerobic degradation of AA and the dehydration of reducing sugars via acid hydrolysis into glucose to fructose are highly correlated to fruit juice browning, as a result, the production of browning intermediates such as furfural and HMF associated with them. HMF, shown in Figure 2.4.3, is a cyclic aldehyde produced as an intermediate to the Maillard reaction as 3-deoxyosone is broken down and to acid-catalyzed degradation of hexose sugars. Commonly HMF has been studied regarding honey, yet it is ubiquitous in any food products that are heated

and contain sugars like fruit purees (Shapla, Solayman, Alam, Khalil, & Gan, 2018). HMF can be utilized to determine the effect of heating on food items that will undergo thermal processing such as fruit purees. Thus, HMF quantification can be utilized to characterize the effects storage duration and thermal processing temperatures will have on food products with low acidic concentrations and high content of sugars.



Hydroxytmethylfurfural (HMF)

Figure 2.4.3 HMF Molecular Structure

2.5. Effect of Thermal Processing and Storage on Reformatted Peaches

Extending the shelf-life of reformatted peaches can be done by way of thermal processing. Tucker et al. (2011), suggests that due to the pH of peaches being a low range (3.6 to 4.1) reformatted peaches such as puree require minimal pressing techniques to achieve shelf stability. In contrast, when high-temperature processing methods are used to process peach puree, they can lead to a degradation of quality parameters such as nutritional content (vitamins and minerals), appearance, texture, and flavor. Before processing a pureed peach, blanching may be used to mitigate the degradation of color degrading enzymes that may be increased during mild thermal processing. Blanching is the act of applying mild heat (less than 100 ˚C) to peaches that have been sliced or cut before processing. This process must be done with precise timing to limit

any detrimental effects of heating on the peach puree quality (Rico, Martin-Diana, Frias, Barat, Henehan, & Barry-Ryan, 2007). Quantifiable peach quality parameters include colorimetric parameters (ΔE*, ΔL*, *L*, a*, b*,* and h°), pH, soluble solids content (SSC), spectrophotometric parameters (BI and HMF), and organoleptic parameters (sugars, organic acids, carotenoids, and antioxidants) (Skrypec, Doh, & Whiteside, 2021). All of these parameters can vary depending on the year, cultivar, harvest conditions, and maturity level of the peaches. Thus, it is important that quality parameters such as the aforementioned be checked before storage and processing as well as after to ensure that quality is maintained, and NEB reactions have been mitigated.

Quality of appearance is critical to the consumer. Quantifying the color of peach puree has been extensively studied especially colorimetric values regarding the *L** value (light to dark), *a** value (red to green), *b** value (yellow to blue), Chroma (C*), Hue angle (h°), ΔE*, and ΔL*. Changes in these colorimetric parameters after thermal processing of peach puree occurs via NEB reactions as the thermal processing will occur in an anaerobic environment. Garza et al. (1999) examined the effects of differing pasteurization temperatures and times on the colorimetric values of peach puree. From this study, it was concluded that as the time and temperature of pasteurization increased both the *L** and *b** values decreased in the puree while the *a** value increased Garza et al. (1999), examined the effects of differing pasteurization temperatures and times on the colorimetric values of peach puree. From this study, it was concluded that as the time and temperature of pasteurization increased both the *L** and *b** values decreased in the puree while the *a** value increased Although not used in this research C*, h°, and ΔE* are also important colorimetric parameters that have been quantified in previous research in regard peach puree. Research suggests that h° changes towards the red and blue axes as heating time increases (Gorny, Hess- Pierce, & Kader, 1998). Oliveira et al. (2014), also studied peach puree and found that C*,

h°, and L^* decreased as storage time, processing temperature, and processing time increased. An increase in ΔE^* as a result of an increased in storage time and the temperature has been demonstrated to corollate to an increase in BI regarding NEB reactions. In addition to the quantifiable colorimetric parameters associated with color change, organoleptic changes in anthocyanins, sugars, acids, and carotenes can be quantified and correlated to color change in peach puree as well other fruits in vegetables (20). Carotenoids provided are not only considered as color compounds for fruits and vegetables like the peach, but they also provide protection against oxidative stress (Skrypec, Doh, & Whiteside, 2021). In a 2012 study by Oliveira et al., pasteurization of peach puree was found to reduce the total carotenoid content up to 65% of its normal standard due to cell wall rupture leading to isomerization of carotenoids. This study also suggested that storage can increase anthocyanin and carotenoid concentration. In contrast, thermal processing methods have been noted to increase the availability of anthocyanin and carotenoid resulting in a high risk of degradation from browning reactions (Tierno, Hornero-Méndez, Gallardo-Guerrero, López-Pardo, R., & de Galarreta, J. I. R. (2015). The degradation of anthocyanins and carotenoid can be manipulated utilizing to control oxidative browning by using MAP. Loss of color, flavor, and nutritional values in foods as a result of non-enzymatic browning reactions has been shown to increase as storage time and processing temperature are increased. All these losses in quality can be attributed to isomerization and degradation of carotenoids and anthocyanin due to NEB reactions.

Polyphenols, which have high antioxidant properties, can also be connected to flavor, color, and nutritional values in fruits and vegetables. Polyphenol degradation of color due to browning has been attributed to a decrease in consumer perception of produce items that are considered to be shelf-stable (Lavelli, Pompei, & Casadei, 2008). Hong et al. (2004), found that

within the first three months of storage of shelf-stable peaches polyphenol levels can decrease up to 43%. Additionally, Cropotova et al. (2016), discovered that the oxidation of polyphenol leads to an increase in antioxidant capacity which thereby directly correlates to an increase in the formation of intermediates of NEB reactions such as furfural and Hydroxymethylfurfural (HMF).

Content or concentration of sugars and acids and how they are related are utilized as parameters of flavor quality (Minas, Tanou, & Molassiotis, 2018). Depending on the concentration of sugar and acids or the ratio of the two a peach may be considered sweet or sour. The concentration or content of the sugars and acids can also be used to determine the flavor in other produce items as well. Concentration or ratio of sugars and acids not only affects flavor but can also affect the texture and aroma of a peach (Skrypec, Doh, & Whiteside, 2021). Although there are many sugars within a peach, the primary sugar or the sugar in the highest concentration is sucrose (Byrne, Nikolic, & Burns, 1991). Other sugars in peaches include glucose, fructose, and sorbitol (Cantín, Gogorcena, & Moreno, 2009). The concentration of sugars is known as Soluble solids content or SSC. SSC is a measure of sucrose content in a solution and is quantified most commonly as °Brix. 1°Brix is equivalent to 1 g of sugar per 100 mL solution (Hidayanto, Tanabe, & Kawai, 2010). Acids are typically measured in contrast to sugars within the food industry. For peaches commonly seen organic acids include malic, citric, and quinic acid (David, Luh, & Marsh, 1956). Malic acid is the predominant acid seen in peaches. Measuring the organic acid content of a peach puree is typically quantified through the titratable acidity (TA) in g malic acid L-1 (David, Luh, & Marsh, 1956). It is important to note that the type, concentration, and ratio of sugar and acid can vary between different cultivars, per year, per season, time or season, and geographical location.

Before thermal processing, it is not uncommon for additional sugar to be added to reformatted peach products such as puree (Giangiacomo, Torreggiani, & Abbo, 1987). Sugar added dry or in the form of syrup is utilized as osmotic pretreatments before processing to mitigate a decrease in quality associated with sugar including color, flavor, texture, and to preserve vitamin C during processing and storage (Giangiacomo, Torreggiani, & Abbo, 1987). Acids can be added in a similar way to mitigate the quality degradation of peaches during processing and storage. Brooks et al. (1993) and Saura et al. (2017) both studied peaches and how sucrose levels respond to increased storage time. From these studies, it can be concluded that sucrose decreases as a response to an increase in storage time, yet an increase in fructose and glucose was seen as storage time increases. It is important to note that the observed increase in glucose and fructose are seen as a response to storage time is pivotal as both sugars can be reduced and participate in the formation of Maillard browning and its intermediates (Ashoor, & Zent (1984).

Additionally, thermal processing can influence the intermediates of non-enzymatic browning like HMF. Moniruzzzaman et al.(2013), noted that the average HMF concentration is 35.98 mg/kg in Malaysian honey when stored at 4-5 ˚C for two months (Moniruzzaman, Khalil, Sulaiman, & Gan, 2013). While Khalil found that the average HMF concentration to have a high of 1139.95 mg/kg in Malaysian honey when stored at 25-30 ˚C for more than a year (Khalil, Sulaiman, & Gan, 2010). These studies demonstrate that increasing storage time and temperature can affect the amount of HMF in a product. Research also suggests that excess in heating temperature and time, low pH, and high moisture content can increase the rate at which HMF is formed ((Moniruzzaman, Khalil, Sulaiman, & Gan, 2013; Khalil, Sulaiman, & Gan, 2010).

2.6 Research Objective

The objective of this research was to determine the effect of thermal processing (pasteurization) at varying temperatures with varying hold-times can have on the rate of browning reactions of peach puree from three different cultivars of peaches. Two freestone (Big Red and August Lady) and one clingstone (Venture) peach cultivars were used during a six-week accelerated storage. Analysis of visual quality and biochemical properties of the peach puree included colorimetric parameters (*L**, *a**, *b*),* °Brix (SSC), pH, and absorbances by way of spectrophotometry at 443 nm to determine HMF concentration and spectrophotometry at 420 nm to browning index (non-enzymatic browning). The results will help determine a more suitable thermal processing method to extend peach puree shelf-life while conserving and providing the utmost quality.

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CHAPTER THREE

MATERALS AND METHODS

3.1 Peach Collection Puree Preparation

Peaches (*Prunus Persica*) were donated from Palmetto Processing Solutions, a division of Titan Farms located in Ridge Spring, SC. Three peach varieties were collected on Mondays of differing weeks to be processed the following Tuesday. The first variety to be collected was Big Red (freestone) denoted as "A", August Lady (freestone) denoted as "B" was collected second, and Venture (clingstone) denoted as "C" was the third and final peach to be collected. Peaches were stored for 24 hours at 38°F (3.3°C) until the time of processing. The peach cultivar, code, and date collected are shown in Table 3.1.1.

Table 3.1.1. Cultivar and Corresponding Code

Cultivar	Code	Date Collected
Big Red (Freestone)	A	07/06/2021
August Lady (Freestone)	B	07/13/2021
Venture (Cling Stone)	C	08/04/2021

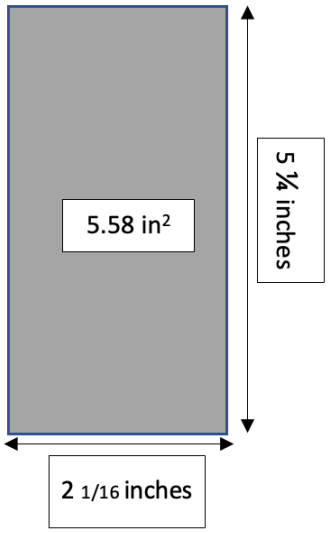
Peaches were washed with warm water, peeled using a hand-held peeler, destoned by-hand, diced using a knife, and then pureed in a Waring Commercial Xtreme blender (MANUFACTURER). Approximately 1000 g of diced peaches were added to the blender during the puree making process for each thermal run. Ascorbic acid was added at 0.5 g/kg fruit weight. The blender was run at the high setting (45,000 RPM motor speed) for 30 seconds to get a consistent puree (MANUFACTURER). After processing the puree, filling, packaging, and sealing took place.

3.2 Packaging, filling, and Sealing

A foil laminate film was used to create the pouches necessary for this experiment. The pouch film structure was comprised of 0.48-gauge Polyethylene Terephthalate (PET), 0.35-gauge Foil, 0.60-gauge Biaxially Oriented Nylon (BON), and 3.25 gauge Cast Polypropylene (PP) (PET/Foil/BON/PP). Rolls of the foil laminate were used in a Three-Side Seal Bag Making Machine (Shanghai Gaoqin) to create the pouches. Approximately 1,800 pouches were made for the project. The machine was run with a base sealing temperature of 135˚C, top bar side sealing temperature of 145˚C, and a bottom bar side sealing temperature of 125˚C. To ensure the pouches created would withstand filling and thermal processing conditions, they were tested randomly throughout production using a pneumatic seal tester (MANUFACTURER) to ensure they withstood at minimum 0.5 Bar (recommended pressure test).

The pouches formed had an interior area of 5.58 in^2 and had an exterior length of 5 1/4 in and width of 2 1/16 in as shown in Figure 3.2.1. Three pouches with Type T thermocouples were created for each oil bath run. This was completed by puncturing a thermocouple wire through the bottom of the pouch opposite of the opening. Then the punctured film and wire were sealed together using epoxy (J-B Weld Steel Reinforced Epoxy). The epoxy was placed in the hole and allowed to cure for 24 hours before the pouch was used.

Figure 3.2.1. Package Dimensions



After the pouches were produced and the puree was made 14 g of puree was inserted into pouches via pipette. Then seal area was then cleaned, sealed as previously described and ready to be thermally processed and stored accordingly. This process would be repeated with all cultivars.

3.3 Thermal Processing and Storage

Thermal processing of the puree consisted of an in-package, batch pasteurization process using a WiseCircu® WCH-12 high temperature oil bath (MANUFACTURER). The heating medium inside the oil bath was canola oil. A modified test tube rack was used to hold the pouches during processing as to ensure each pouch was heated adequately at an equal rate and in a consistent location for each batch. The delivered thermal processes consisted of a matrix of processing temperatures and hold times as shown in Table 3.3.1. Processing temperatures were 70˚C, 80˚C, 90˚C, and 100˚C and processing hold times were 1, 3, 5, and 10 minutes. One sample was left unprocessed and stored at 0˚C as a control variable which was not heated. The control variable was created to correspond with each variety at processing temperature to be used as a comparison to heated variables example each week.

After the pouches were heated to the desired temperature and hold time, they were placed into an ice water bath for 5 minutes to cool and prevent further browning reactions as a from taking place. After 5 minutes, the samples were either set aside for testing or moved into storage. Pouches for testing were set out at room temperature for 30 minutes before being analyzed, these were Week 0 samples. Pouches for storage, were held for 6 weeks in a Caron Environmental Chamber at accelerated conditions of 35˚C and 50% RH (Relative Humidity). Analytical testing of stored pouches occurred after 2, 4, and 6 weeks in accelerated conditions. Prior to testing, these stored pouches sat out at room temperature for approximately one hour before being analyzed. This process was repeated for all varieties and their designated temperatures and hold time (A, B, C).

Table 3.3.1. Cultivar Code, Temperature, and Hold Time

Code	Temperature (°C)	Hold Time (min)	Code	Temperature (°C)	Hold Time (min)	Code	Temperature °C	Hold Time (min)
A	70	0	B	70	0	C	70	0
A	70	1	B	70	1	C	70	1
A	70	3	B	70	3	C	70	3
A	70	5	B	70	5	C	70	5
A	70	10	B	70	10	C	70	10
A	80	0	B	80	0	C	80	0
A	80	1	B	80	1	C	80	1
A	80	3	B	80	3	C	80	3
A	80	5	B	80	5	C	80	5
A	80	10	B	80	10	C	80	10
A	90	0	B	90	0	C	90	0
A	90	1	B	90	1	C	90	1
A	90	3	B	90	3	C	90	3
A	90	5	B	90	5	C	90	5
A	90	10	B	90	10	C	90	10
A	90	0	B	90	0	C	90	**0**
A	100	1	B	100	1	C	100	1
A	100	3	B	100	3	C	100	3
A	100	5	B	100	5	C	100	5
A	100	10	B	100	10	C	100	10

3.4 Analytical Methods

Analytical tests were performed the day of thermal processing of the pouches for Week 0 samples and after set intervals of storage for Week 2, Week 4, and Week 6 samples. Six pouches of each variable were evaluated in triplicate each for color, Browning Index, pH, Brix, and HMF measurement.

3.5 Color Determination

Samples were analyzed immediately after opening the pouch to minimize change due to light exposure and air. The color of the peach puree samples was measured using a Hunter Labs Aeros Spectrometer (Reston, VA), which quantified the color in the CIELAB color space as L*, a*, and b* values (Adekunte et al., 2010). The 25 g of peach puree was poured into a 90 mm x 15 mm polystyrene petri dish and analyzed under the spectrometer.

3.6 Brix Determination

Brix values were measured using an Atago Pocket Brix-Acidity Meter (MANUFACTURER). This was done by placing approximately 0.3 mL onto the sensor, covering it, and measuring the Brix.

3.7 pH Determination

The pH was measured using a digital Orion Star A214 pH/ISE meter (Thermo Fisher Scientific, Waltham, MA) with a glass electrode.

3.8 Browning Index

Browning index (BI) was measured using a spectrophotometric method with modifications (Klim & Nagy, 1988). BI measurements were performed by adding 5 g of peach puree and 5 ml of ≥99.5% ethyl alcohol into a 15 mL Falcon tube. The tube was vortexed for 1 minute using a Fisher-brand Touch- mixer (MANUFACTURER). Then the tubes were centrifuged for 30 minutes at approximately 3500 rpm at 23˚C using an IEC HN-SII Centrifuge (MANUFACTURER). 1 mL of the supernatant was then pipetted into glass cuvettes and measured using a Genesys 10S UV-Vis Spectrometer (MANUFACTURER). The spectrophotometer was calibrated using water and absorbance values were measured at 420 nm.

3.9 Hydroxymethylfurfural (HMF)

Hydroxymethylfurfural (HMF) content was measured using a spectrophotometric method as described by (Camara et. al, 2003). This method measured a thiobarbituric acid (TBA) reaction at 443 nm. 5 mL of ethyl alcohol (96%) and 2.5 g of sample were added to a 15 mL Falcon tube and vortexed using a Fisher-brand Touch-Mixer (MANUFACTURER). The tube was then centrifuged for 20 minutes at 2,500 RPM using a IEC HN-SII Centrifuge (MANUFACTURER). 2 mL of the supernatant was then removed and added to a new Falcon tube with 2 mL of 10% trichloroacetic acid (TCA) and 2 mL of 0.3% TBA. The samples were then placed into a Cole-Parmer StableTemp water bath (MANUFACTURER) for 20 minutes at 70˚C. The samples were then removed from the water bath and allowed to sit at room temperature for 10 minutes. The samples were then measured for absorbance at 443 nm with a Genesys 10S UV-Vis Spectrometer (MANUFACTURER).

3.10 Statistical Analyses

For each combination of cultivar, temperature and hold time (Table 3.3.1), an Analysis of Variance (ANOVA) was used to compare the means of the seven variables among the four different shelf-life times. The three pouches per combination were used as the replications in the ANOVA. Fisher's protected least significant test was used to make specific comparisons among the four means.

The data for the seven variables were analyzed in in the original scale and normalized by dividing by the initial value collected at Week 0 of testing prior to storage. This allowed relative changes to be detected within any given variable. Normalized values were reported as L^*/L_0^*, a^*/a_0^*, b^*/b_0^*, BI $((A_{420}) /(A_{420_o}))$, and HMF $((A_{443}) /(A_{443_o}))$, pH, and Brix° (SSC). For the normalized data, a value of 1 indicates no change, a value above 1 indicates an increase, and a

value below 1 indicates a decrease relative to the initial Week 0 value. All statistical calculations were performed using JMP Pro 14 Statistical Software (SAS Institute, Inc, Cary, NC). P-values less than 0.05 were considered evidence of statistical significance.

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CHAPTER FOUR

RESULTS AND DISCUSSION

This study was intended to determine the influence of different thermal processing temperatures and time on the shelf-life quality of pasteurized peach puree during storage. L^*, a^*, b^*, BI (A_{420}), and HMF (A_{443}) variations during six weeks of accelerated storage were observed and relatively compared. Variations were expected due to the nature of batch processing. Thus, the data were normalized using value variations for each testing period, Week n, compared to the initial value collected at Week 0 of testing before storage. This allowed relative color changes to be detected within any given variable. Data were reported as L^*/L_0^*, a^*/a_0^*, b^*/b_0^*, BI ((A_{420}) /(A_{420_o})), and HMF ((A_{443}) /(A_{443_o})), pH, and Brix° (SSC). For the reported data, a value of 1 indicates no change, a value above 1 indicates an increase, and a value below 1 indicates a decrease relative to the initial Week 0 value.

4.1 Color

The CIELAB color space describes color across three axes: L^*, a^*, and b^*. L^* value represents the relative lightness of any given sample and is scaled from 0 (black) to 100(white). The a^* value represents relative redness and is scaled -100 (green) to +100 (red). The b^* value represents relative yellowness and is scaled -100 (blue) to +100 (yellow). During storage, L^*/L_0^*, a^*/a_0^*, b^*/b_0^* were reported and can be seen graphically in Figures 4.1.1, 4.1.2, 4.1. 3, 4.1. 4, 4.1.5, 4.1.6, 4.1.7, 4.1,8, and 4.1.9 and tabularized with significant differences between weeks shown in Tables 4.1.1, 4.1.2, 4.1.3, 4.1.4, 4.1.5, 4.1.6, 4.1.7, 4.1.8, and 4.1.9.

Table 4.1.1. Relative variations across storage at 35°C between hold times for Cultivar A at 70°C, 80°C, 90°C, and 100°C for color parameters L^*/L_0^*.

Code	Temperature (C)	Hold Time	0	2	4	6
A	70	0	1.00 $_{A}$	0.80 $_{D}$	0.83 $_{C}$	0.94 $_{B}$
A	70	1	1.00 $_{A}$	0.92 $_{B}$	0.83 $_{C}$	0.75 $_{D}$
A	70	3	1.00 $_{A}$	0.95 $_{A}$	1.03 $_{A}$	1.04 $_{A}$
A	70	5	1.00 $_{A}$	0.93 $_{B}$	0.90 $_{C}$	0.85 $_{D}$
A	70	10	1.00 $_{A}$	0.92 $_{B}$	0.89 $_{D}$	0.91 $_{C}$
A	80	0	1.00 $_{A}$	0.80 $_{D}$	0.87 $_{C}$	0.91 $_{B}$
A	80	1	1.00 $_{A}$	0.89 $_{B}$	0.86 $_{C}$	0.84 $_{D}$
A	80	3	1.00 $_{A}$	0.90 $_{B}$	0.90 $_{B}$	0.98 $_{A}$
A	80	5	1.00 $_{A}$	0.94 $_{C}$	0.96 $_{B}$	0.91 $_{D}$
A	80	10	1.00 $_{A}$	0.93 $_{B}$	0.90 $_{C}$	0.88 $_{D}$
A	90	0	1.00 $_{A}$	0.89 $_{C}$	0.99 $_{B}$	0.86 $_{D}$
A	90	1	1.00 $_{A}$	0.82 $_{C}$	0.85 $_{B}$	0.71 $_{D}$
A	90	3	1.00 $_{A}$	0.84 $_{D}$	0.87 $_{C}$	0.91 $_{B}$
A	90	5	1.00 $_{A}$	0.79 $_{D}$	0.83 $_{C}$	0.84 $_{B}$
A	90	10	1.00 $_{A}$	0.87 $_{D}$	0.92 $_{C}$	0.94 $_{B}$
A	100	0	1.00 $_{BC}$	1.22 $_{A}$	1.05 $_{B}$	0.99 $_{C}$
A	100	1	1.00 $_{A}$	0.88 $_{B}$	0.86 $_{C}$	0.77 $_{D}$
A	100	3	1.00 $_{A}$	0.93 $_{B}$	0.89 $_{C}$	0.84 $_{D}$
A	100	5	1.00 $_{A}$	0.98 $_{B}$	0.95 $_{C}$	0.85 $_{D}$
A	100	10	1.00 $_{A}$	0.98 $_{B}$	0.93 $_{D}$	0.96 $_{C}$

*Different letters withing the same row indicate significant difference ($p< 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

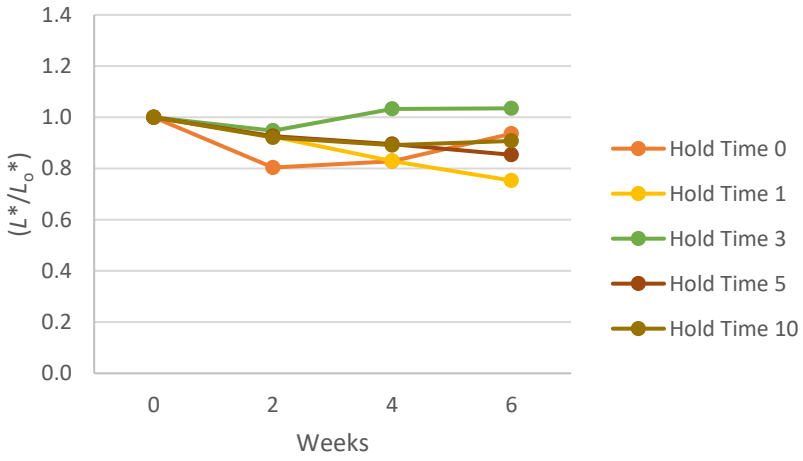
Table 4.1.2. Mean at weeks 0 and 6 for Cultivar A stored at 35°C between hold times at 70°C, 80°C, 90°C, and 100°C for color parameters L^* and ΔL^*.

Code	Temperature (C)	Hold Time	0	6	ΔL^*
A	**70**	**0**	**70.8**	**66.4**	**4.4**
A	**70**	**1**	**71.4**	**53.8**	**17.7**
A	**70**	**3**	**67.8**	**70.2**	**2.4**
A	**70**	**5**	**71.3**	**60.8**	**10.4**
A	**70**	**10**	**70.7**	**64.2**	**6.5**
A	**80**	**0**	**69.4**	**62.9**	**6.5**
A	**80**	**1**	**70.2**	**59.2**	**10.9**
A	**80**	**3**	**69.3**	**68.1**	**1.2**
A	**80**	**5**	**67.1**	**61.2**	**5.9**
A	**80**	**10**	**69.4**	**60.9**	**8.5**
A	**90**	**0**	**68.3**	**58.9**	**9.4**
A	**90**	**1**	**73.3**	**52.1**	**21.3**
A	**90**	**3**	**73.7**	**66.7**	**7.0**
A	**90**	**5**	**77.2**	**65.1**	**12.1**
A	**90**	**10**	**74.1**	**69.9**	**4.3**
A	**100**	**0**	**54.0**	**53.5**	**0.5**
A	**100**	**1**	**70.5**	**54.0**	**16.5**
A	**100**	**3**	**73.5**	**61.6**	**11.8**
A	**100**	**5**	**70.5**	**60.2**	**10.3**
A	**100**	**10**	**60.5**	**57.8**	**2.7**

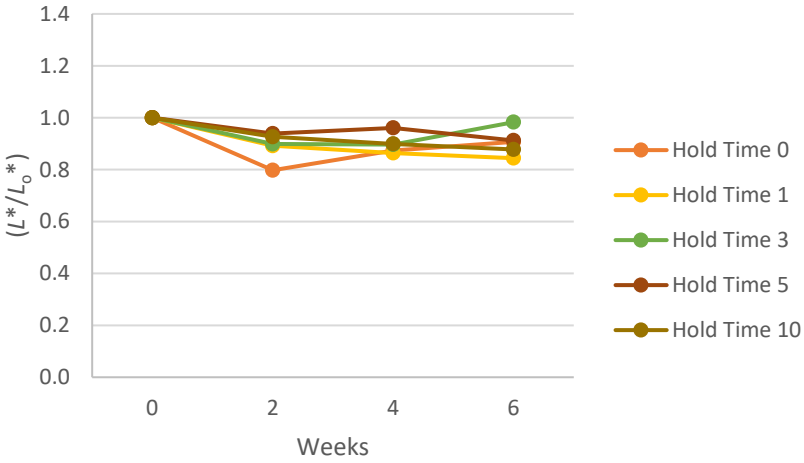
*Different letters withing the same row indicate significant difference ($p< 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

*$\Delta L^* = L_0^* - L^*$

(i)


1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(L^*/L_o^*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

(ii)


1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(L^*/L_o^*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

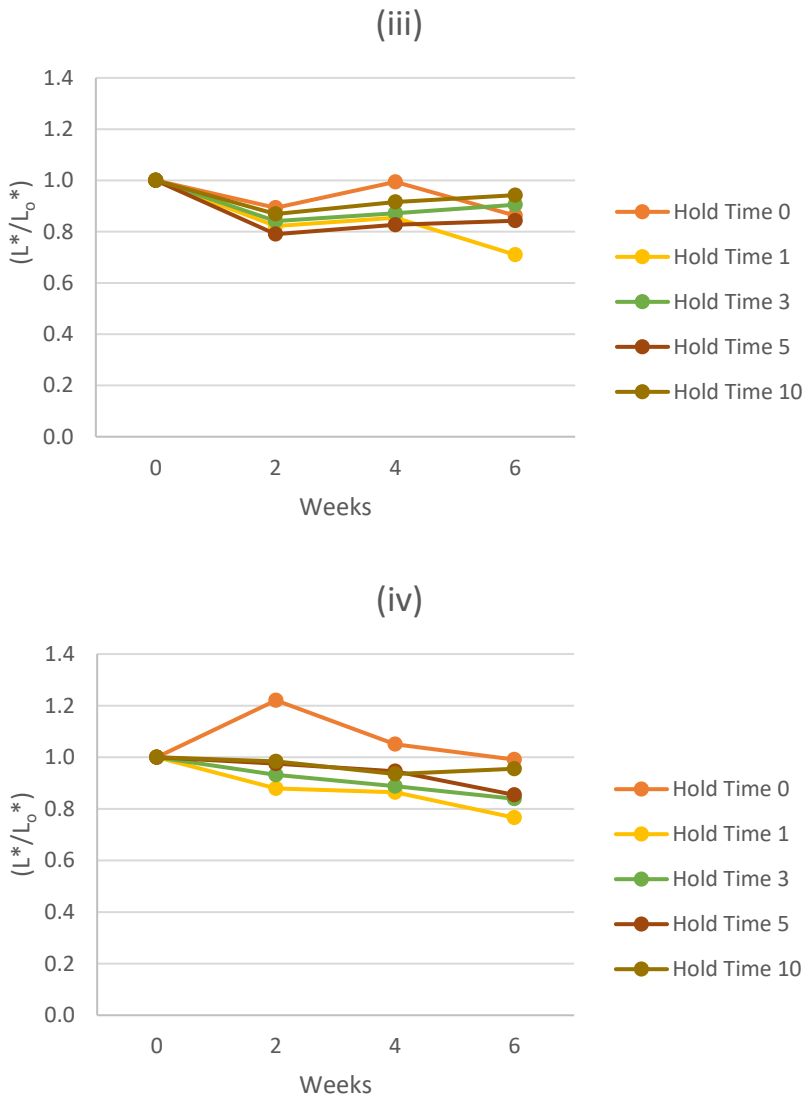
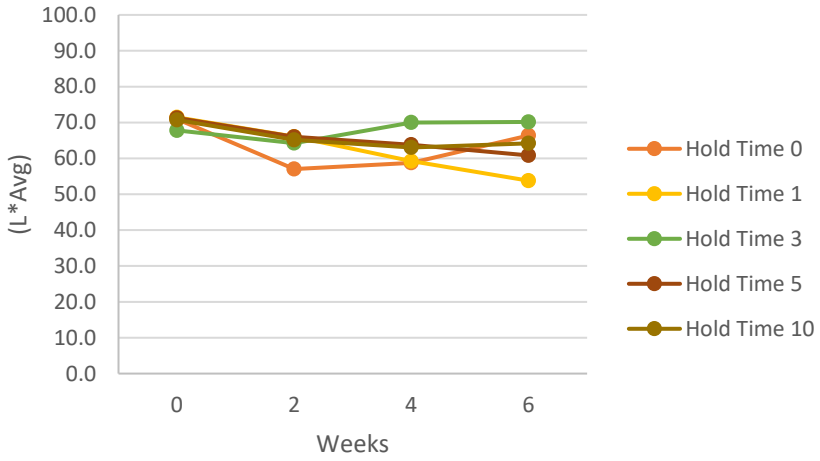
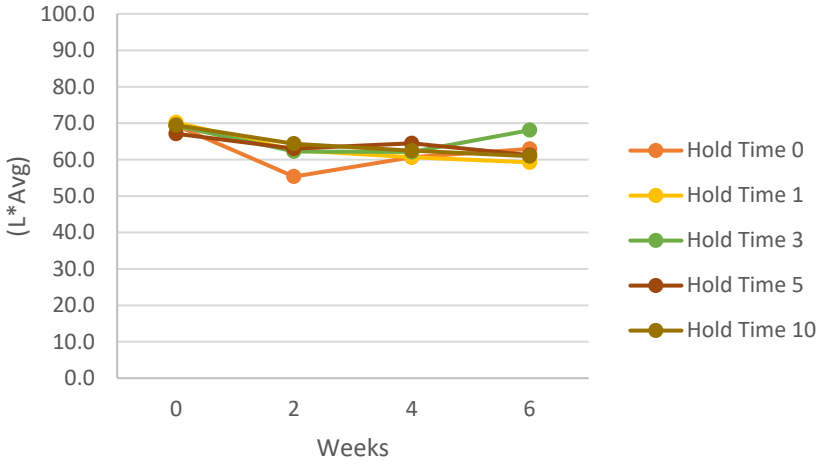


Figure 4.1.1. Relative variations across storage at 35°C between hold times for Cultivar A at 70°C (i), 80°C (ii), 90°C (iii), and 100°C (iv) for color parameters L^*/L_0^*.

(i)


100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
(L*Avg)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

(ii)


100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
(L*Avg)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

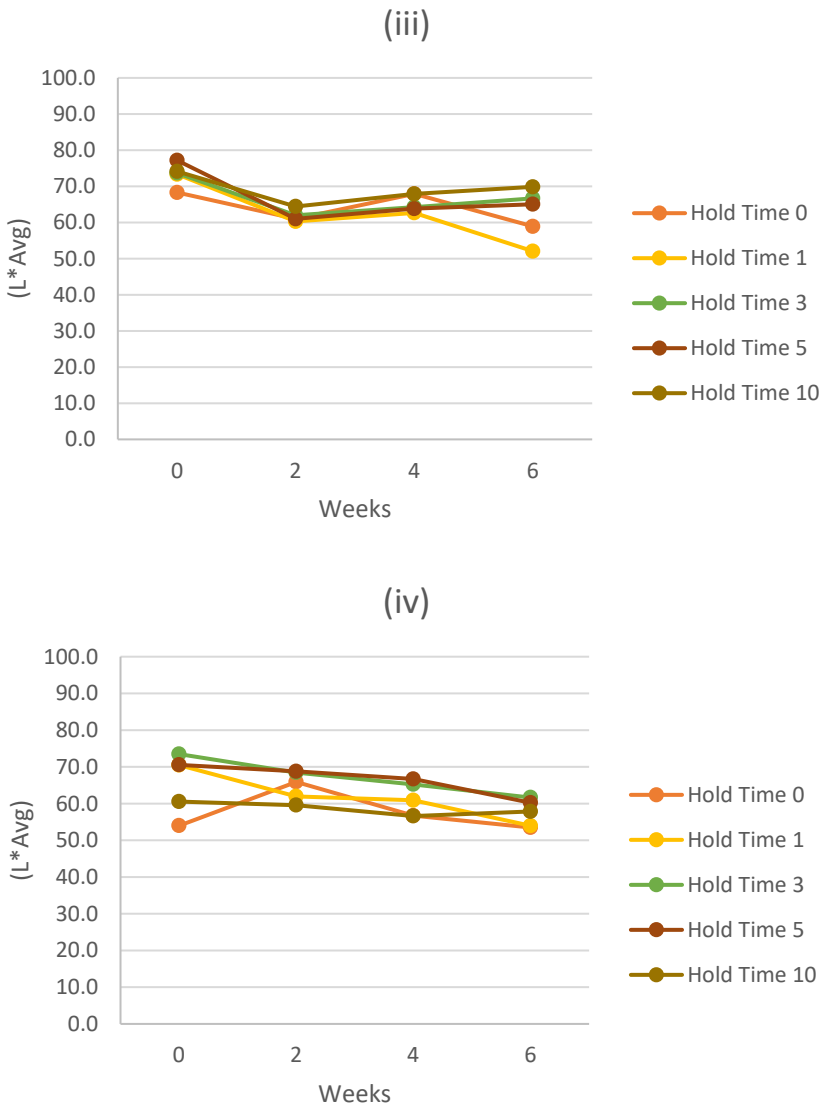


Figure 4.1.2. Mean across storage at 35°C between hold times for Cultivar A at 70°C (i), 80°C (ii), 90°C (iii), and 100°C (iv) for color parameter *L**.

Table 4.1.3. Relative variations across storage at 35°C between hold times for Cultivar B at 70°C, 80°C, 90°C, and 100°C for color parameters L^*/L_0^*.

Code	Temperature (C)	Hold Time	0	2	4	6
B	70	0	1.00 $_{B}$	1.08 $_{A}$	0.99 $_{C}$	0.86 $_{D}$
B	70	1	1.00 $_{A}$	0.90 $_{C}$	0.93 $_{B}$	0.87 $_{D}$
B	70	3	1.00 $_{A}$	1.01 $_{A}$	0.98 $_{B}$	0.84 $_{C}$
B	70	5	1.00 $_{A}$	0.97 $_{B}$	0.93 $_{C}$	0.86 $_{D}$
B	70	10	1.00 $_{A}$	0.93 $_{C}$	0.96 $_{D}$	0.86 $_{D}$
B	80	0	1.00 $_{A}$	0.89 $_{B}$	0.89 $_{B}$	0.97 $_{A}$
B	80	1	1.00 $_{D}$	1.15 $_{A}$	1.11 $_{B}$	1.01 $_{C}$
B	80	3	1.00 $_{A}$	0.99 $_{A}$	0.97 $_{B}$	0.95 $_{C}$
B	80	5	1.00 $_{A}$	1.00 $_{A}$	0.93 $_{B}$	0.93 $_{B}$
B	80	10	1.00 $_{C}$	1.10 $_{A}$	1.03 $_{B}$	0.96 $_{D}$
B	90	0	1.00 $_{A}$	0.84 $_{C}$	0.95 $_{D}$	0.93 $_{B}$
B	90	1	1.00 $_{A}$	0.84 $_{D}$	0.96 $_{D}$	0.88 $_{C}$
B	90	3	1.00 $_{A}$	0.81 $_{D}$	0.87 $_{D}$	0.82 $_{C}$
B	90	5	1.00 $_{A}$	0.86 $_{B}$	0.85 $_{C}$	0.83 $_{D}$
B	90	10	1.00 $_{A}$	0.89 $_{C}$	0.86 $_{D}$	0.91 $_{B}$
B	100	0	1.00 $_{A}$	0.90 $_{C}$	0.92 $_{B}$	0.84 $_{D}$
B	100	1	1.00 $_{A}$	0.87 $_{C}$	0.96 $_{B}$	0.85 $_{D}$
B	100	3	1.00 $_{A}$	0.86 $_{D}$	0.88 $_{C}$	0.86 $_{D}$
B	100	5	1.00 $_{A}$	0.94 $_{B}$	0.84 $_{D}$	0.84 $_{D}$
B	100	10	1.00 $_{A}$	0.82 $_{C}$	0.87 $_{B}$	0.83 $_{C}$

*Different letters withing the same row indicate significant difference ($p< 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

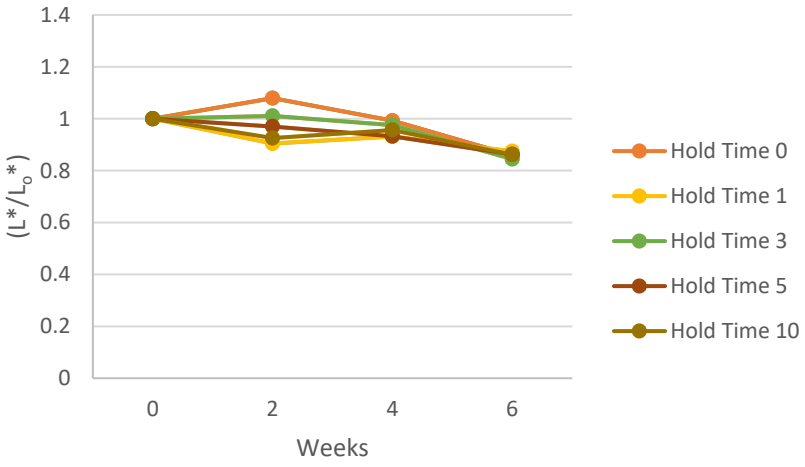
Table 4.1.4. Mean at weeks 0 and 6 for Cultivar B stored at 35°C between hold times at 70°C, 80°C, 90°C, and 100°C for color parameters *L* and* Δ*L**.

Code	Temperature (C)	Hold Time	0	6	ΔL*
B	**70**	**0**	**64.6**	**55.5**	**9.1**
B	**70**	**1**	**73.3**	**64.1**	**9.2**
B	**70**	**3**	**72.8**	**61.5**	**11.3**
B	**70**	**5**	**70.6**	**60.9**	**9.7**
B	**70**	**10**	**70.4**	**60.6**	**9.8**
B	**80**	**0**	**71.9**	**55.5**	**16.4**
B	**80**	**1**	**64.2**	**64.7**	**0.5**
B	**80**	**3**	**67.9**	**64.7**	**3.1**
B	**80**	**5**	**67.3**	**62.7**	**4.6**
B	**80**	**10**	**64.5**	**62.0**	**2.5**
B	**90**	**0**	**64.6**	**60.2**	**4.4**
B	**90**	**1**	**70.8**	**62.1**	**8.6**
B	**90**	**3**	**74.3**	**60.7**	**13.6**
B	**90**	**5**	**72.7**	**60.6**	**12.2**
B	**90**	**10**	**70.1**	**63.7**	**6.4**
B	**100**	**0**	**69.5**	**58.5**	**11.0**
B	**100**	**1**	**70.9**	**60.5**	**10.4**
B	**100**	**3**	**69.8**	**63.3**	**6.5**
B	**100**	**5**	**70.0**	**61.5**	**8.6**
B	**100**	**10**	**69.4**	**60.2**	**9.2**

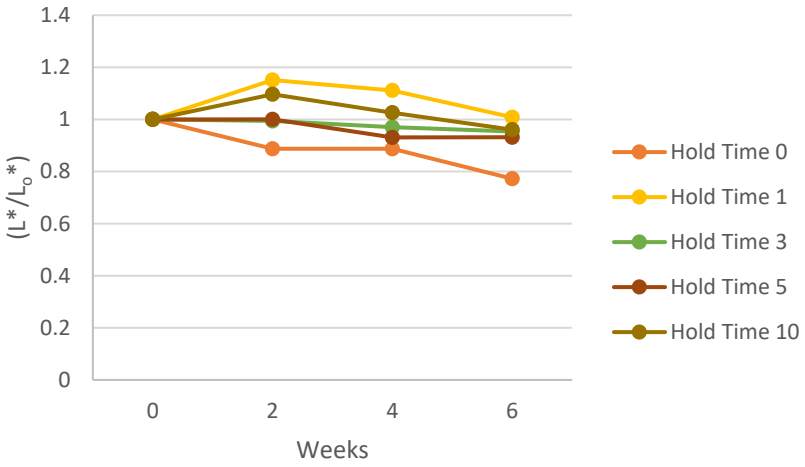
*Different letters withing the same row indicate significant difference ($p < 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

*$\Delta L^* = L_0^* - L^*$

(i)


1.4
1.2
1
0.8
0.6
0.4
0.2
0
(L*/Lo*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

(ii)


1.4
1.2
1
0.8
0.6
0.4
0.2
0
(L*/Lo*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

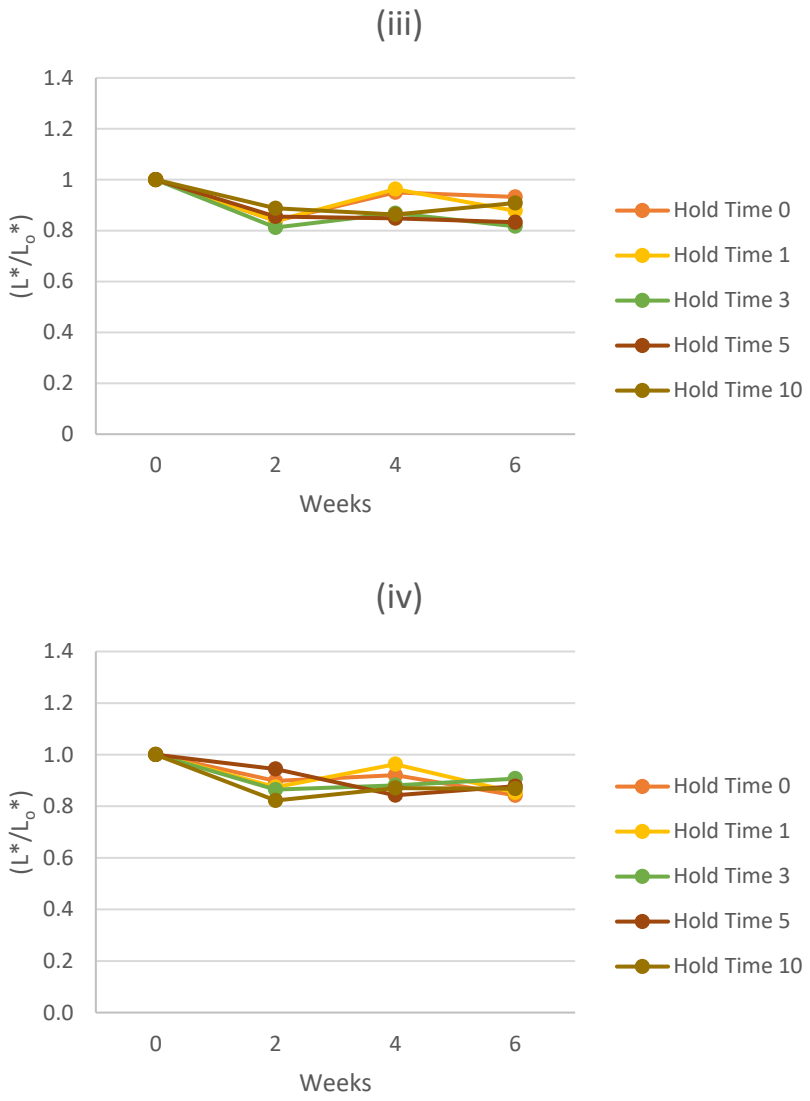
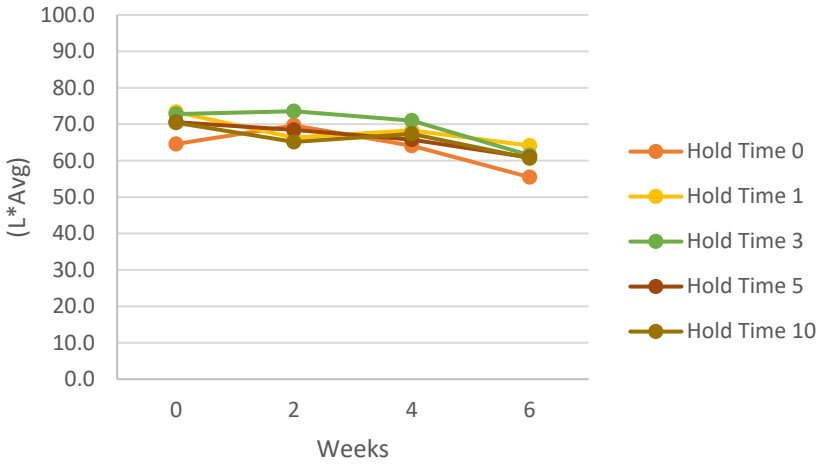
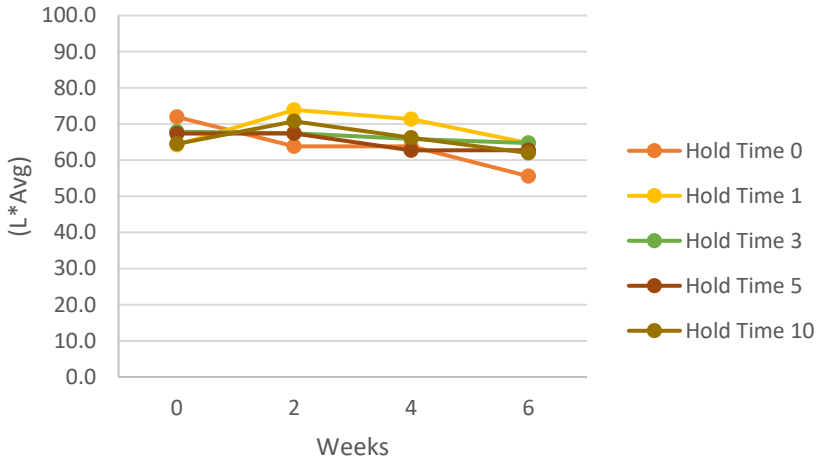


Figure 4.1.3. Relative variations across storage at 35°C between hold times for Cultivar B at 70°C (i), 80°C (ii), 90°C (iii), and 100°C (iv) for color parameters L^*/L_0^*.

(i)


100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
(L*Avg)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

(ii)


100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
(L*Avg)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

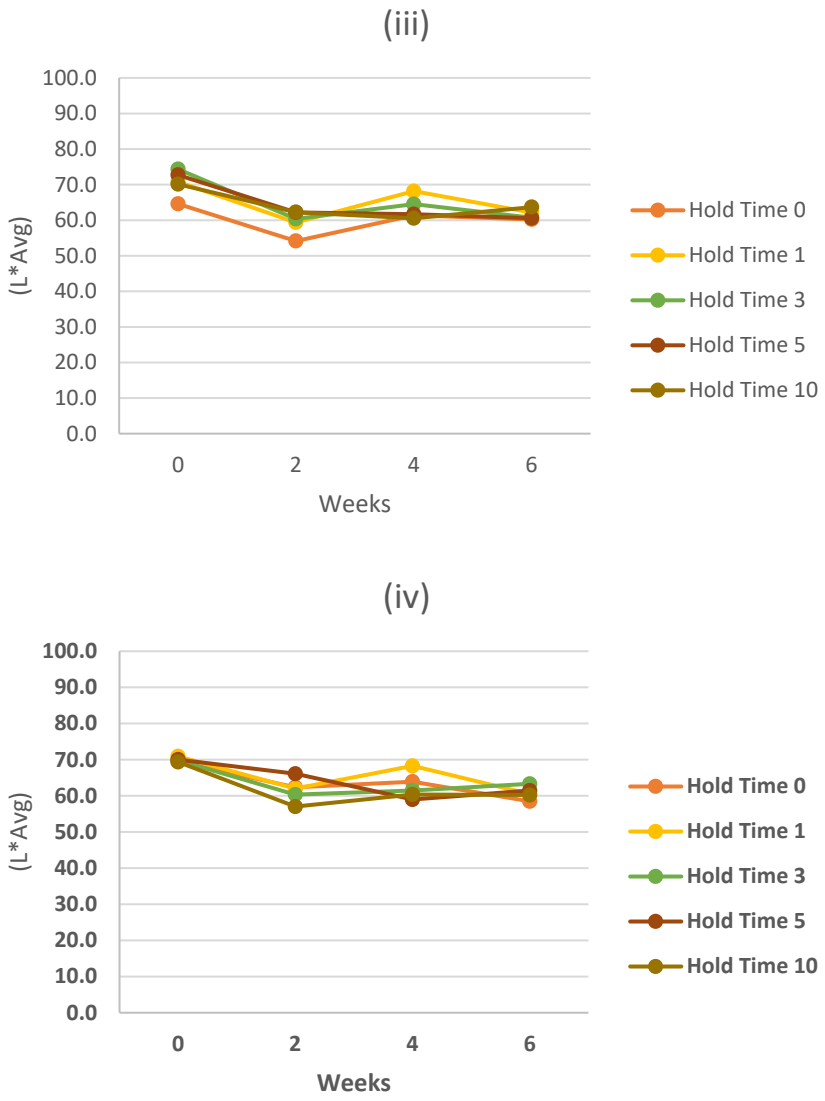


Figure 4.1.4. Mean across storage at 35°C between hold times for Cultivar B at 70°C (i), 80°C (ii), 90°C (iii), and 100°C (iv) for color parameter *L**.

Table 4.1.5. Relative variations across storage at 35°C between hold times for Cultivar C at 70°C, 80°C, 90°C, and 100°C for color parameters L^*/L_0^*.

Code	Temperature (C)	Hold Time	0	2	4	6
C	70	0.00	1.00 $_{A}$	1.02 $_{A}$	0.90 $_{B}$	0.90 $_{B}$
C	70	1.00	1.00 $_{A}$	1.07 $_{A}$	0.94 $_{B}$	0.91 $_{C}$
C	70	3.00	1.00 $_{A}$	0.89 $_{A}$	0.98 $_{B}$	0.96 $_{C}$
C	70	5.00	1.00 $_{A}$	1.08 $_{A}$	0.90 $_{B}$	0.84 $_{C}$
C	70	10.00	1.00 $_{A}$	0.95 $_{A}$	0.95 $_{B}$	0.88 $_{C}$
C	80	0.00	1.00 $_{A}$	0.85 $_{B}$	0.82 $_{C}$	0.80 $_{D}$
C	80	1.00	1.00 $_{A}$	0.84 $_{C}$	0.88 $_{B}$	0.80 $_{D}$
C	80	3.00	1.00 $_{B}$	1.01 $_{A}$	0.95 $_{C}$	0.78 $_{D}$
C	80	5.00	1.00 $_{B}$	1.01 $_{A}$	0.93 $_{C}$	0.79 $_{D}$
C	80	10.00	1.00 $_{A}$	0.97 $_{B}$	0.93 $_{C}$	0.77 $_{D}$
C	90	0.00	1.00 $_{C}$	1.02 $_{A}$	1.02 $_{B}$	0.93 $_{D}$
C	90	1.00	1.00 $_{A}$	0.98 $_{B}$	0.90 $_{D}$	0.91 $_{C}$
C	90	3.00	1.00 $_{A}$	0.98 $_{B}$	0.89 $_{D}$	0.90 $_{C}$
C	90	5.00	1.00 $_{A}$	1.00 $_{A}$	0.97 $_{B}$	0.96 $_{B}$
C	90	10.00	1.00 $_{A}$	0.95 $_{B}$	0.84 $_{D}$	0.89 $_{C}$
C	100	0.00	1.00 $_{A}$	1.00 $_{A}$	0.90 $_{B}$	0.90 $_{B}$
C	100	1.00	1.00 $_{A}$	0.98 $_{B}$	0.97 $_{C}$	0.96 $_{D}$
C	100	3.00	1.00 $_{A}$	1.00 $_{A}$	0.92 $_{B}$	0.90 $_{C}$
C	100	5.00	1.00 $_{A}$	0.98 $_{B}$	0.97 $_{C}$	0.96 $_{D}$
C	100	10.00	1.00 $_{A}$	0.99 $_{AB}$	0.99 $_{B}$	0.90 $_{C}$

*Different letters withing the same row indicate significant difference ($p< 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

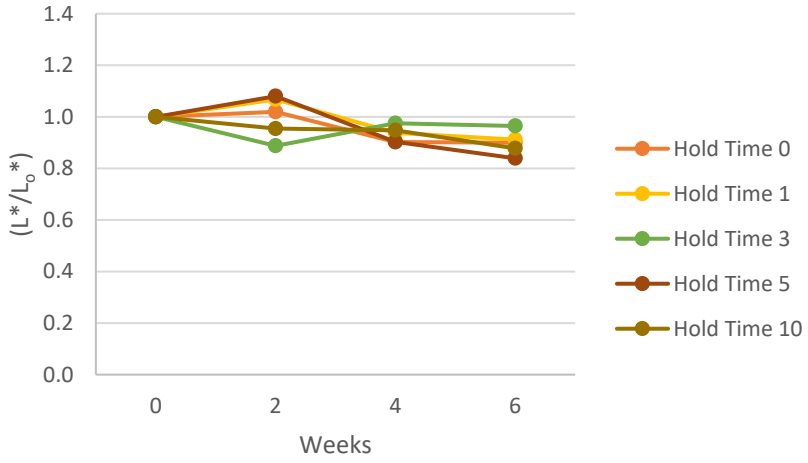
Table 4.1.6. Mean at weeks 0 and 6 for Cultivar C stored at 35°C between hold times at 70°C, 80°C, 90°C, and 100°C for color parameters *L* and* Δ*L**.

Code	Temperature (C)	Hold Time	0	6	ΔL*
C	**70**	**0**	**70.8**	**63.7**	**7.1**
C	**70**	**1**	**69.2**	**63.1**	**6.1**
C	**70**	**3**	**65.0**	**62.7**	**2.3**
C	**70**	**5**	**73.2**	**61.5**	**11.8**
C	**70**	**10**	**67.2**	**59.0**	**8.2**
C	**80**	**0**	**77.7**	**62.1**	**15.5**
C	**80**	**1**	**75.2**	**60.2**	**15.0**
C	**80**	**3**	**72.5**	**63.8**	**8.7**
C	**80**	**5**	**70.4**	**64.5**	**5.9**
C	**80**	**10**	**69.3**	**63.2**	**6.1**
C	**90**	**0**	**69.4**	**64.6**	**4.8**
C	**90**	**1**	**72.3**	**65.7**	**6.7**
C	**90**	**3**	**72.8**	**65.7**	**7.1**
C	**90**	**5**	**69.6**	**66.9**	**2.8**
C	**90**	**10**	**75.1**	**62.0**	**13.1**
C	**100**	**0**	**64.0**	**63.7**	**0.3**
C	**100**	**1**	**69.2**	**66.6**	**2.6**
C	**100**	**3**	**70.1**	**62.8**	**7.3**
C	**100**	**5**	**68.2**	**65.2**	**3.0**
C	**100**	**10**	**70.2**	**63.1**	**7.1**

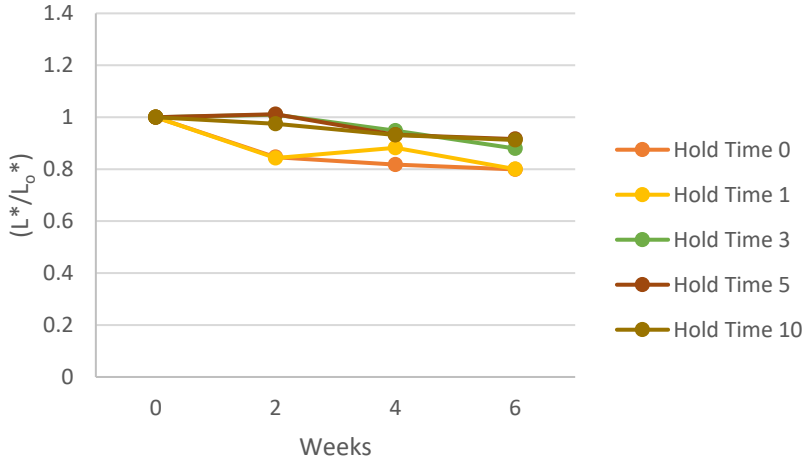
*Different letters withing the same row indicate significant difference ($p < 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

*$\Delta L^* = L_0^* - L^*$

(i)


1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(L*/Lo*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

(ii)


1.4
1.2
1
0.8
0.6
0.4
0.2
0
(L*/Lo*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

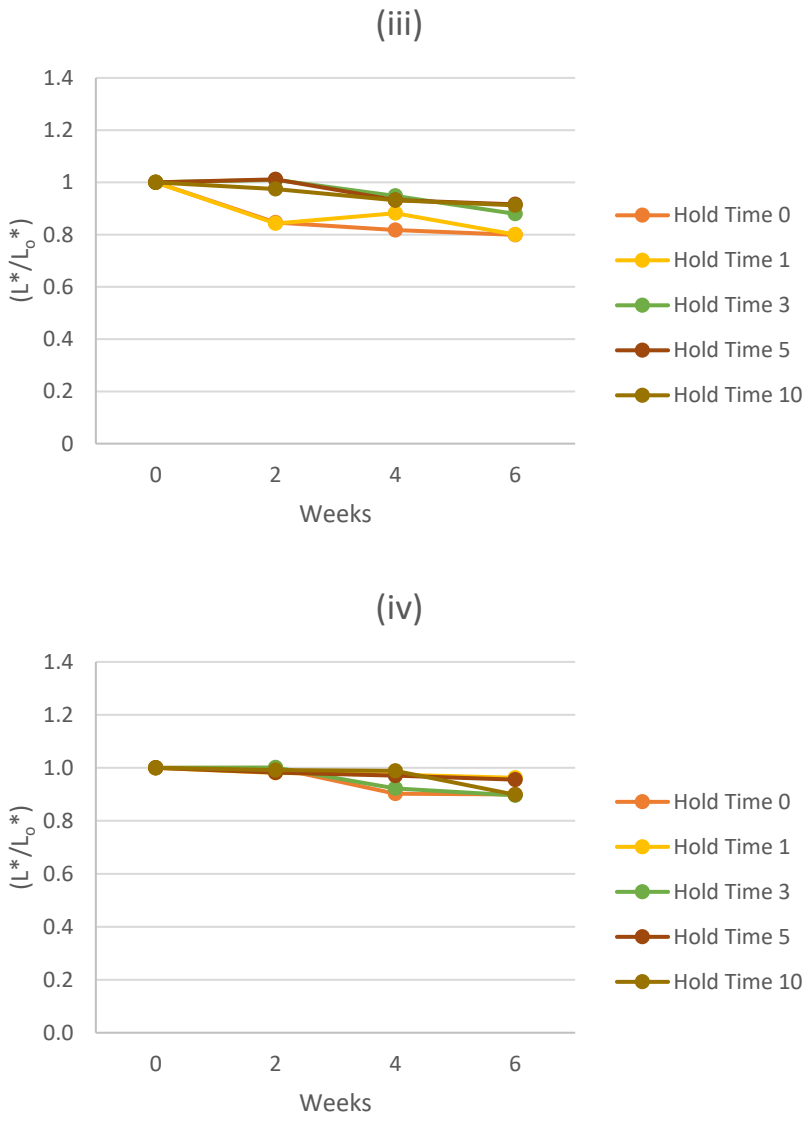
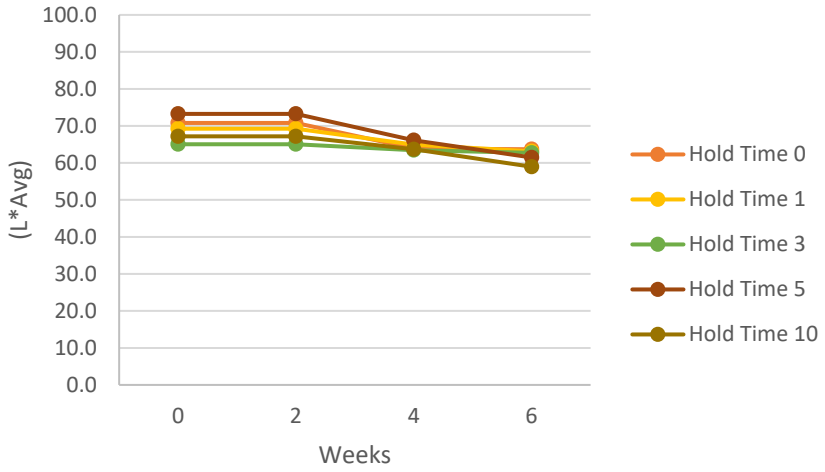
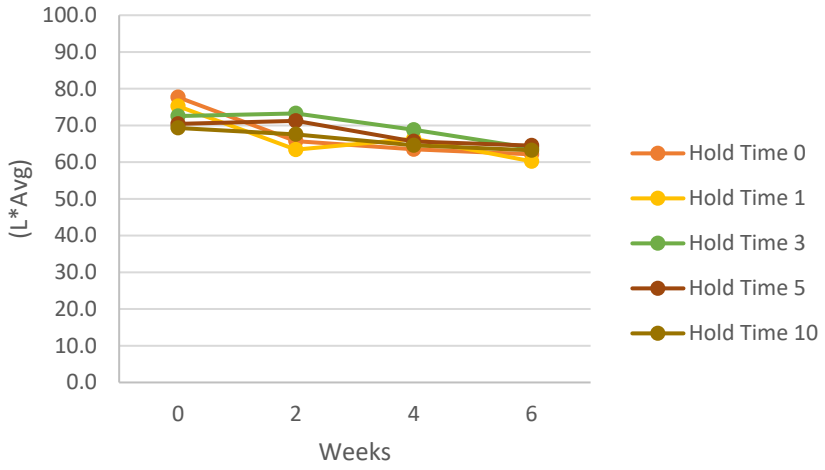


Figure 4.1.5. Relative variations across storage at 35°C between hold times for Cultivar C at 70°C (i), 80°C (ii), 90°C (iii), and 100°C (iv) for color parameters L^*/L_0^*.

(i)


100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
(L*Avg)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

(ii)


100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
(L*Avg)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

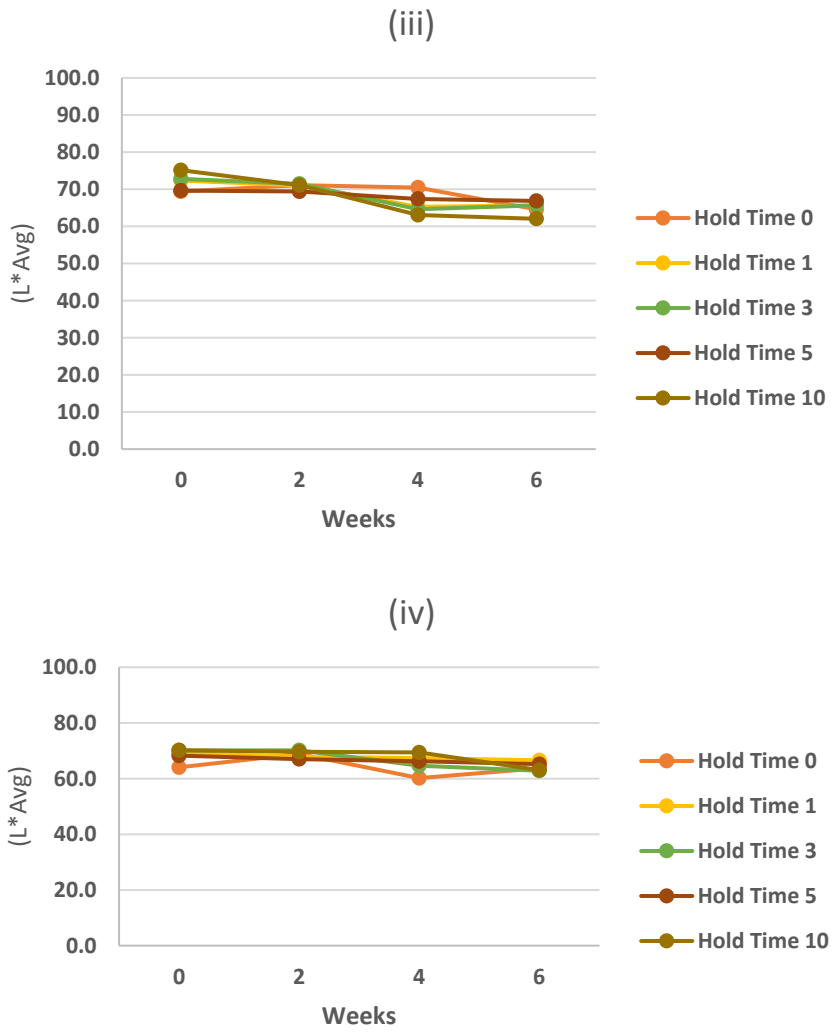
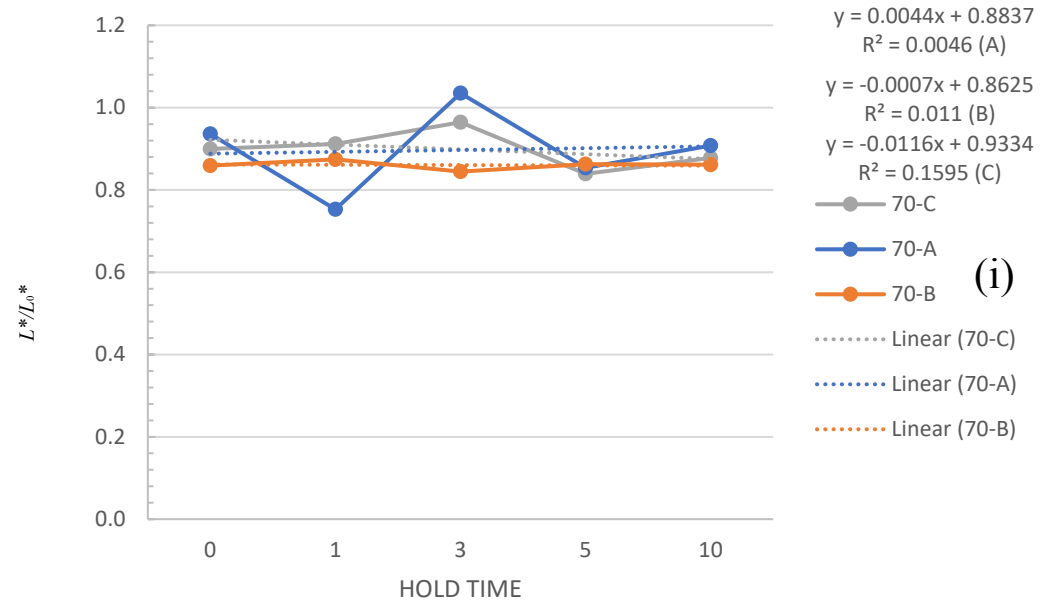
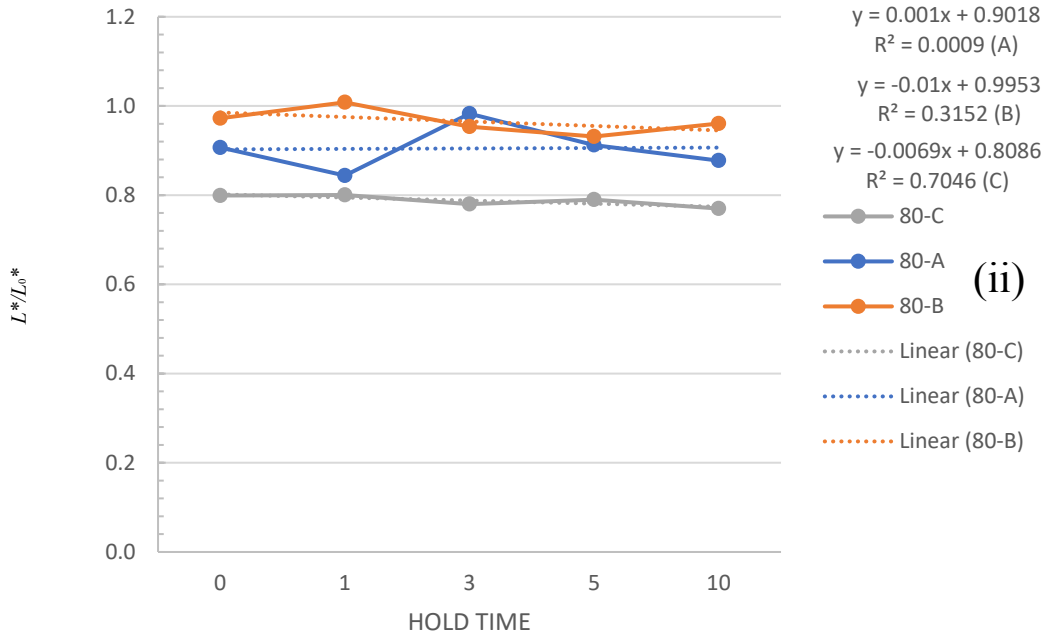


Figure 4.1.6. Mean across storage at 35°C between hold times for Cultivar C at 70°C (i), 80°C (ii), 90°C (iii), and 100°C (iv) for color parameter *L**.


1.2
1.0
0.8
0.6
0.4
0.2
0.0
L*/L₀*
0
1
3
5
10
HOLD TIME
y = 0.0044x + 0.8837
R² = 0.0046 (A)
y = -0.0007x + 0.8625
R² = 0.011 (B)
y = -0.0116x + 0.9334
R² = 0.1595 (C)
70-C
70-A
70-B
Linear (70-C)
Linear (70-A)
Linear (70-B)
(i)


1.2
1.0
0.8
0.6
0.4
0.2
0.0
L*/L₀*
0
1
3
5
10
HOLD TIME
y = 0.001x + 0.9018
R² = 0.0009 (A)
y = -0.01x + 0.9953
R² = 0.3152 (B)
y = -0.0069x + 0.8086
R² = 0.7046 (C)
80-C
80-A
80-B
Linear (80-C)
Linear (80-A)
Linear (80-B)
(ii)

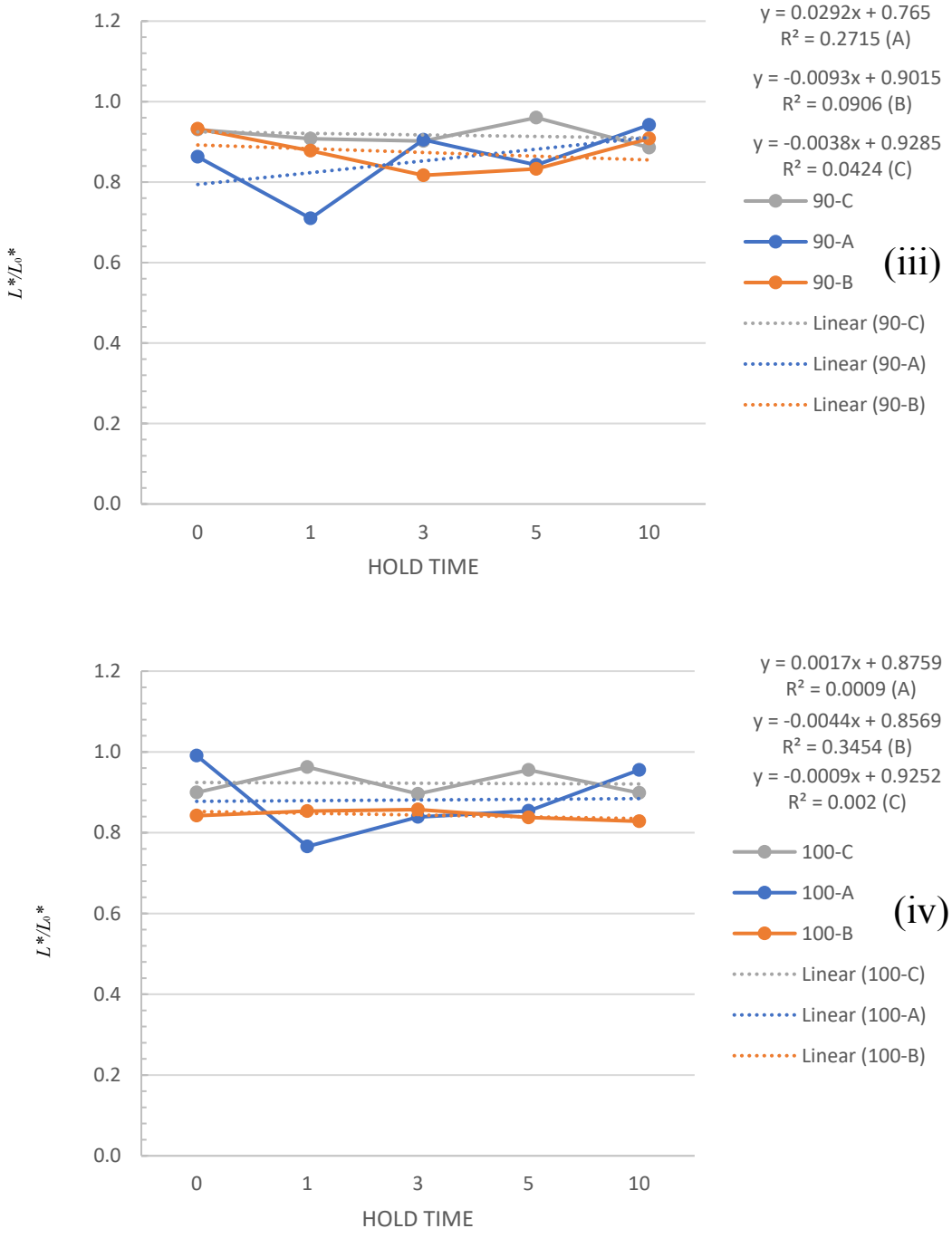


Figure 4.1.7. Relative variation across hold times for all cultivars at final week of storage at 35°C for color parameters L^*/L_0^* at 70°C (i), 80°C (ii), 90°C (iii), and 100°C (iv)

4.1.2 L^*/L_0^*, Mean L^*, and ΔL^*

For cultivar A, when comparing relative lightness (L^*/L_0^*), all temperatures at hold times showed an overall decrease from the initial week of testing to the final week except for temperature 70°C with a hold time of 3 minutes. However, when examining Table 4.1.1, (i), there is no significant difference from the L^*/L_0^* initially to the final week of storage. The decrease in L^*/L_0^* in all other variables throughout storage is a representation of peach puree darkening over time. This can also be concluded by examining Figure 4.1.2 as it indicates that the mean L^* value can be seen to decrease in each temperature at each hold time except for 70°C with a hold time of 3 minutes. Affirming that the darkening of peach puree is occurring. Figure 4.1.7 displays the effect of varying hold times at all temperatures for all cultivars on color parameter L^* in terms of relative lightness *(L^*/L_0^*)* at the final week of testing. The slope associated with the trendline for cultivar A indicates that the L^* value was not negatively affected by increasing hold time at any temperature of pasteurization increased for cultivar A. Overall, increasing storage time did increase the degradation of relative lightness while data on increasing hold time and temperature were inconclusive.

For Cultivar B, when comparing relative lightness (L^*/L_0^*), Figure 4.1.3 indicates all temperatures at hold times decreased from the initial week of testing to the final week. This decrease in L^*/L_0^* represents a darkening of the peach purees over storage time. This conclusion can also be drawn from Figure 4.1.4 as all data points for mean L^* values were seen to decrease from week 0 to week 6 of testing. Regarding cultivar B, Figure 4.1.7 indicates that an increase in hold time at all temperatures results in a decrease in the L^* value. This is indicated by the presence of a negative trendline slope for cultivar B at all temperatures of pasteurization. A negative trendline indicates that as the hold time of pasteurization increased a decrease in relative lightness

(L^*/L_0^*) was seen at all temps. Examining the negative trendlines for cultivar B seen in figure 4.1.7 an increase in hold time was more influential in decreasing relative lightness than an increased temperature. The effect of increased pasteurization temperature of processing on L^* values was inconclusive for Cultivar B however temperatures greater than 70°C have a more negative effect on relative lightness.

For Cultivar C, when comparing relative lightness (L^*/L_0^*), figure 4.1.5 displays all temperatures at all hold times decreased from the initial week of testing to the final week, representing a darkening of puree over time. Figure 4.1.6 also concludes that all purees darkened as storage time increased by displaying that all mean L^* values were decreased from week 0 to week 6 of testing. Figure 4.1.7 indicates that as hold time increased a darkening of puree was seen at all processing temperatures. This is indicated by the negative trendline at all temperatures as hold time increased. Similarly, to the trendline results for cultivar B, the trendlines for cultivar C were inconclusive as to what temperature of pasteurization leads to an increased darkening of puree rather than an increase in hold time leads to an increase in L^* values regardless of browning.

Oliveira et al. (2014), notes that increased storage time can also negatively affect the L^*value. All peach cultivars regardless of time and temperature followed this suggested conclusion by Oliveira et al. (2014), except for Cultivar A processing temperature 70°C with a hold time of 3. Cultivar A processing temperature 70°C with a hold time of 3 saw an increase at the final week of testing in terms of relative lightness, yet this increase wasn't significant when compared to week 0 based on results from the student's t-test. This deviation from the expected decrease over storage time from the suggested trend of previous data from Oliveira et al. (2014), could be attributed to the randomization in selection of pouch testing. Another possible source of this deviation could be a human error when preparing the puree or during testing. Garza et al. (1999) and Oliveira et al.

(2014), both suggest that increasing thermal processing time and temperature can negatively impact, or reduce, the L^* value of peach puree. Meaning as the temperature and time of processes increases the L^* value will decrease indicating Non-Enzymatic Browning (NEB) (Garza, Ibarz, Pagan, & Giner, 1999). Utilizing this knowledge, in terms of (L^*/L_0^*), a decrease should be seen as hold time, temperature, and storage increases. Data for both cultivar B and C were seen to decrease in terms of relative lightness (L^*/L_0^*) as hold time increased at all temperatures. Data points for cultivars B and C were inconclusive on the hypothesis that increasing the temperature of pasteurization affects the darkening of peach puree.

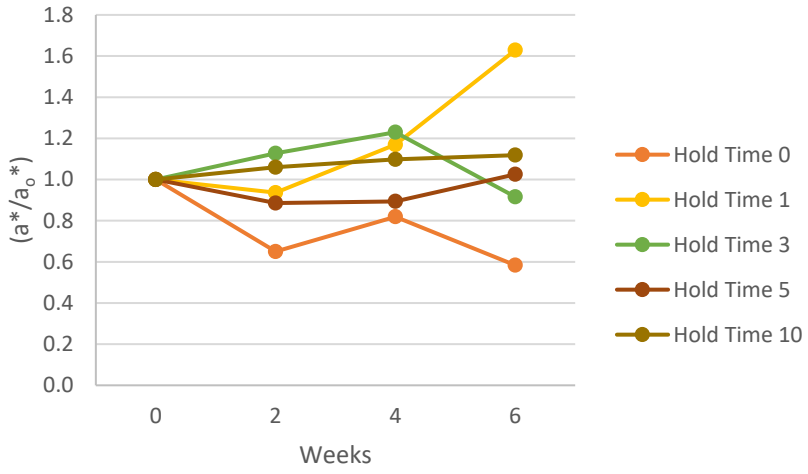
Previous research performed by Cáceres et al. (2016), suggests that an ΔL and peach browning are highly correlated. This study deduced that a ΔL of 4.7 or greater is noticeable to the human eye and can be related to low consumer response. This does not mean that an ΔL value less than 4.7 is not indicative of browning, rather that browning is occurring, but it will go unnoticed by the human eye. Examining the change in L^* value (ΔL^*) for all cultivars from the initial week of testing to the final week of testing it is evident that a darkening of puree is taking place throughout storage due to NEB in all cultivars. Not all values for cultivars A, B, and C would be noticeable by the human eye according to the conclusions made by Cáceres et al. (2016), including, A-70-(0 and 3), A-80-3, A-90-10, A-100-(0 and 10), B-80-(1,3,5, and 10), C-70-3, C-90-5, and C-100-(0,1, and 5).

Table 4.1.7. Relative variations across storage at 35°C between hold times for Cultivar A at 70°C, 80°C, 90°C, and 100°C for color parameters a^*/a_0^*.

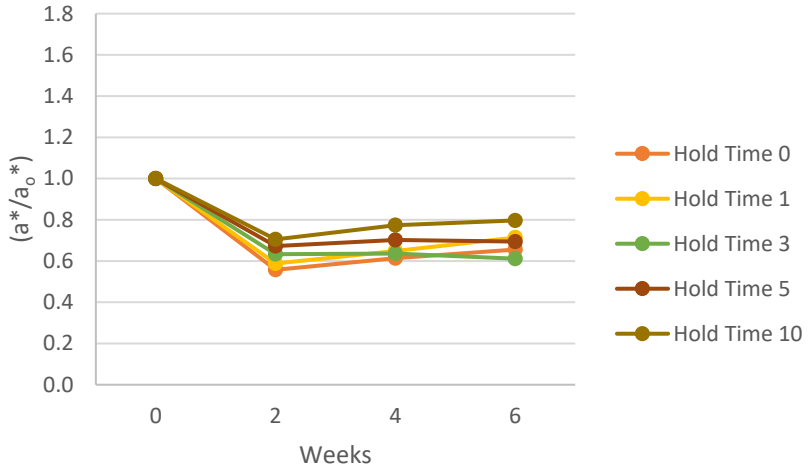
Code	Temperature (C)	Hold Time	0	2	4	6
A	70	0	1.00 $_{A}$	0.65$_{B}$	0.82 $_{AB}$	0.58 $_{B}$
A	70	1	1.00 $_{C}$	0.94 $_{D}$	1.17 $_{B}$	1.63 $_{A}$
A	70	3	1.00 $_{C}$	1.13 $_{B}$	1.23 $_{A}$	0.92 $_{D}$
A	70	5	1.00 $_{A}$	0.89 $_{B}$	0.89 $_{B}$	1.03 $_{A}$
A	70	10	1.00 $_{B}$	1.06 $_{AB}$	1.10 $_{AB}$	1.12 $_{A}$
A	80	0	1.00 $_{A}$	0.56 $_{D}$	0.61 $_{C}$	0.66 $_{B}$
A	80	1	1.00 $_{A}$	0.59 $_{D}$	0.65 $_{C}$	0.71 $_{B}$
A	80	3	1.00 $_{A}$	0.63 $_{B}$	0.64 $_{B}$	0.61 $_{C}$
A	80	5	1.00 $_{A}$	0.67 $_{C}$	0.70 $_{B}$	0.69 $_{B}$
A	80	10	1.00 $_{A}$	0.70 $_{D}$	0.77 $_{C}$	0.80 $_{B}$
A	90	0	1.00 $_{A}$	0.60 $_{D}$	0.70 $_{C}$	0.81 $_{B}$
A	90	1	1.00 $_{A}$	0.82 $_{D}$	0.84 $_{C}$	0.98 $_{B}$
A	90	3	1.00 $_{A}$	0.77 $_{C}$	0.87 $_{B}$	0.69 $_{D}$
A	90	5	1.00 $_{A}$	0.83 $_{C}$	0.96 $_{B}$	0.77 $_{D}$
A	90	10	1.00 $_{A}$	0.82 $_{C}$	0.93 $_{B}$	0.66 $_{D}$
A	100	0	1.00 $_{A}$	0.70 $_{C}$	0.66 $_{C}$	0.76 $_{B}$
A	100	1	1.00 $_{D}$	1.22 $_{B}$	1.14 $_{C}$	1.31 $_{A}$
A	100	3	1.00 $_{B}$	1.05 $_{A}$	1.01 $_{B}$	1.06 $_{A}$
A	100	5	1.00 $_{A}$	0.86 $_{B}$	0.82 $_{C}$	0.86 $_{B}$
A	100	10	1.00 $_{B}$	1.17 $_{A}$	0.93 $_{C}$	0.94 $_{C}$

*Different letters withing the same row indicate significant difference ($p< 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

(i)


1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(a*/a$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

(ii)


1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(a*/a$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

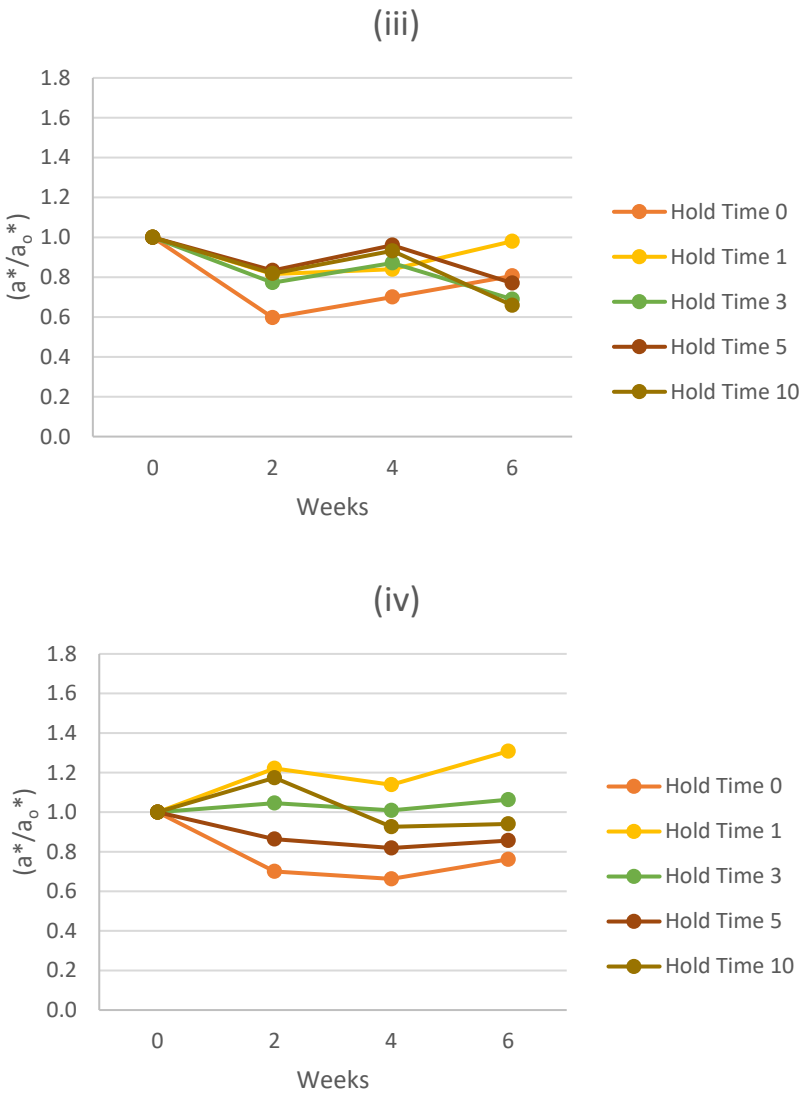


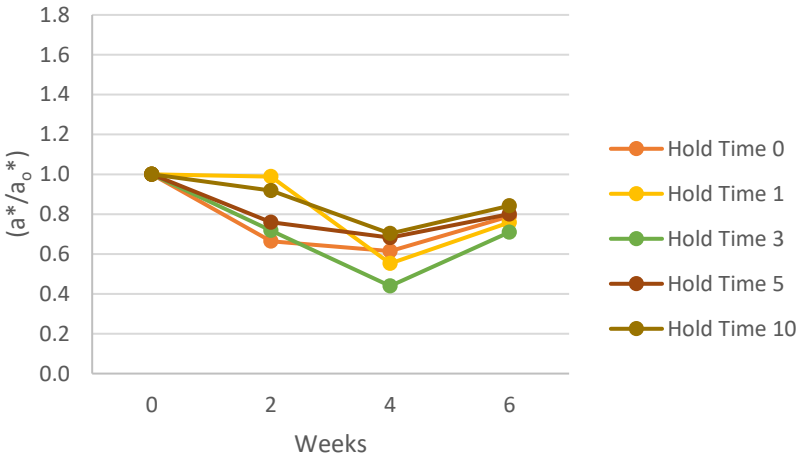
Figure 4.1.8. Relative variations across storage at 35°C between hold times for Cultivar A at 70°C (i), 80°C (ii), 90°C (iii), and 100°C (iv) for color parameters a^*/a_0^*.

Table 4.1.8. Relative variations across storage at 35°C between hold times for Cultivar B at 70°C, 80°C, 90°C, and 100°C for color parameters a^*/a_0^*.

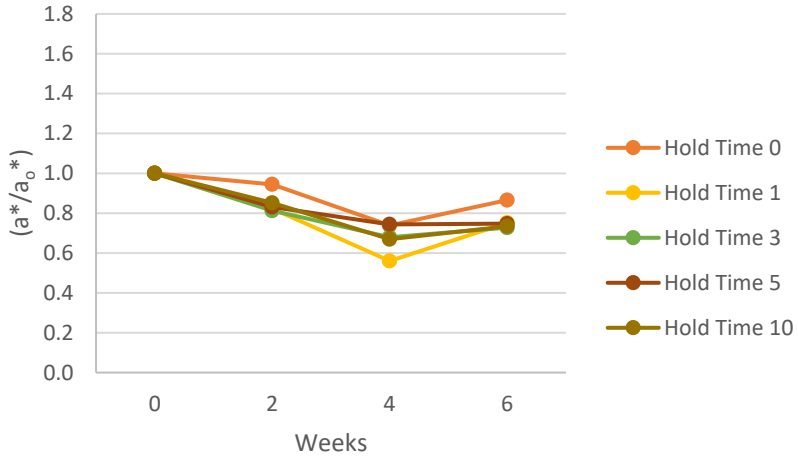
Code	Temperature (C)	Hold Time	0	2	4	6
B	70	0	1.00 $_{A}$	0.66 $_{C}$	0.61 $_{D}$	0.79 $_{B}$
B	70	1	1.00 $_{A}$	0.99 $_{A}$	0.55 $_{C}$	0.76 $_{B}$
B	70	3	1.00 $_{A}$	0.72 $_{B}$	0.44 $_{C}$	0.71 $_{B}$
B	70	5	1.00 $_{A}$	0.76 $_{C}$	0.68 $_{D}$	0.80 $_{B}$
B	70	10	1.00 $_{A}$	0.92 $_{B}$	0.70 $_{D}$	0.84 $_{C}$
B	80	0	1.00 $_{A}$	0.94 $_{B}$	0.74 $_{D}$	0.87 $_{C}$
B	80	1	1.00 $_{A}$	0.82 $_{B}$	0.56 $_{D}$	0.75 $_{C}$
B	80	3	1.00 $_{A}$	0.81 $_{B}$	0.68 $_{D}$	0.73 $_{C}$
B	80	5	1.00 $_{A}$	0.83 $_{B}$	0.74 $_{C}$	0.75 $_{C}$
B	80	10	1.00 $_{A}$	0.85 $_{B}$	0.67 $_{D}$	0.73 $_{C}$
B	90	0	1.00 $_{A}$	0.69 $_{C}$	0.90 $_{B}$	0.66 $_{C}$
B	90	1	1.00 $_{A}$	0.72 $_{B}$	0.68 $_{C}$	0.72 $_{B}$
B	90	3	1.00 $_{A}$	0.80 $_{C}$	0.85 $_{BC}$	0.94 $_{AB}$
B	90	5	1.00 $_{A}$	0.71 $_{D}$	0.82 $_{C}$	0.88 $_{B}$
B	90	10	1.00 $_{A}$	0.72 $_{D}$	0.86 $_{B}$	0.82 $_{C}$
B	100	0	1.00 $_{A}$	0.68 $_{C}$	0.71 $_{B}$	0.71 $_{B}$
B	100	1	1.00 $_{A}$	0.76 $_{C}$	0.64 $_{B}$	0.78 $_{B}$
B	100	3	1.00 $_{A}$	0.91 $_{B}$	0.87 $_{C}$	0.85 $_{D}$
B	100	5	1.00 $_{A}$	0.77 $_{D}$	0.95 $_{B}$	0.86 $_{C}$
B	100	10	1.00 $_{A}$	0.93 $_{AB}$	0.84 $_{C}$	0.85 $_{BC}$

*Different letters withing the same row indicate significant difference ($p< 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

(i)


1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(a*/a$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

(ii)


1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(a*/a$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

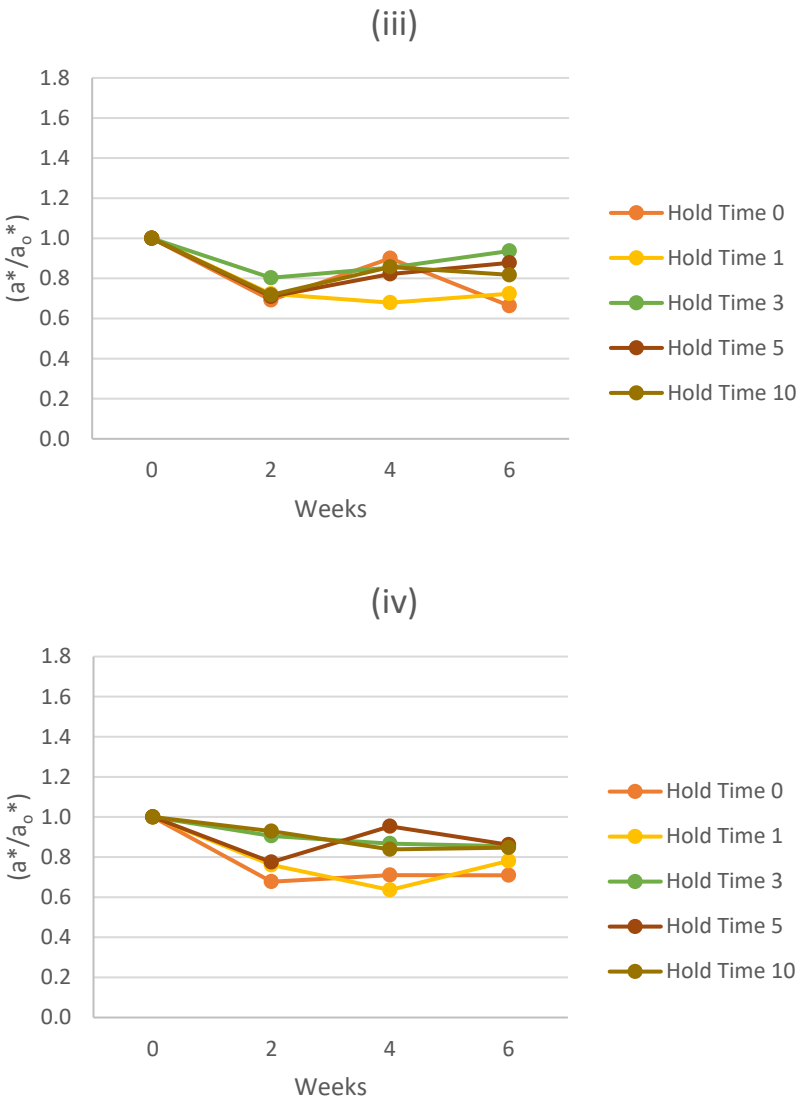


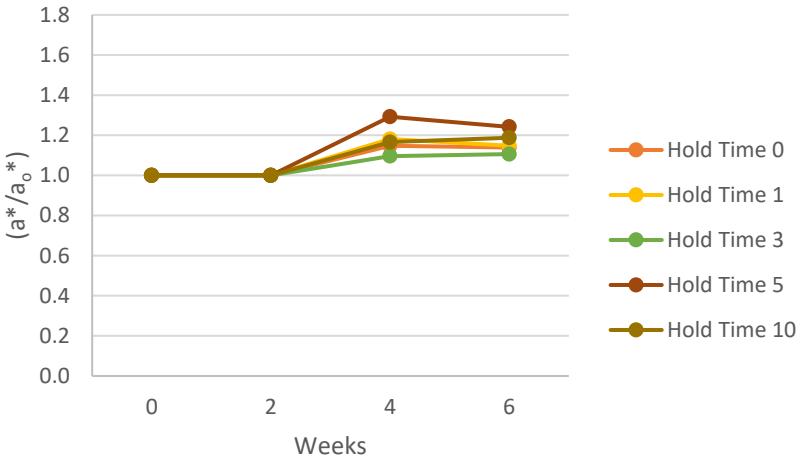
Figure 4.1.9. Relative variations across storage at 35°C between hold times for Cultivar B at 70°C (i), 80°C (ii), 90°C (iii), and 100°C (iv) for color parameters a^*/a_0^*.

Table 4.1.9. Relative variations across storage at 35°C between hold times for Cultivar C at 70°C, 80°C, 90°C, and 100°C for color parameters a^*/a_0^*.

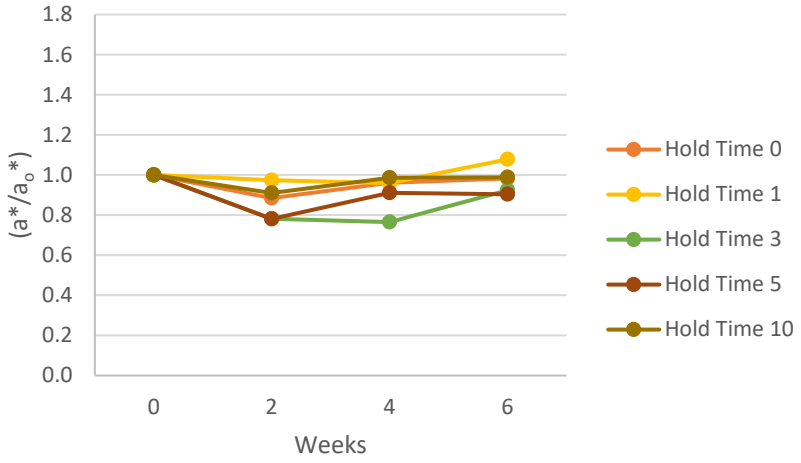
Code	Temperature (C)	Hold Time	0	2	4	6
C	70	0	1.00 $_{B}$	1.00 $_{B}$	1.15 $_{A}$	1.14 $_{A}$
C	70	1	1.00 $_{C}$	1.00 $_{C}$	1.18 $_{A}$	1.15 $_{B}$
C	70	3	1.00 $_{B}$	1.00 $_{B}$	1.10 $_{A}$	1.11 $_{A}$
C	70	5	1.00 $_{C}$	1.00 $_{C}$	1.29 $_{A}$	1.24 $_{B}$
C	70	10	1.00 $_{C}$	1.00 $_{C}$	1.17 $_{B}$	1.19 $_{A}$
C	80	0	1.00 $_{A}$	0.88 $_{C}$	0.96 $_{B}$	0.98 $_{AB}$
C	80	1	1.00 $_{B}$	0.97 $_{BC}$	0.96 $_{C}$	1.08 $_{A}$
C	80	3	1.00 $_{A}$	0.78 $_{C}$	0.77 $_{D}$	0.92 $_{B}$
C	80	5	1.00 $_{A}$	0.78 $_{C}$	0.91 $_{B}$	0.90 $_{B}$
C	80	10	1.00 $_{A}$	0.91 $_{C}$	0.99 $_{B}$	0.99 $_{B}$
C	90	0	1.00 $_{A}$	0.70 $_{D}$	0.75 $_{C}$	0.82 $_{B}$
C	90	1	1.00 $_{A}$	0.80 $_{D}$	0.93 $_{B}$	0.92 $_{C}$
C	90	3	1.00 $_{B}$	0.93 $_{D}$	1.07 $_{A}$	0.98 $_{C}$
C	90	5	1.00 $_{B}$	1.02 $_{AB}$	1.01 $_{B}$	1.03 $_{A}$
C	90	10	1.00 $_{C}$	0.95 $_{D}$	1.12 $_{B}$	1.16 $_{A}$
C	100	0	1.00 $_{A}$	0.80	0.95 $_{B}$	0.88 $_{C}$
C	100	1	1.00 $_{A}$	0.81 $_{B}$	0.79 $_{C}$	0.79 $_{D}$
C	100	3	1.00 $_{A}$	0.85	0.95 $_{C}$	0.96 $_{B}$
C	100	5	1.00 $_{A}$	0.96 $_{B}$	0.96 $_{B}$	0.94 $_{C}$
C	100	10	1.00 $_{B}$	0.97 $_{C}$	0.93 $_{D}$	1.14 $_{A}$

*Different letters withing the same row indicate significant difference ($p< 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

(i)


1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(a*/a$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

(ii)


1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(a*/a$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

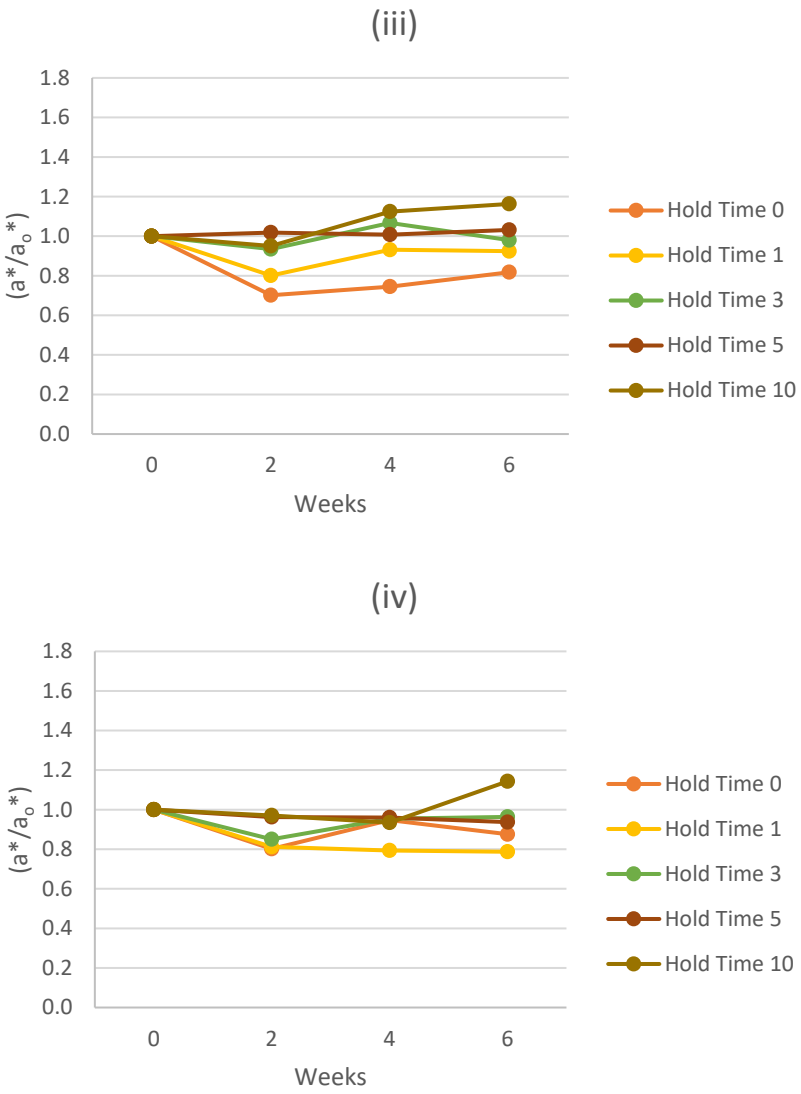
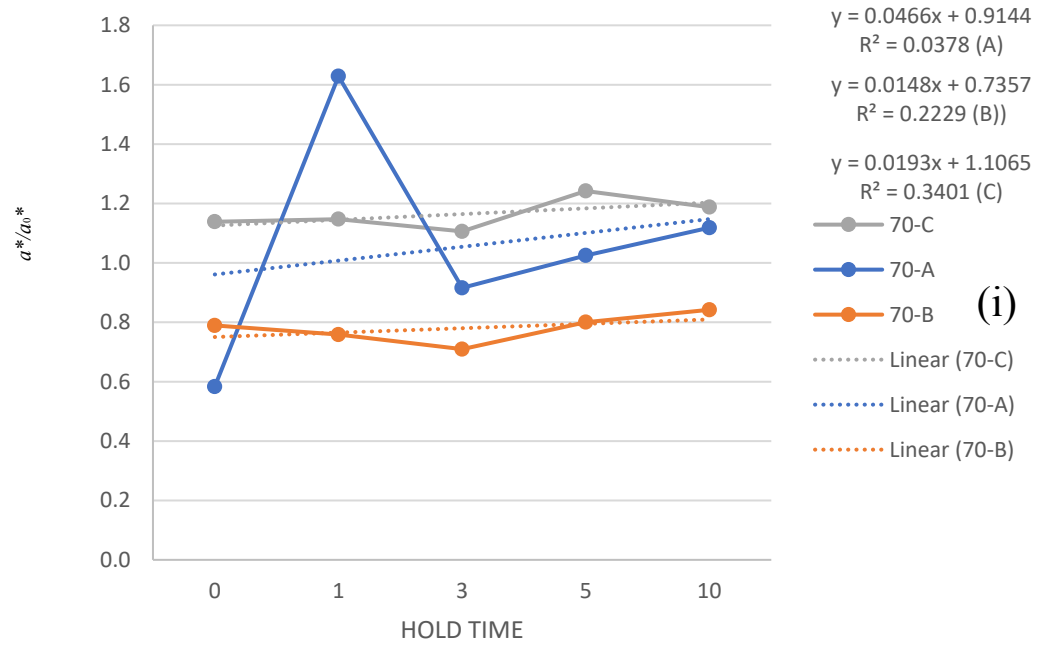
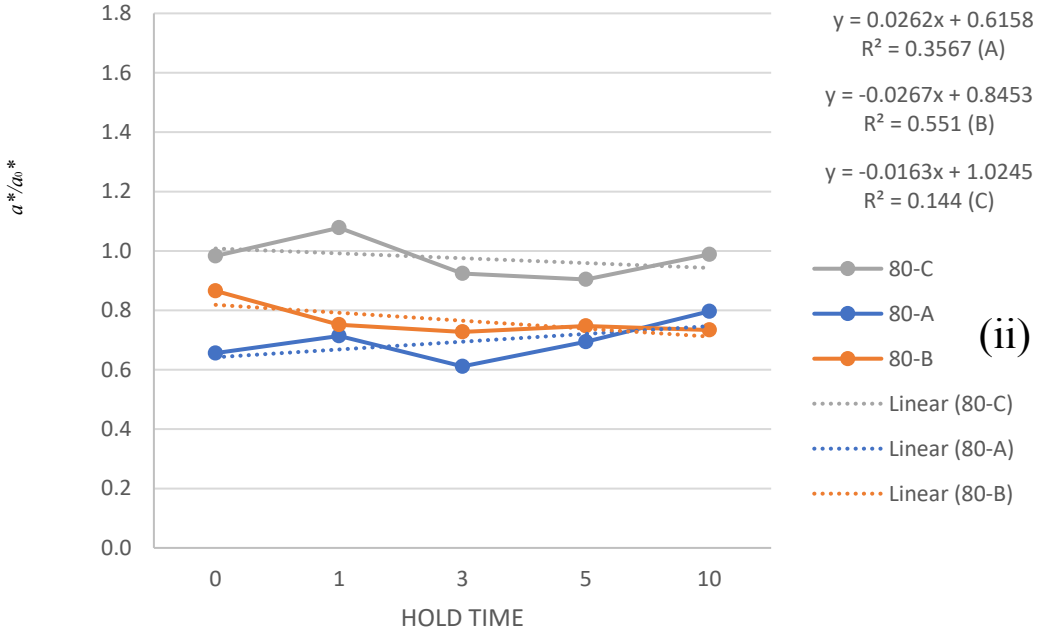


Figure 4.1.10. Relative variations across storage at 35°C between hold times for Cultivar C at 70°C (i), 80°C (ii), 90°C (iii), and 100°C (iv) for color parameters a^*/a_0^*.


1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
a*/a0*
0
1
3
5
10
HOLD TIME
y = 0.0466x + 0.9144
R² = 0.0378 (A)
y = 0.0148x + 0.7357
R² = 0.2229 (B))
y = 0.0193x + 1.1065
R² = 0.3401 (C)
70-C
70-A
70-B
Linear (70-C)
Linear (70-A)
Linear (70-B)
(i)


1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
a*/a0*
0
1
3
5
10
HOLD TIME
y = 0.0262x + 0.6158
R² = 0.3567 (A)
y = -0.0267x + 0.8453
R² = 0.551 (B)
y = -0.0163x + 1.0245
R² = 0.144 (C)
80-C
80-A
80-B
Linear (80-C)
Linear (80-A)
Linear (80-B)
(ii)

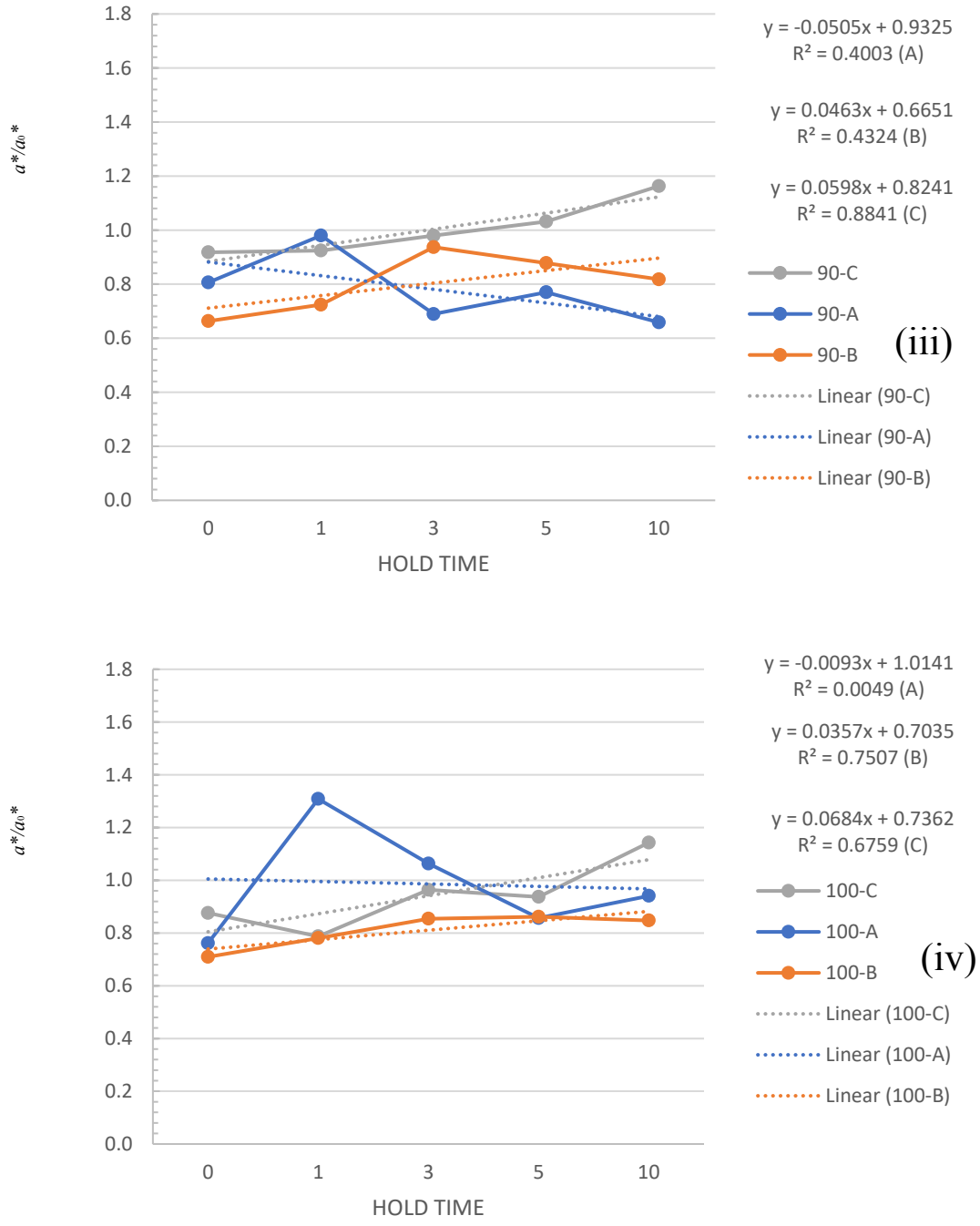


Figure 4.1.11. Relative variation across hold times for all cultivars at final week of storage at 35°C for color parameters a^*/a_0^* at 70°C (i), 80°C (ii), 90°C (iii), and 100°

4.1.3. *a** and *a*/ao**

Lavelli et al. (2008), suggest that a decrease in a^* value is indicative of a positive progression of color (meaning redder). Positive color progression associated with a decrease in a^*

value or relative redness (a^*/a_0^*) is undesirable according to Lavelli et al. (2008). A decrease in a^* value or unwanted positive progression of color (redness) throughout storage can be attributed to the degradation of unstable anthocyanin present in a peach puree. Anthocyanins are known to interact with intermediates of the Maillard reaction such as intermediates such as furfural including HMF creating brown pigments associated with NEB of peach puree. In terms according to Lavelli et al. (2008), a decrease in a^* value or relative redness (a^*/a_0^*) can be correlated to NEB reactions occurring over time resulting in the browning of puree. Alternatively, Gonzalez et al. (1992), states that an increase in time and temperature of thermal treatment will correspondingly be related to an increase in a^* value of fresh sliced peaches. Slicing is not the same process as pureeing, but the increase in a^* value seen in sliced peaches suggests that an increase in a^* value or relative redness (a^*/a_0^*) may be indicative that enzymatic browning is occurring more prevalently than NEB due to increase exposure to oxygen during processing. Gonzalez et al. (1992) suggest that a^* value can vary depending on the cultivar.

Figure 4.1.8 displays the relative variations across storage at 35°C between hold times for Cultivar A at 70°C (i), 80°C (ii), 90°C (iii), and 100°C (iv) for color parameters a^*/a_0. Cultivar A at temperature 70°C data was inconsistent throughout storage with some data increasing and others decreasing in relative redness (a^*/a_0^*). 70°C at the following hold times experienced an increase throughout storage: 1 min, 5 min, and 10 min. In contrast, to hold times 0 min and 3 min decreased. Both Lavelli et al. (2008), and Gonzalez et al. (1992), suggest darkening of puree occurred as storage time increased for all hold times at a 70°C. However, cultivar A at 70°C may have experienced both enzymatic browning and NEB reactions that lead to the darkening of the puree over time. The errors allowing enzymatic browning to occur in cultivar A at 70°C could have occurred during processing to produce puree as well as during filling and sealing of peaches into

the pouches that were stored and over the 6 weeks of experimentation. All data for cultivar A at 80°C decreased throughout storage regardless of hold time. According to Lavelli et al. (2008), this decrease in relative redness (a^*/a_0^*) is associated with the NEB of peach puree over time. All data for cultivar A at 90°C was similar to that of 80°C meaning that all hold times decreased relative redness (a^*/a_0^*) throughout storage indicative of darkening of puree related to NEB reactions. Data for cultivar A at 100°C were inconsistent as hold times of 1 and 3 increase in relative redness (a^*/a_0^*) throughout storage, which Gonzalez et al. (1992), suggests is attributed to enzymatic browning and hold times 0 min, 1 min, and 10 min increased suggesting NEB. It can be deduced that darkening of puree did in fact occur over time. Figure 4.1.11 displays the effect of varying hold times at all temperatures for all cultivars on color parameter a^* in terms of relative redness (a^*/a_0^*) at the final week of testing. For cultivar A at temperatures 70°C and 80°C, the trendline indicates that an increase in hold time is directly correlated to an increase in relative redness (a^*/a_0^*). In contrast, temperatures 90°C and 100°C decreased as hold time increased. Although inconsistent as temperature increased, according to suggestions by Lavelli et al. (2008) and Gonzalez et al. (1992), although mild, it is clear increased the darkening of puree occurred as hold time increased. A negative trendline suggests NEB and a positive trendline suggests enzymatic browning (Lavelli et al. (2008) and Gonzalez et al. (1992). Inconsistency of data does not allow for a conclusion to be made as to the effect of increasing the temperature of processing when comparing the temperatures of processing.

In Figure 4.1.9, Cultivar B resulted in a relative redness (a^*/a_0^*) that decreased regardless of hold time or temperature over storage time. This affirms suggestions made by Lavelli et al. (2008), where this decrease in relative redness (a^*/a_0^*) can be attributed to the darkening of puree resulting from NEB. Figure 4.1.11 illustrates cultivar B at temperatures 70°C, 90°C, and 100°C

and the trendlines suggest that as hold time increases the relative redness (a^*/a_0^*) decreases. A temperature 80°C showed a decrease in relative redness (a^*/a_0^*) as hold time increased. According to suggestions by Lavelli et al. (2008) and Gonzalez et al. (1992), although minimal, it is clear that increased darkening of puree occurred as hold time increased. A negative trendline suggests NEB taking and a positive trendline would suggest enzymatic browning (Lavelli, V., Pompei, C., & Casadei, M. A. 2008; Gonzalez, Mauromoustakos, Prokakis, & Aselage, 1992). Although, the inconsistency of data does not allow for conclusions to be made on the effect of increasing the temperature of processing.

Cultivar C, displayed in figure 4.1.10, shows relative redness (a^*/a_0^*) at a temperature of 70°C to increase regardless of hold time throughout storage. Gonzalez et al. (1992), suggests this would be indicative that puree is darkening overtime in storage as a result of enzymatic browning. Cultivar B at 80°C was inconsistent as hold times 5 min and 10 min increased in relative redness (a^*/a_0^*), while hold times 0 min, 1 min, and 3 min decreased as storage time increased. Thus, both enzymatic browning and NEB reactions can be related to the darkening of the pure over time at 80°C. At 90°C, all relative redness (a^*/a_0^*) decreased except for the hold time of 1 min during storage. Thus, both enzymatic browning and NEB reactions can be related to the darkening of the puree overtime at 90°C. 100°C follows the same trend where the 10 min hold time increased in relative redness (a^*/a_0^*), while the rest decreased. Meaning that enzymatic browning and NEB reactions can be related to the darkening of the puree over time at 100°C. Figure 4.1.11 illustrates the trendlines of cultivar C at temperatures 70°C, 90°C, and 100°C. The trendlines suggest that as hold time increases as the relative redness (a^*/a_0^*) decreases. On the other hand, temperature 80°C, showed a decrease in relative redness (a^*/a_0^*) as hold time increased. Although inconsistent, as both temperature and hold time increased, it appears the darkening of puree also progressed. A

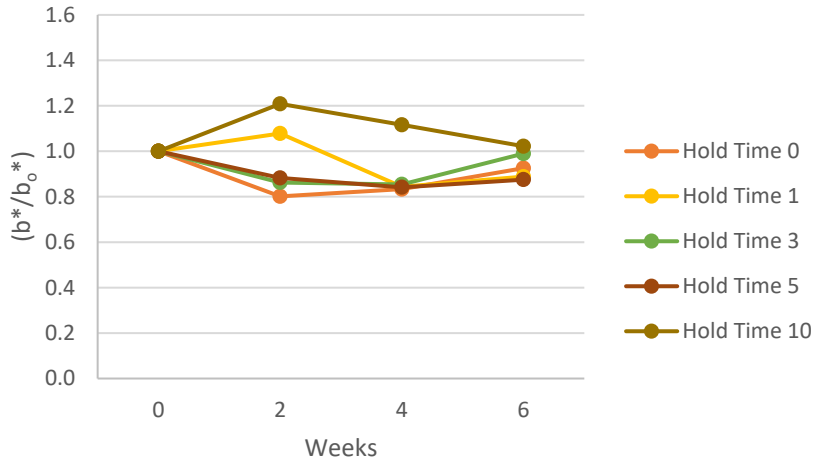
negative trendline would suggest NEB and a positive trendline would suggest enzymatic browning (Lavelli, V., Pompei, C., & Casadei, M. A. 2008; Gonzalez, Mauromoustakos, Prokakis, & Aselage, 1992). Inconsistency of data does not allow for a conclusion to be made as to the effect of increasing the temperature of processing.

Table 4.1.10. Relative variations across storage at 35°C between hold times for Cultivar A at 70°C, 80°C, 90°C, and 100°C for color parameters b^*/b_0

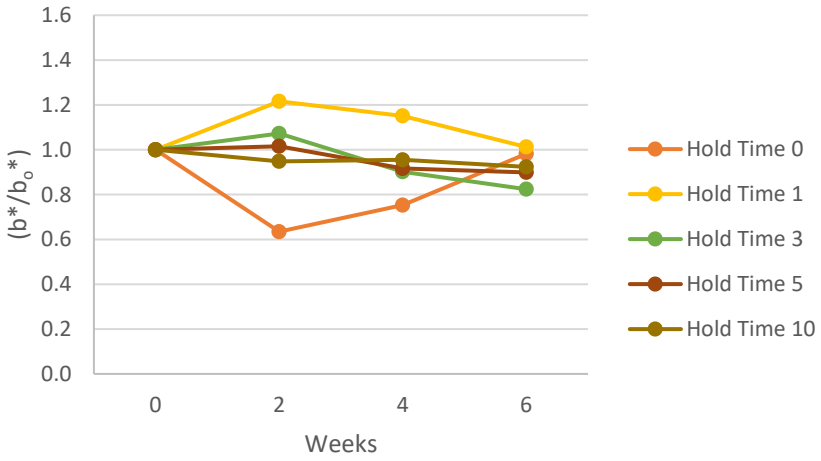
Code	Temperature (C)	Hold Time	0	2	4	6
A	70	0	1.00 $_{A}$	0.80 $_{D}$	0.83 $_{C}$	0.93 $_{B}$
A	70	1	1.00 $_{B}$	1.08 $_{A}$	0.84 $_{D}$	0.89 $_{C}$
A	70	3	1.00 $_{A}$	0.86 $_{B}$	0.85 $_{B}$	0.99 $_{A}$
A	70	5	1.00 $_{A}$	0.88 $_{B}$	0.84 $_{C}$	0.88 $_{B}$
A	70	10	1.00 $_{C}$	1.21 $_{A}$	1.12 $_{B}$	1.02 $_{C}$
A	80	0	1.00 $_{A}$	0.63 $_{B}$	0.75 $_{B}$	0.98 $_{A}$
A	80	1	1.00 $_{C}$	1.22 $_{A}$	1.15 $_{B}$	1.01 $_{C}$
A	80	3	1.00 $_{B}$	1.07 $_{A}$	0.90 $_{C}$	0.82 $_{D}$
A	80	5	1.00 $_{A}$	1.02 $_{A}$	0.92 $_{A}$	0.90 $_{A}$
A	80	10	1.00 $_{A}$	0.95 $_{B}$	0.95 $_{B}$	0.92 $_{C}$
A	90	0	1.00 $_{C}$	0.94 $_{D}$	1.09 $_{B}$	1.26 $_{A}$
A	90	1	1.00 $_{C}$	0.90 $_{D}$	1.19 $_{B}$	1.38 $_{A}$
A	90	3	1.00 $_{C}$	1.14 $_{A}$	1.09 $_{B}$	0.98 $_{D}$
A	90	5	1.00 $_{C}$	1.10 $_{A}$	1.07 $_{B}$	0.86 $_{D}$
A	90	10	1.00 $_{B}$	1.06 $_{A}$	1.05 $_{A}$	0.95 $_{C}$
A	100	0	1.00 $_{C}$	0.95 $_{D}$	1.18 $_{B}$	1.27 $_{A}$
A	100	1	1.00 $_{A}$	0.67 $_{D}$	0.77 $_{C}$	0.83 $_{B}$
A	100	3	1.00 $_{A}$	0.63 $_{D}$	0.70 $_{C}$	0.72 $_{B}$
A	100	5	1.00 $_{A}$	0.86 $_{B}$	0.74 $_{D}$	0.82 $_{C}$
A	100	10	1.00 $_{B}$	1.18 $_{A}$	0.90 $_{C}$	0.87 $_{C}$

*Different letters withing the same row indicate significant difference ($p< 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

(i)


1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(b*/b$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

(ii)


1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(b*/b$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

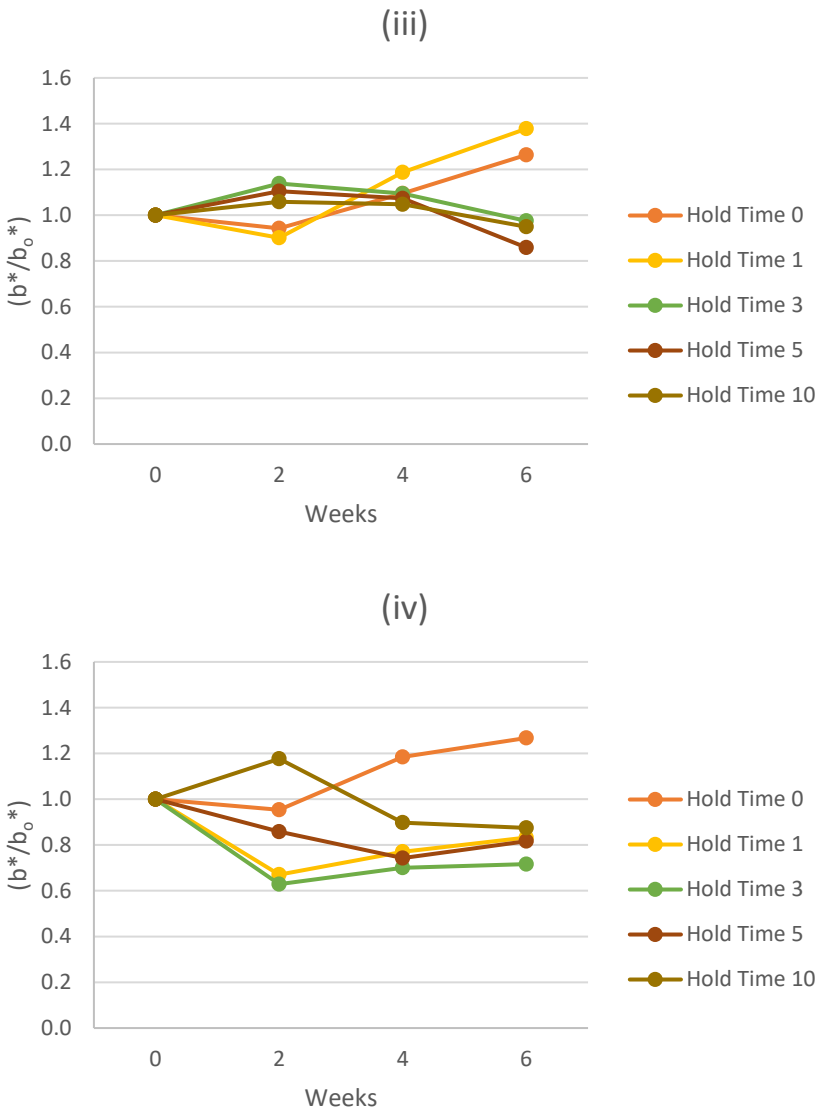


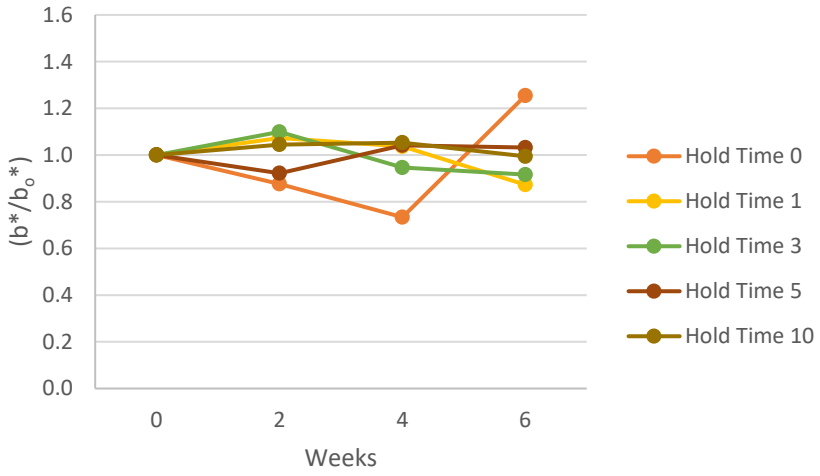
Figure 4.1.12. Relative variations across storage at 35°C between hold times for Cultivar A at 70°C (i), 80°C (ii), 90°C (iii), and 100°C (iv) for color parameters b^*/b_0^*.

Table 4.1.11. Relative variations across storage at 35°C between hold times for Cultivar B at 70°C, 80°C, 90°C, and 100°C for color parameters b^*/b_0^*.

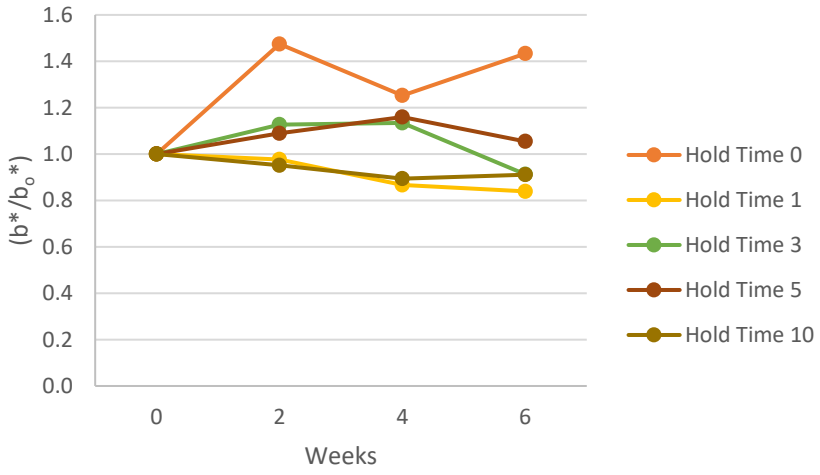
Code	Temperature (C)	Hold Time	0	2	4	6
B	70	0	1.00 $_{B}$	0.88 $_{C}$	0.73	1.25 $_{A}$
B	70	1	1.00 $_{B}$	1.07 $_{A}$	1.04	0.87 $_{C}$
B	70	3	1.00 $_{B}$	1.10 $_{A}$	0.95 $_{A}$	0.92 $_{C}$
B	70	5	1.00 $_{C}$	0.92 $_{D}$	1.04 $_{A}$	1.03 $_{B}$
B	70	10	1.00 $_{A}$	1.04 $_{A}$	1.05 $_{A}$	0.99 $_{A}$
B	80	0	1.00 $_{C}$	1.47 $_{A}$	1.25 $_{B}$	1.43 $_{A}$
B	80	1	1.00 $_{A}$	0.98 $_{A}$	0.87 $_{B}$	0.84 $_{C}$
B	80	3	1.00 $_{B}$	1.13 $_{A}$	1.13 $_{A}$	0.91 $_{C}$
B	80	5	1.00 $_{A}$	1.09 $_{A}$	1.16 $_{A}$	1.05 $_{A}$
B	80	10	1.00 $_{A}$	0.95 $_{B}$	0.89 $_{C}$	0.91 $_{C}$
B	90	0	1.00 $_{B}$	1.42 $_{A}$	1.21 $_{B}$	1.12 $_{B}$
B	90	1	1.00 $_{A}$	0.79 $_{D}$	0.94 $_{C}$	0.97 $_{B}$
B	90	3	1.00 $_{A}$	0.89 $_{AB}$	0.89 $_{AB}$	0.86 $_{B}$
B	90	5	1.00 $_{B}$	0.95 $_{C}$	1.05 $_{A}$	1.06 $_{A}$
B	90	10	1.00 $_{D}$	1.08 $_{C}$	1.27 $_{A}$	1.18 $_{B}$
B	100	0	1.00 $_{A}$	0.68 $_{C}$	0.71 $_{B}$	0.71 $_{B}$
B	100	1	1.00 $_{A}$	0.76 $_{C}$	0.64 $_{D}$	0.78 $_{B}$
B	100	3	1.00 $_{A}$	0.91 $_{B}$	0.87 $_{C}$	0.85 $_{D}$
B	100	5	1.00 $_{A}$	0.77 $_{D}$	0.95 $_{B}$	0.86 $_{C}$
B	100	10	1.00 $_{A}$	0.93 $_{AB}$	0.84 $_{C}$	0.85 $_{BC}$

*Different letters withing the same row indicate significant difference ($p< 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

(i)


1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(b*/b$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

(ii)


1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(b*/b$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

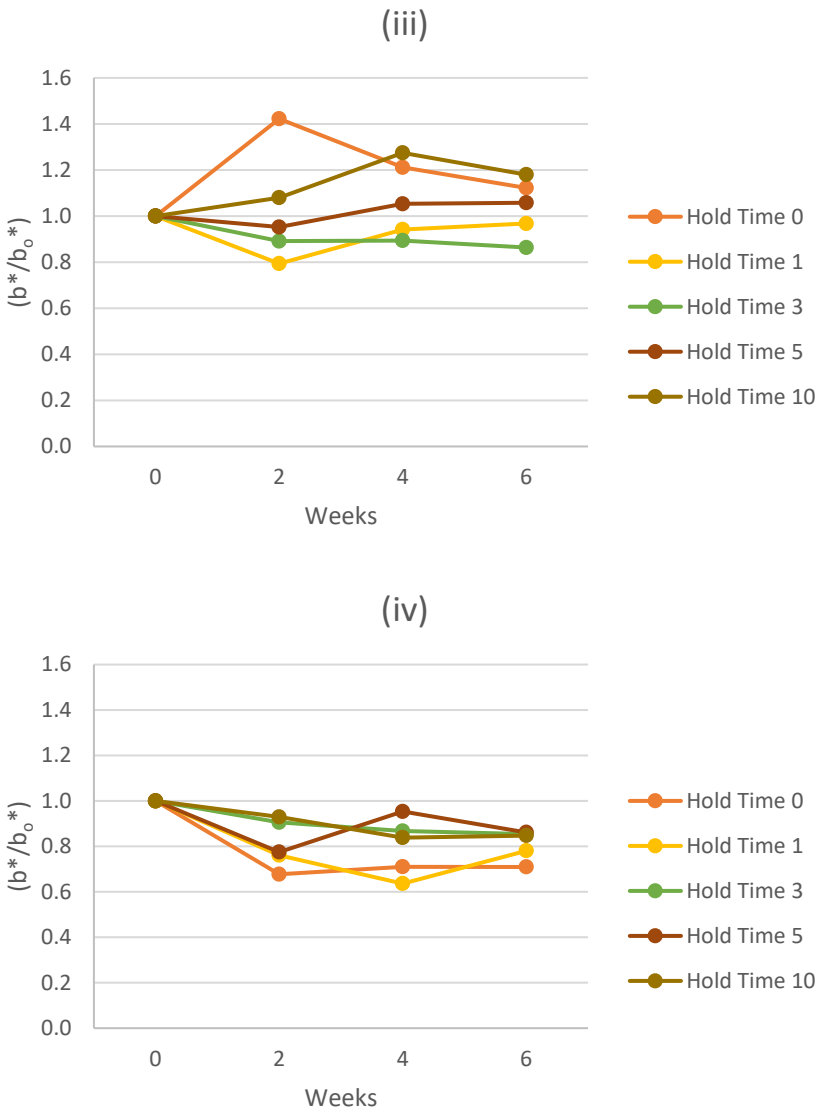


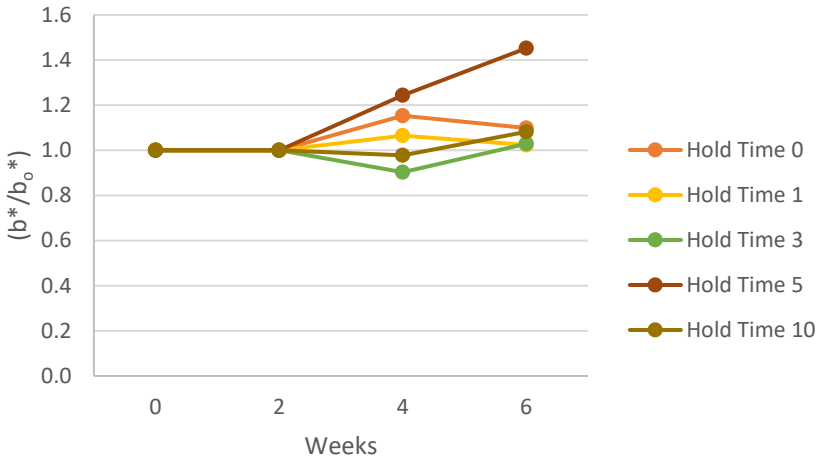
Figure 4.1.13. Relative variations across storage at 35°C between hold times for Cultivar B at 70°C (i), 80°C (ii), 90°C (iii), and 100°C (iv) for color parameters b^*/b_0^*.

Table 4.1.12. Relative variations across storage at 35°C between hold times for Cultivar B at 70°C, 80°C, 90°C, and 100°C for color parameters b^*/b_0^*.

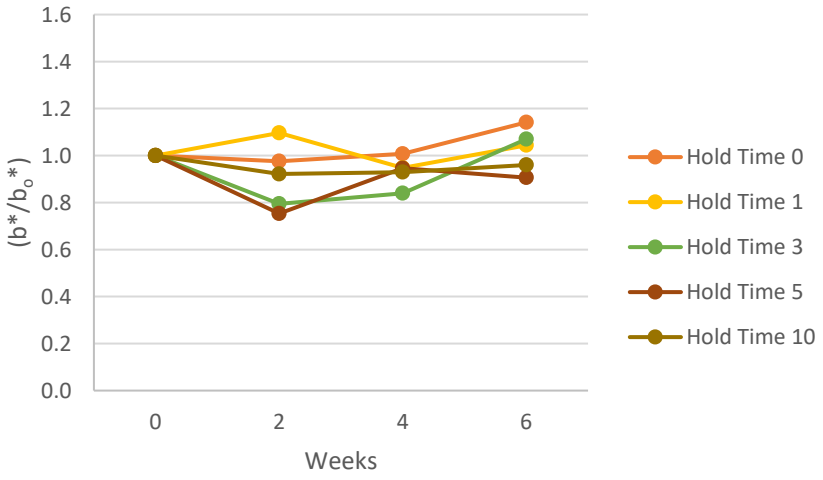
Code	Temperature (C)	Hold Time	0	2	4	6
C	70	0	1.00 $_{B}$	1.00 $_{B}$	1.15 $_{A}$	1.10 $_{A}$
C	70	1	1.00 $_{C}$	1.00 $_{C}$	1.07 $_{A}$	1.02 $_{B}$
C	70	3	1.00 $_{B}$	1.00 $_{B}$	0.90 $_{C}$	1.03 $_{A}$
C	70	5	1.00 $_{C}$	1.00 $_{C}$	1.24 $_{B}$	1.45 $_{A}$
C	70	10	1.00 $_{B}$	1.00 $_{B}$	0.98	1.08 $_{A}$
C	80	0	1.00 $_{B}$	0.98 $_{B}$	1.0 $_{B}$	1.14 $_{A}$
C	80	1	1.00 $_{C}$	1.10 $_{A}$	0.95 $_{D}$	1.04 $_{B}$
C	80	3	1.00 $_{B}$	0.79 $_{D}$	0.84 $_{C}$	1.07 $_{A}$
C	80	5	1.00 $_{A}$	0.75 $_{D}$	0.95 $_{B}$	0.91 $_{C}$
C	80	10	1.00 $_{A}$	0.92 $_{C}$	0.93 $_{C}$	0.96 $_{B}$
C	90	0	1.00 $_{A}$	0.74	0.69 $_{D}$	0.86 $_{B}$
C	90	1	1.00 $_{A}$	0.98	0.99 $_{B}$	0.85 $_{D}$
C	90	3	1.00 $_{A}$	0.88	0.94 $_{B}$	0.86 $_{D}$
C	90	5	1.00 $_{A}$	0.82	0.83 $_{B}$	0.78 $_{C}$
C	90	10	1.00 $_{D}$	1.04	1.07 $_{B}$	1.10 $_{A}$
C	100	0	1.00 $_{B}$	0.91	1.04 $_{A}$	0.85 $_{D}$
C	100	1	1.00 $_{A}$	0.88	0.84 $_{C}$	0.75 $_{D}$
C	100	3	1.00 $_{A}$	0.88	0.91 $_{B}$	0.93 $_{B}$
C	100	5	1.00 $_{A}$	0.88	0.91 $_{B}$	0.85 $_{D}$
C	100	10	1.00 $_{A}$	0.80 $_{D}$	0.84 $_{C}$	0.88 $_{B}$

*Different letters withing the same row indicate significant difference ($p< 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

(i)


1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(b*/b$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

(ii)


1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(b*/b$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

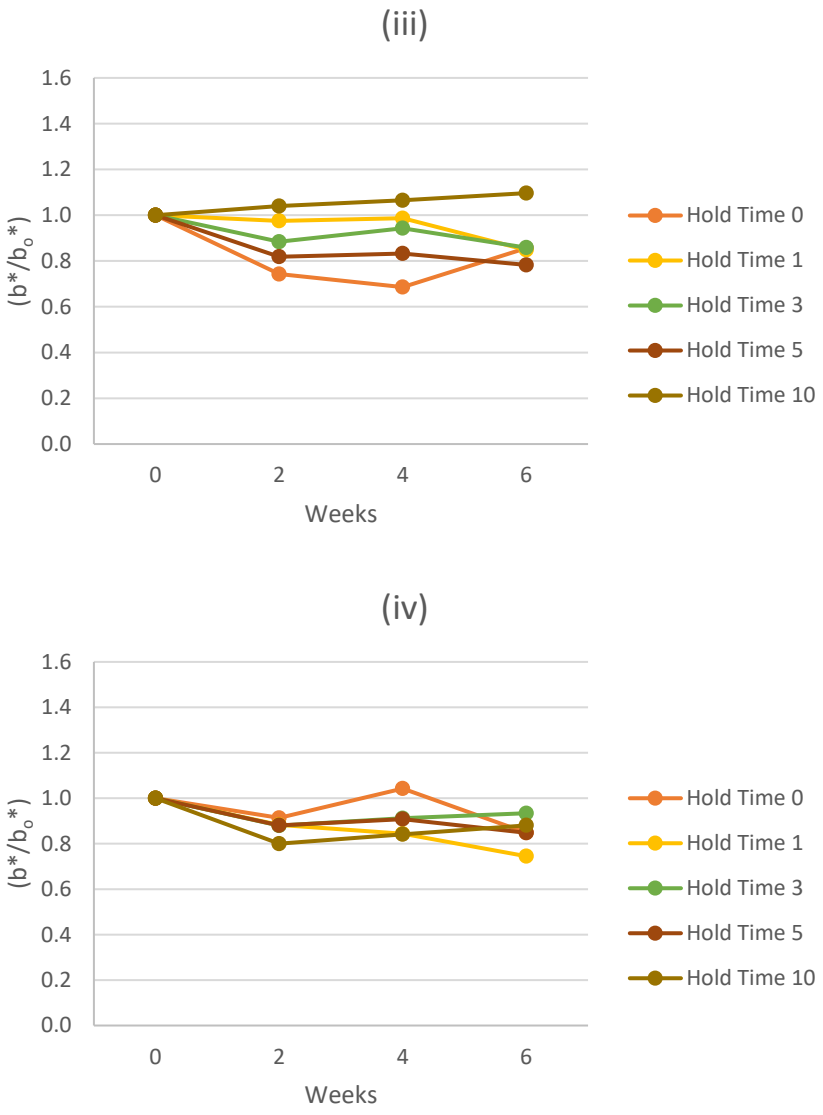
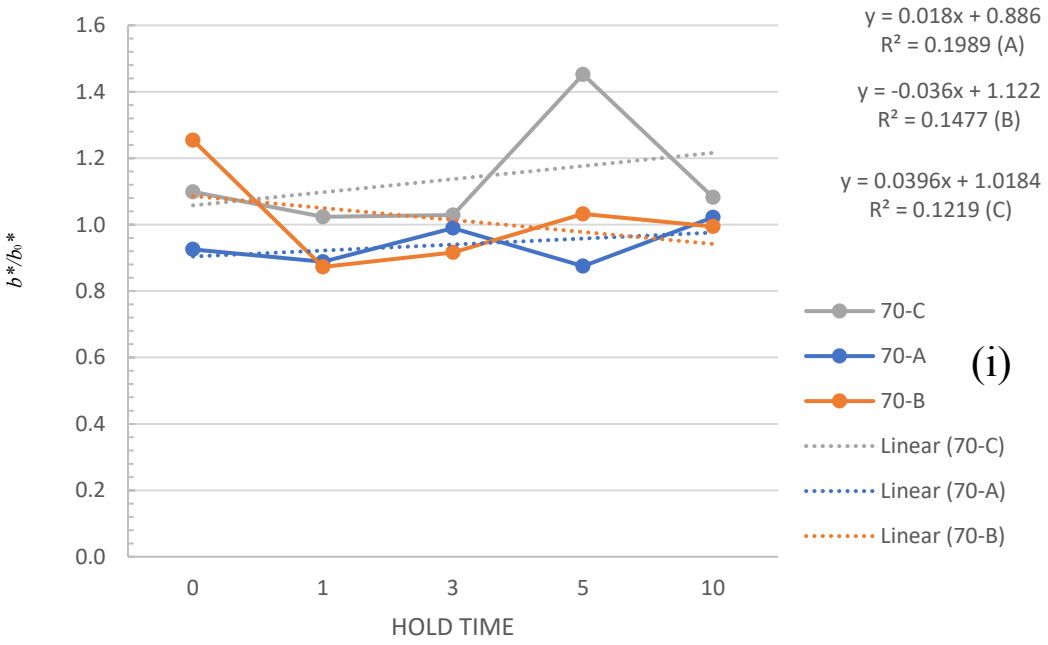
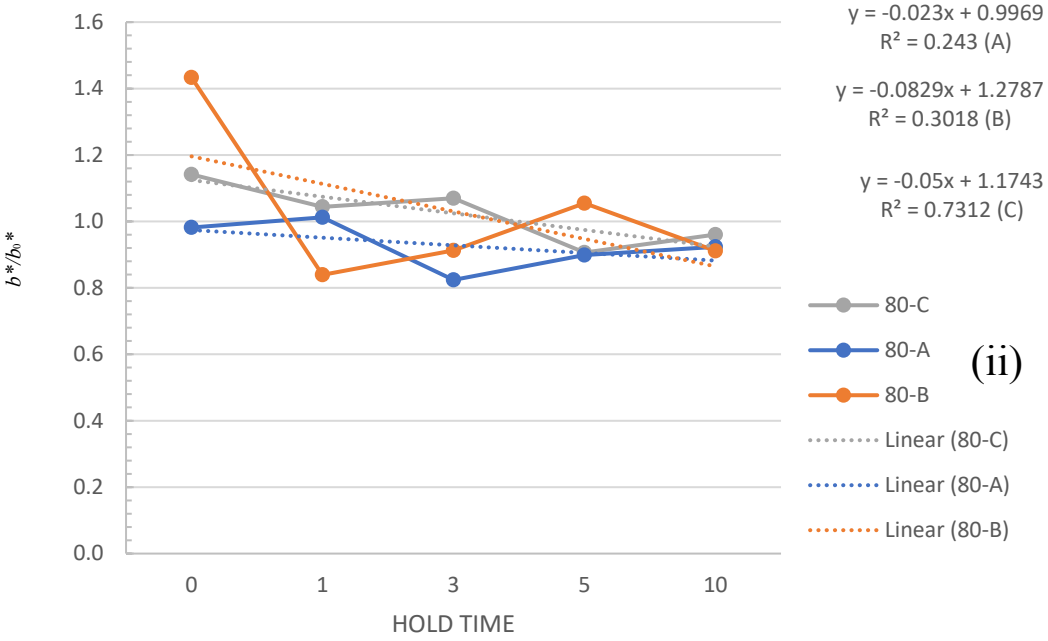


Figure 4.1.14. Relative variations across storage at 35°C between hold times for Cultivar C at 70°C (i), 80°C (ii), 90°C (iii), and 100°C (iv) for color parameters b^*/b_0^*.


y = 0.018x + 0.886
R² = 0.1989 (A)
y = -0.036x + 1.122
R² = 0.1477 (B)
y = 0.0396x + 1.0184
R² = 0.1219 (C)
70-C
70-A
70-B
Linear (70-C)
Linear (70-A)
Linear (70-B)
b*/b₀*
HOLD TIME
0
1
3
5
10
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

(i)


y = -0.023x + 0.9969
R² = 0.243 (A)
y = -0.0829x + 1.2787
R² = 0.3018 (B)
y = -0.05x + 1.1743
R² = 0.7312 (C)
80-C
80-A
80-B
Linear (80-C)
Linear (80-A)
Linear (80-B)
b*/b₀*
HOLD TIME
0
1
3
5
10
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

(ii)

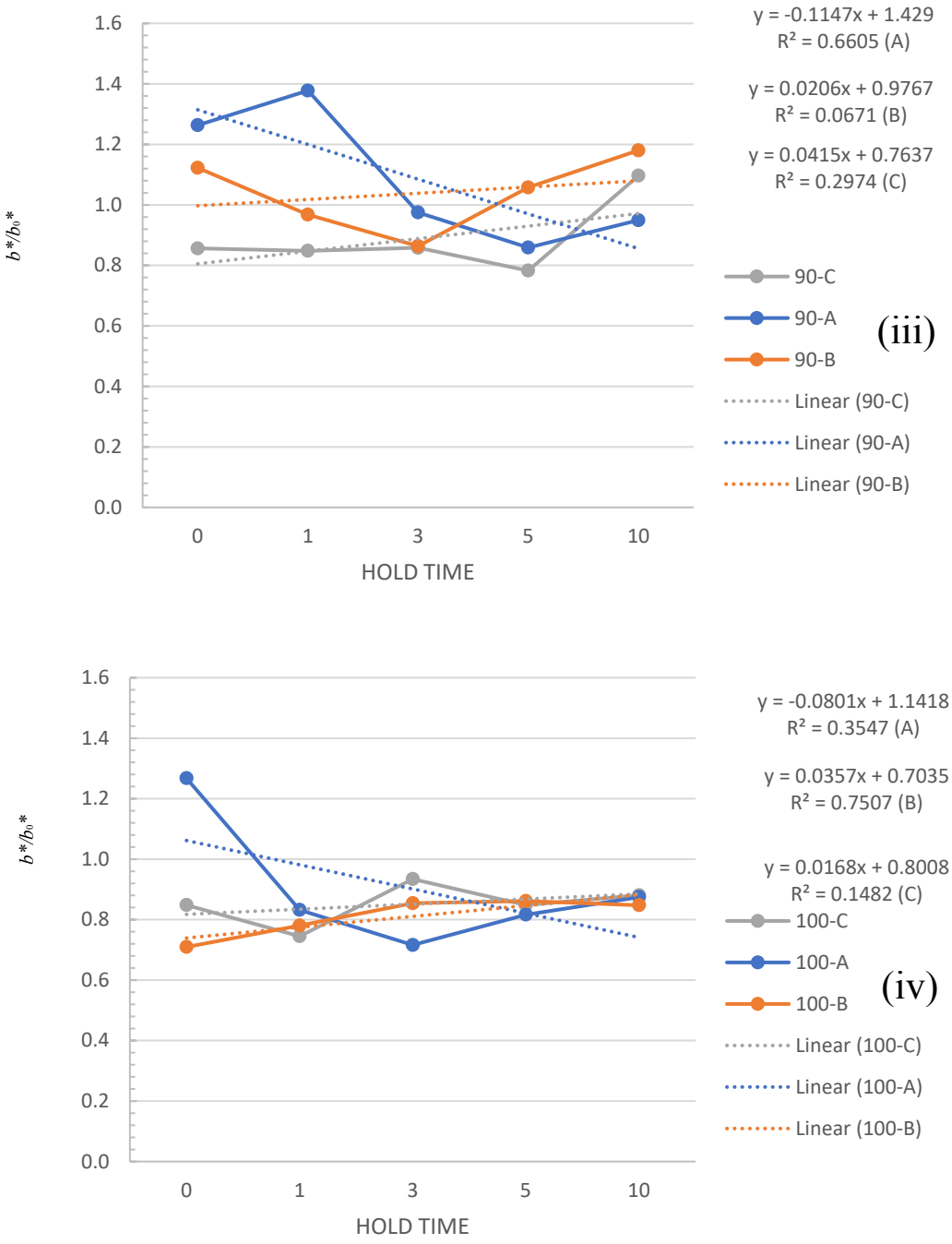


Figure 4.1.15. Relative variation across hold times for all cultivars at final week of storage at 35°C for color parameters b^*/b_0^* at 70°C (i), 80°C (ii), 90°C (iii), and 100°.

4.1.4. *b** and *b*/bo**

Lavelli et al. (2008), suggest that the positive color correlation of peach puree can be attributed to an increase in relative yellowness (b^*/b_0^*) as well as relative lightness (L^*/L_0^*). Figure 4.1.12 indicates that for cultivar A, relative yellowness (b^*/b_0^*) varied between all hold times and temperatures over storage. Meaning there was no true trend in the data was apparent. At 70°C, all hold times over time in storage in storage except for a hold time of 10 minutes. Utilizing the student's t-Test this increase at a hold time of 10 minutes can be said to be insignificant in comparison to the relative lightness observed at week 0, displayed in Table 4.1.10. Similarly, at 80°C all hold time decreased in relative yellowness except for one, hold time of 1 min over storage. Utilizing the student's t-Test this increase at a hold time of 1 min can be said to be insignificant in comparison to the relative lightness observed at Week 0, displayed in Table 4.1.11. Data for 90°C were increasing at hold times 0 and 1 min while hold times 3, 5, and 10 min decreased. Unlike temperatures 70°C and 80°C in which the data was not significant compared to Week 0, according to the student's t-Test all data were significantly different at 90°C during the final week of storage. Temperature 100°C followed the same inconsistent trend, with a hold of 1 minute increasing with all the other hold times decreasing. According to the student's t-Test, this increase was significant at week 6. Out of the 25 total data points graphed on how in terms of relative yellowness cultivar A was affected over storage 64% decreased regardless of the combination of hold time and temperature. According to Lavelli et al. (2008), this would be this would not be a positive progression of puree color. Thus, degradation of relative yellowness is taking place in over half of the variables for cultivar A. Figure 4.1.15 displays the effect of varying hold time at all temperatures for all cultivars on the color parameter (b^*/b_0^*) at the final week of storage. At 70°C the slope of the trendline for cultivar A indicates as hold time increased relative lightness was not

more negatively affected. For 80°C, 90°C, and 100°C increasing hold time did indicate to more negatively affect relative lightness based on the negative trendline present for cultivar A. The greatest negative slope was seen at 90°C meaning that when compared to 70°C and 80°C. 100°C did negatively affect relative yellowness just not as great as 90°C. Throughout storage of puree the inconsistency of data seen in color parameter (b^*/b_0^*) may be due to human error during processing or due to physiological variation within peaches used to make puree from cultivar A. Inconsistency of data does not allow for a conclusion to be made as to the effect of increasing temperature of processing.

For cultivar B, Figure 4.1.13 indicates that relative yellowness (b^*/b_0^*) varied between hold time and temperature over storage. There was no obvious trend over storage except at 100°C. At 70°C hold times 1, 3, and 5 expressed a decrease in relative yellowness hold times 0 and 5 increased relative lightness over time. According to the student's t-test data at increasing hold times were significant, displayed in table 4.1.12. Similarly, at 80°C hold times 1, 3, and 10 minutes decreased in relative yellowness while hold times 0 and 5 increased over storage. According to the student's t-test data at increasing hold times were significant, displayed in table 4.1.12. At 90°C hold times 0, 5, and 10 increased in relative yellowness while hold times 1 and 3 decreased. According to the student's t-test data at increasing hold time 0 was not significant and hold time 10 and 10 were, displayed in table 4.1.12. At 100°C all hold times decreased relative yellowness throughout storage. Out of the 25 total data points graphed on how in terms of relative yellowness cultivar B was affected over storage 52% decreased regardless of the combination of hold time and temperature. This would be this would not be a positive progression of puree color (Lavelli, Pompei, & Casadei, 2008). 52% of the purees for cultivar B experienced degradation of relative yellowness throughout storage. Figure 4.1.15 indicates that at 70°C and 80°C as hold time

increased relative yellowness (b^*/b_0^*) was more negatively affected based on negative trendlines for cultivar B. In contrast, temperatures 90°C and 100°C displayed that as hold time increased, although minute, relative yellowness (b^*/b_0^*) did not. Throughout the storage of puree, the inconsistency of data seen in color parameter (b^*/b_0^*) may be due to human error during processing or due to physiological variation within peaches used to make puree from cultivar B. Inconsistency of data does not allow for a conclusion to be made as to the effect of increasing temperature of processing.

For cultivar C, Figure 4.1.14 indicates that relative yellowness (b^*/b_0^*) varied between hold time and temperature over storage. At 70°C all hold times increased relative yellowness over storage. Table 4.1.12 indicates this increase in relative yellowness was significant from weeks 0-6. At 80°C hold times 3 and 10 decreased in relative yellowness while hold times 0, 1, and 5 increased. Table 4.1.13 indicates this increase to be significant over storage. At 90°C all hold times decreased in relative yellowness except for hold time 10 minute. Table 4.1.12 indicates this increase in relative yellowness was significant from weeks 0-6. Temperature 100°C all hold times decreased in relative yellowness over storage. 44% of the purees for cultivar B experienced degradation of relative yellowness throughout storage. According to Lavelli et al. (2008), this would be a positive progression of puree color. Figure 4.1.15 illustrates that at 70°C, 90°C, and 100°C as hold time increased relative yellowness (b^*/b_0^*) was not more negatively affected. In contrast, at 80°C increasing hold time did in fact negatively affect relative yellowness (b^*/b_0^*). Similarly, to cultivars A and B the inconsistency of data over storage seen in color parameter (b^*/b_0^*) may be due to human error during processing or due to physiological variation within peaches used to make puree from cultivar B. Inconsistency of data does not allow for a conclusion to be made as to the effect of increasing temperature of processing.

4.2. Browning Index (BI) and Hydroxymethylfurfural (HMF) Analysis

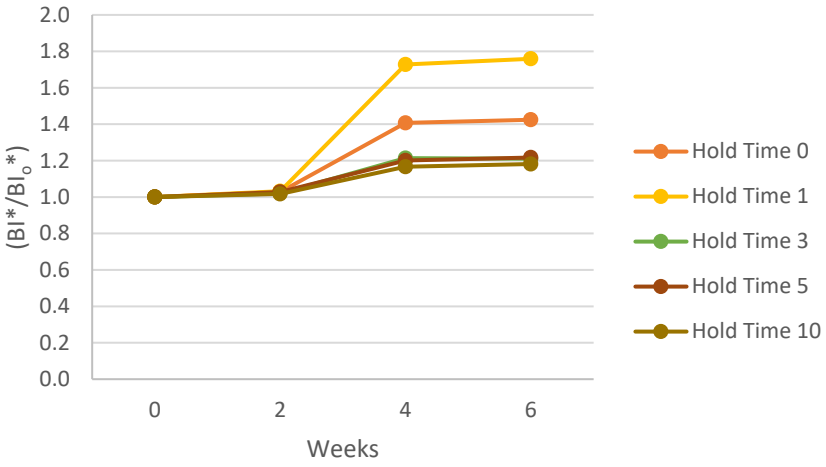
Spectrophotometric absorption at 420 nm after ethanol extraction was utilized to analyze the browning development of each puree throughout storage at the varying temperature and hold time treatments to detect brown pigments associated with the browning index (BI). Additional spectrophotometric absorption at 443 nm after thiobarbituric acid (TBA) extraction was utilized to detect the presence or concentration of the Hydroxymethylfurfural (HMF) molecule within each puree throughout storage at the varying temperature and hold time treatments. Beer's law suggests that absorption and concentration are directly proportional when a linear slope is present (Fuwa et al. 1963). Thus, linear trendlines can be extrapolated for BI and HMF to assume that when an increasing trendline is seen so is the concentration and vice versa for decreasing trendlines. Lyu et al. (2018), discovered that NEB reactions can be highly correlated to increasing BI and HMF. Collectively, research into NEB reactions, HMF, and BI suggest that when storage, processing time, and processing temperature are increased so should the absorption at 420 nm (BI) and 443 nm (HMF) (Lyu, Liu, Bi, Wu, Zhou, Ruan, Zhao, Jiao, 2018; Khalil, Sulaiman, & Gan, 2010; Moniruzzaman, Khalil, Sulaiman, & Gan, 2013; Cámara, Matallana, Sánchez-Mata, Lillo Ayué, & Labra, 2003). It is important to note that BI only detects brown pigments. BI will not delineate between the enzymatic browning and non-enzymatic browning reactions. However, HMF is an intermediate involved in a cascade of reactions leading to the formation of melanoidins associated with Maillard browning reactions (NEB).

Table 4.2.1 Relative variations across storage at 35°C between hold times for Cultivar A at 70°C, 80°C, 90°C, and 100°C for Browning Index absorbance at 420 nm.

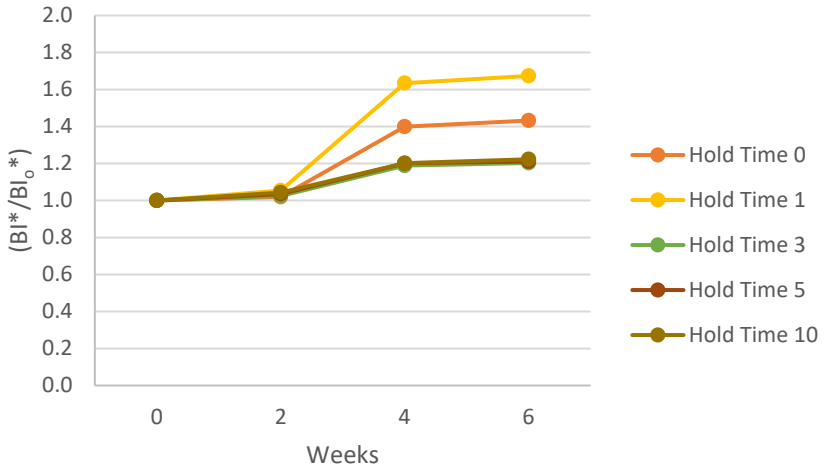
Code	Temperature (C)	Hold Time	0	2	4	6
A	70	0	1.00 $_{D}$	1.03 $_{B}$	1.41 $_{B}$	1.42 $_{A}$
A	70	1	1.00 $_{B}$	1.03 $_{B}$	1.73 $_{A}$	1.76 $_{A}$
A	70	3	1.00 $_{C}$	1.02 $_{B}$	1.21 $_{A}$	1.21 $_{A}$
A	70	5	1.00 $_{B}$	1.03 $_{A}$	1.20 $_{A}$	1.22 $_{A}$
A	70	10	1.00 $_{D}$	1.02 $_{A}$	1.17 $_{B}$	1.18 $_{A}$
A	80	0	1.00 $_{D}$	1.02 $_{C}$	1.40 $_{B}$	1.43 $_{A}$
A	80	1	1.00 $_{B}$	1.05 $_{B}$	1.63 $_{A}$	1.67 $_{A}$
A	80	3	1.00 $_{B}$	1.02 $_{B}$	1.19 $_{A}$	1.20 $_{A}$
A	80	5	1.00 $_{C}$	1.04 $_{B}$	1.20 $_{A}$	1.21 $_{A}$
A	80	10	1.00 $_{C}$	1.04 $_{B}$	1.20 $_{A}$	1.22 $_{A}$
A	90	0	1.00 $_{B}$	1.02 $_{B}$	1.23 $_{A}$	1.27 $_{A}$
A	90	1	1.00 $_{D}$	1.06 $_{C}$	1.62 $_{B}$	1.68 $_{A}$
A	90	3	1.00 $_{D}$	1.01 $_{C}$	1.20 $_{B}$	1.22 $_{A}$
A	90	5	1.00 $_{D}$	1.07 $_{C}$	1.21 $_{B}$	1.25 $_{A}$
A	90	10	1.00 $_{C}$	1.07 $_{B}$	1.21 $_{A}$	1.22 $_{A}$
A	100	0	1.00 $_{D}$	1.05 $_{C}$	1.29 $_{B}$	1.32 $_{A}$
A	100	1	1.00 $_{C}$	1.06 $_{B}$	1.51 $_{A}$	1.57 $_{A}$
A	100	3	1.00 $_{B}$	1.03 $_{B}$	1.22 $_{A}$	1.24 $_{A}$
A	100	5	1.00 $_{C}$	1.08 $_{B}$	1.24 $_{A}$	1.26 $_{A}$
A	100	10	1.00 $_{C}$	1.08 $_{B}$	1.22 $_{A}$	1.23 $_{A}$

*Different letters withing the same row indicate significant difference ($p < 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

(i)


2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(BI*/BI$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

(ii)


2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(BI*/BI$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

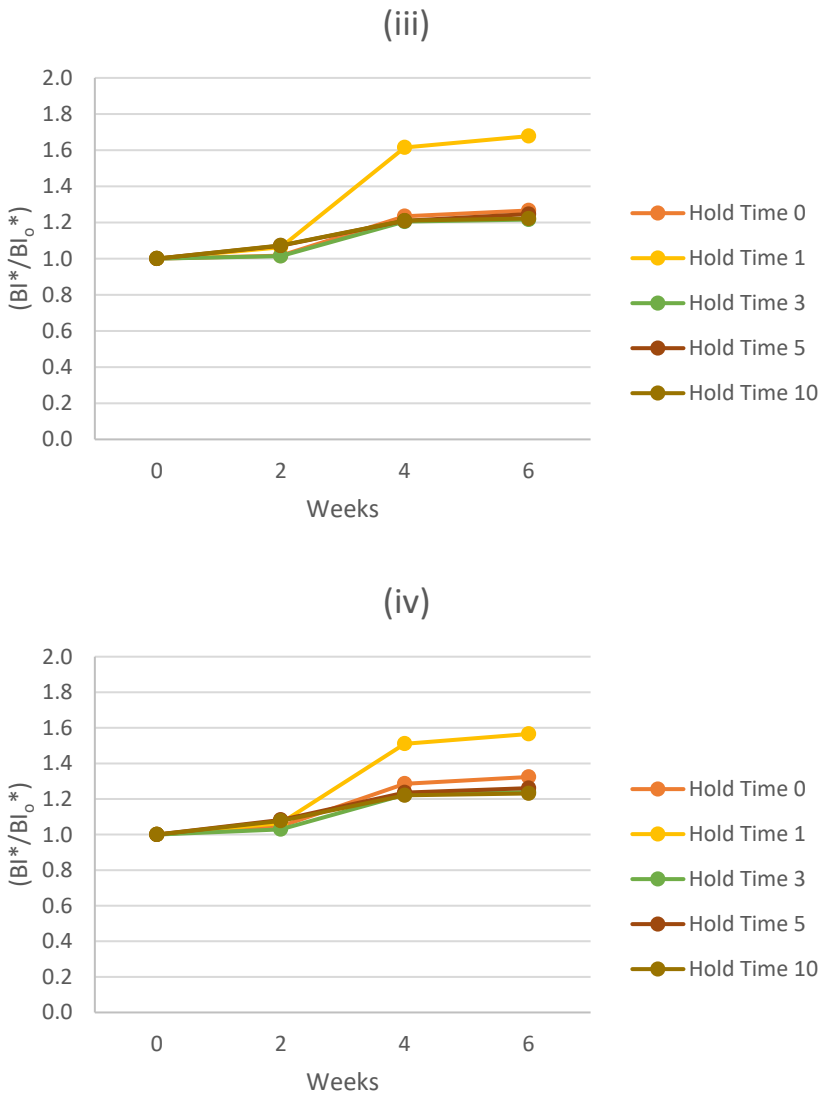


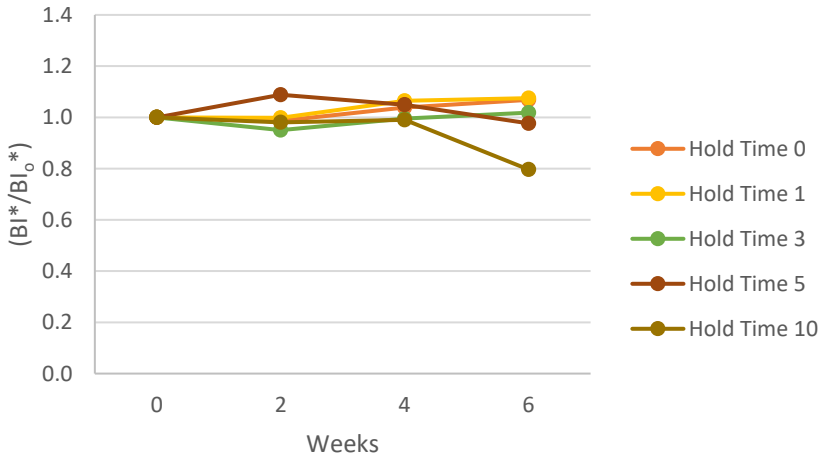
Figure 4.2.1 Relative variations across storage at 35°C between hold times for Cultivar A at 70°C (i), 80°C (ii), 90°C (iii), and 100°C (iv) for Browning Index absorbance at 420 nm.

Table 4.2.2 Relative variations across storage at 35°C between hold times for Cultivar B at 70°C, 80°C, 90°C, and 100°C for Browning Index absorbance at 420 nm.

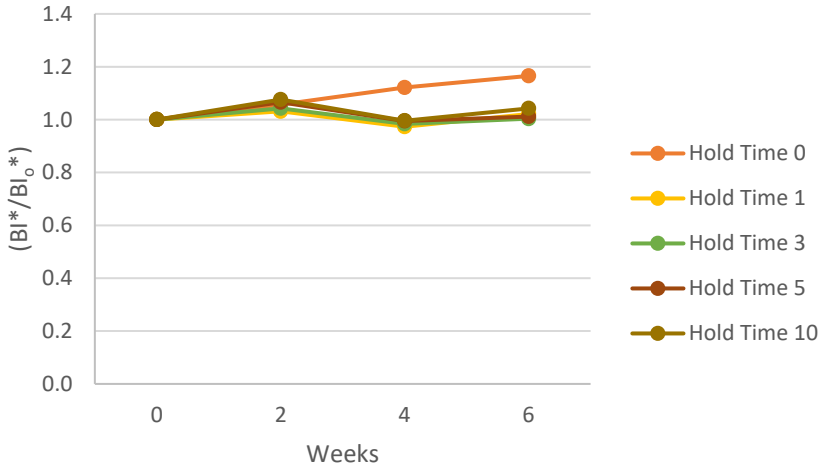
Code	Temperature (C)	Hold Time	0	2	4	6
B	70	0	1.00 $_{A}$	0.99 $_{A}$	1.04 $_{A}$	1.07 $_{A}$
B	70	1	1.00 $_{A}$	1.00 $_{A}$	1.06 $_{A}$	1.08 $_{A}$
B	70	3	1.00 c	0.95 $_{B}$	1.00 $_{AB}$	1.02 $_{A}$
B	70	5	1.00 $_{A}$	1.09 $_{A}$	1.05 $_{B}$	0.98 $_{A}$
B	70	10	1.00 $_{A}$	0.98 $_{A}$	0.99 $_{A}$	0.80 $_{B}$
B	80	0	1.00 $_{D}$	1.06 $_{C}$	1.12 $_{B}$	1.17 $_{A}$
B	80	1	1.00 $_{A}$	1.03 $_{A}$	0.97 $_{A}$	1.02 $_{A}$
B	80	3	1.00 $_{B}$	1.04 $_{A}$	0.98 c	1.00 $_{B}$
B	80	5	1.00 $_{B}$	1.07 $_{A}$	0.99 c	1.01 $_{B}$
B	80	10	1.00 c	1.08 $_{A}$	1.00 c	1.04 $_{B}$
B	90	0	1.00 $_{D}$	1.08 $_{C}$	1.14 $_{B}$	1.21 $_{A}$
B	90	1	1.00 c	1.03 $_{B}$	0.99 c	1.08 $_{A}$
B	90	3	1.00 c	1.05 $_{B}$	1.01 c	1.09 $_{A}$
B	90	5	1.00 $_{B}$	1.05 $_{A}$	1.00 $_{B}$	1.06 $_{A}$
B	90	10	1.00 c	1.05 $_{B}$	1.00 c	1.07 $_{A}$
B	100	0	1.00 $_{D}$	1.10 c	1.15 $_{B}$	1.22 $_{A}$
B	100	1	1.00 $_{D}$	1.04 $_{B}$	1.02 c	1.10 $_{A}$
B	100	3	1.00 c	1.02 $_{B}$	1.02 $_{B}$	1.08 $_{A}$
B	100	5	1.00 $_{D}$	1.02 c	1.04 $_{B}$	1.07 $_{A}$
B	100	10	1.00 $_{D}$	1.03 c	1.08 $_{B}$	1.13 $_{A}$

*Different letters withing the same row indicate significant difference ($p < 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

(i)


1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(BI*/BI$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

(ii)


1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(BI*/BI$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

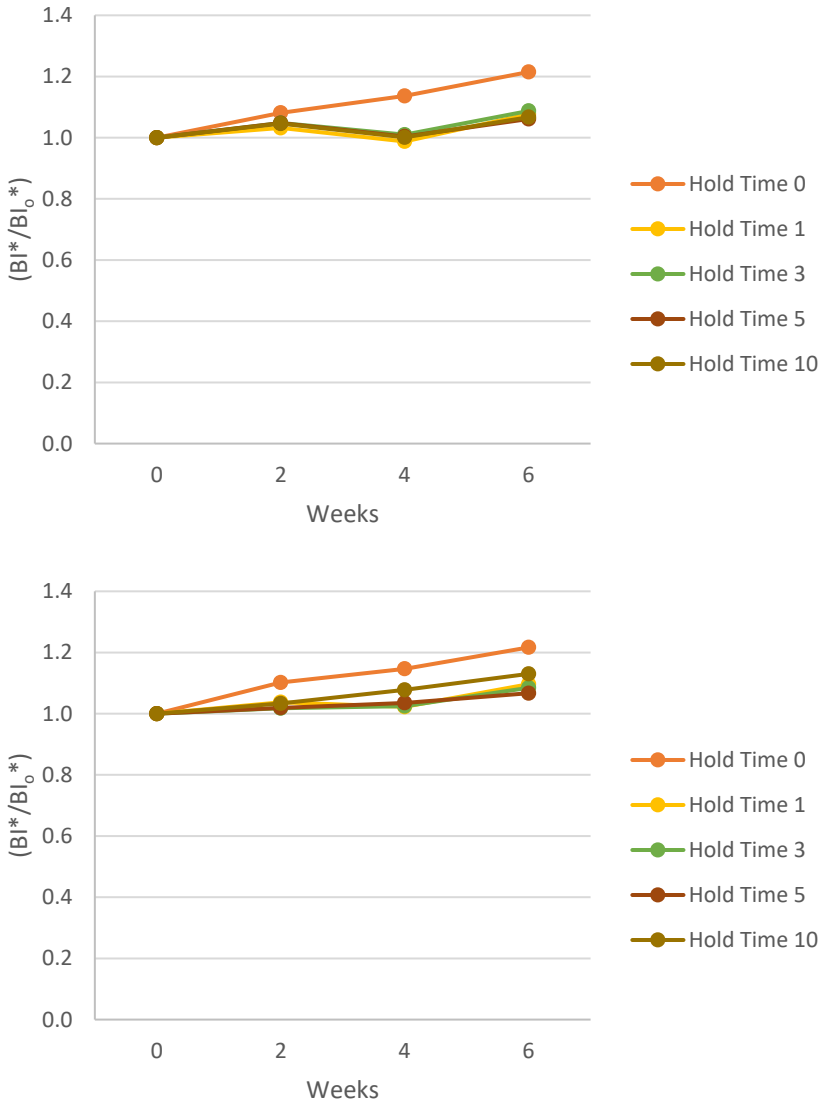


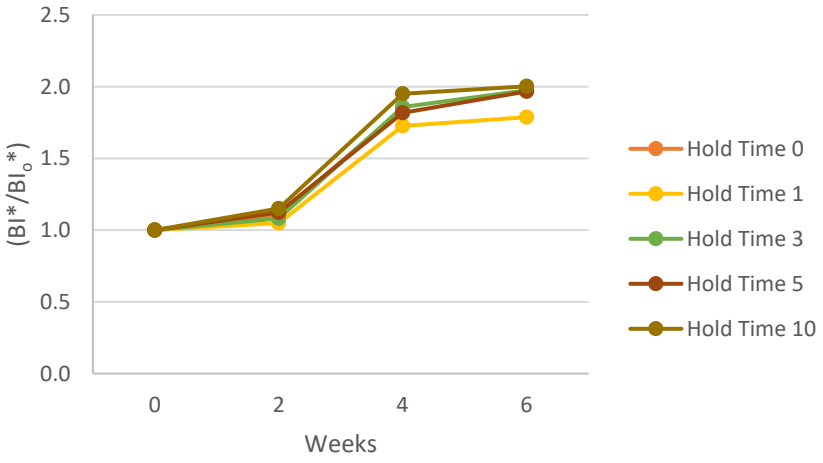
Figure 4.2.2 Relative variations across storage at 35°C between hold times for Cultivar B at 70°C (i), 80°C (ii), 90°C (iii), and 100°C (iv) for Browning Index absorbance at 420 nm**.**

Table 4.2.3 Relative variations across storage at 35°C between hold times for Cultivar C at 70°C, 80°C, 90°C, and 100°C for Browning Index absorbance at 420 nm.

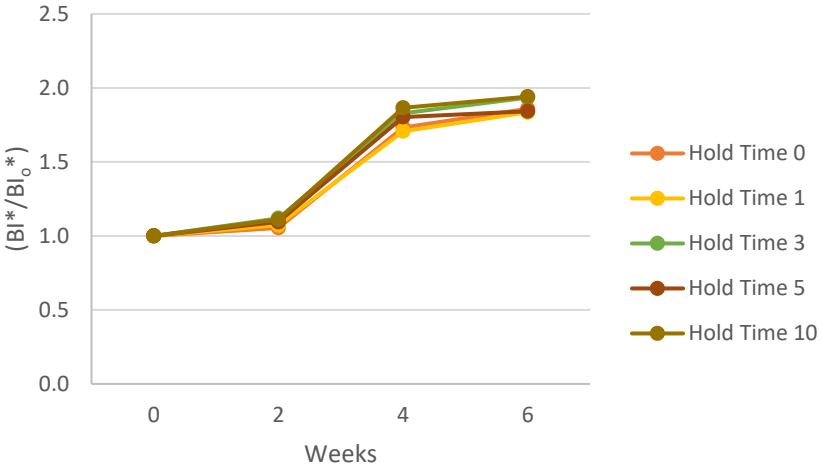
Code	Temperature (C)	Hold Time	0	2	4	6
C	70	0	1.00 $_{B}$	1.11 $_{B}$	1.84 $_{A}$	1.93 $_{A}$
C	70	1	1.00 $_{D}$	1.05 $_{C}$	1.73 $_{B}$	1.79 $_{A}$
C	70	3	1.00 $_{D}$	1.08 $_{C}$	1.86 $_{B}$	1.98 $_{A}$
C	70	5	1.00 $_{B}$	1.12 $_{B}$	1.82 $_{A}$	1.97 $_{A}$
C	70	10	1.00 $_{D}$	1.15 $_{C}$	1.95 $_{B}$	2.00 $_{A}$
C	80	0	1.00 $_{D}$	1.05 $_{C}$	1.73 $_{B}$	1.86 $_{A}$
C	80	1	1.00 $_{D}$	1.07 $_{C}$	1.71 $_{B}$	1.84 $_{A}$
C	80	3	1.00 $_{D}$	1.12 $_{C}$	1.83 $_{B}$	1.93 $_{A}$
C	80	5	1.00 $_{C}$	1.09 $_{B}$	1.80 $_{A}$	1.84 $_{A}$
C	80	10	1.00 $_{D}$	1.11 $_{C}$	1.87 $_{B}$	1.94 $_{A}$
C	90	0	1.00 $_{D}$	1.17 $_{C}$	1.71 $_{B}$	1.85 $_{A}$
C	90	1	1.00 $_{D}$	1.16 $_{C}$	1.69 $_{B}$	1.82 $_{A}$
C	90	3	1.00 $_{D}$	1.15 $_{C}$	1.83 $_{B}$	1.93 $_{A}$
C	90	5	1.00 $_{D}$	1.09 $_{C}$	1.82 $_{B}$	1.85 $_{A}$
C	90	10	1.00 $_{D}$	1.09 $_{C}$	1.80 $_{B}$	1.83 $_{A}$
C	100	0	1.00 $_{D}$	1.16 $_{C}$	1.76 $_{B}$	1.86 $_{A}$
C	100	1	1.00 $_{D}$	1.18 $_{C}$	1.77 $_{B}$	1.85 $_{A}$
C	100	3	1.00 $_{D}$	1.19 $_{C}$	1.79 $_{B}$	1.86 $_{A}$
C	100	5	1.00 $_{C}$	1.20 $_{B}$	1.87 $_{A}$	1.90 $_{A}$
C	100	10	1.00 $_{D}$	1.15 $_{C}$	1.77 $_{B}$	1.80 $_{A}$

*Different letters withing the same row indicate significant difference ($p< 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

(i)


2.5
2.0
1.5
1.0
0.5
0.0
(BI*/BI$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

(ii)


2.5
2.0
1.5
1.0
0.5
0.0
(BI*/BI$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

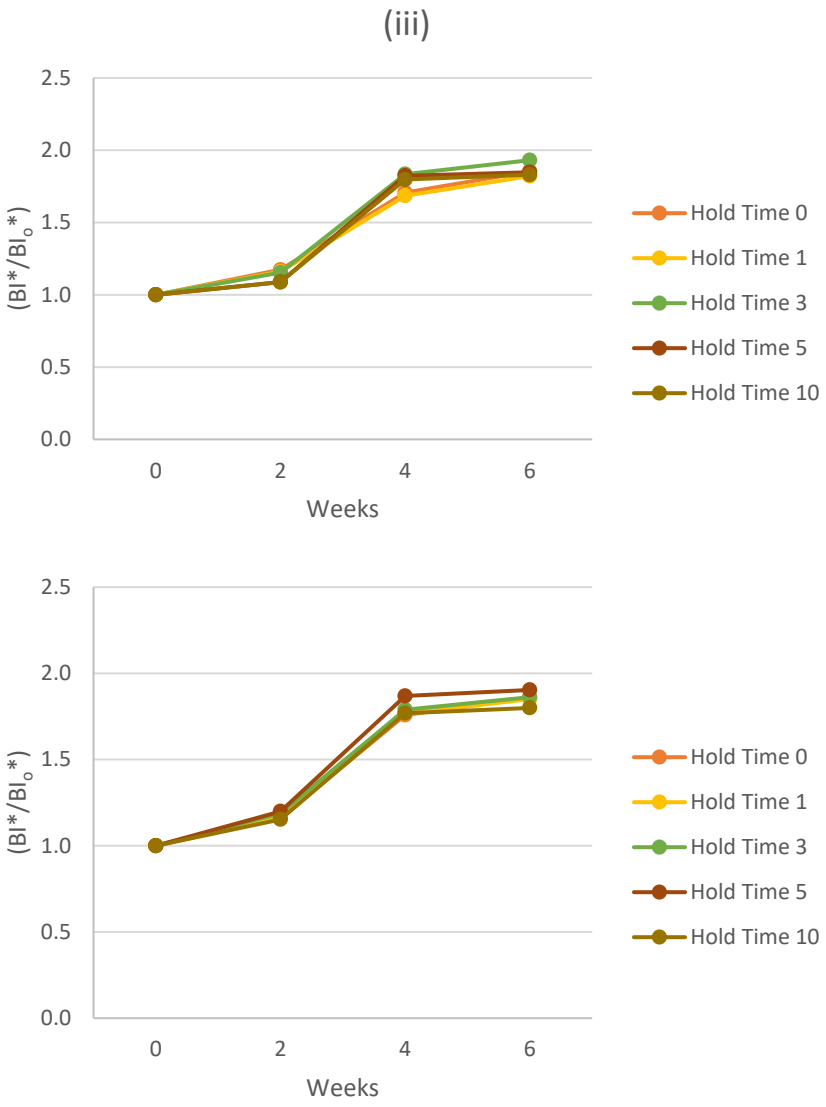
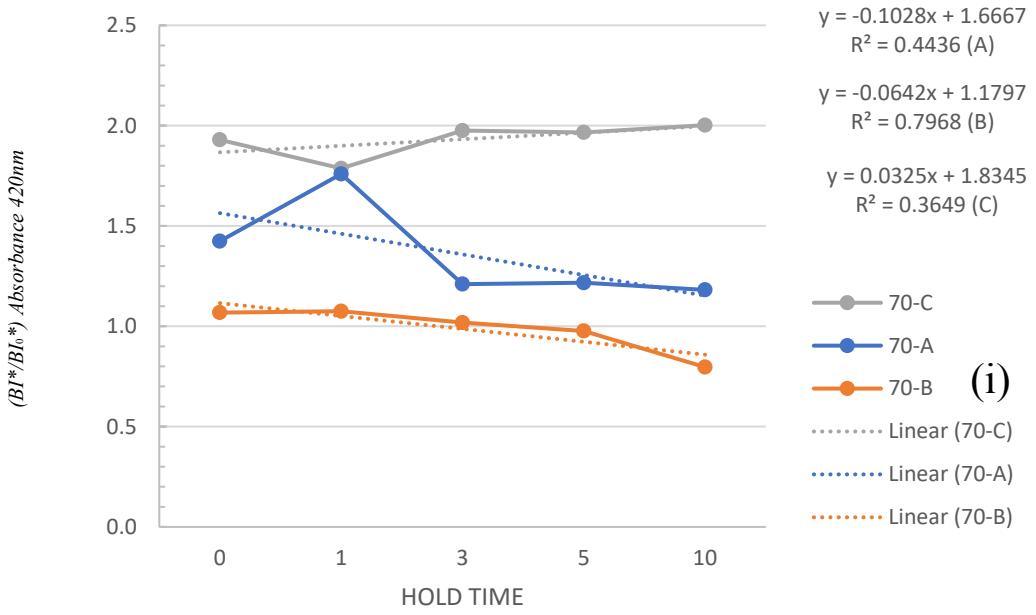
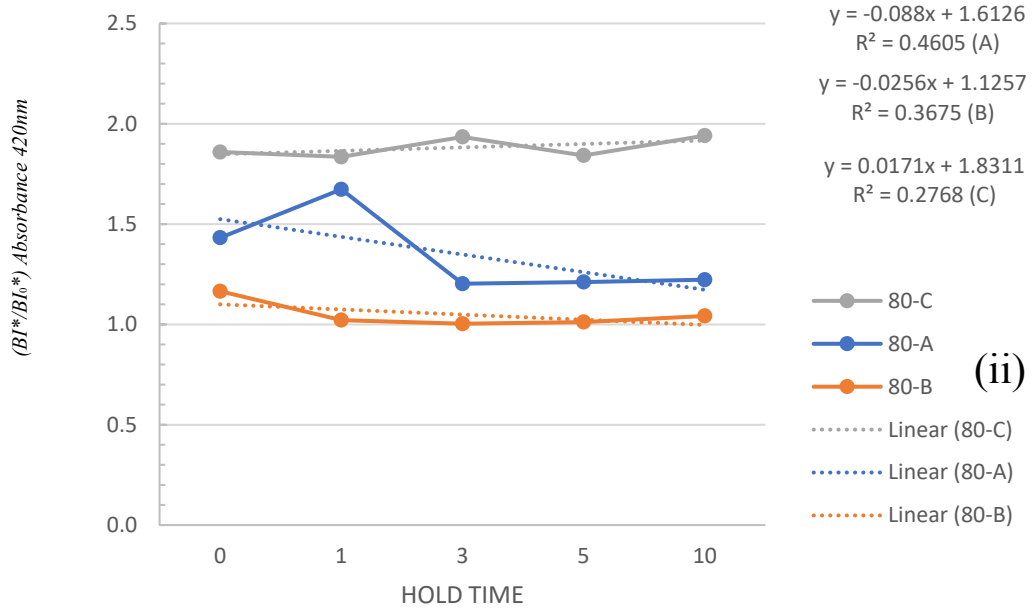


Figure 4.2.3 Relative variations across storage at 35°C between hold times for Cultivar C at 70°C (i), 80°C (ii), 90°C (iii), and 100°C (iv) for Browning Index absorbance at 420 nm**.**


(BI*/BI₀*) Absorbance 420nm
2.5
2.0
1.5
1.0
0.5
0.0
0
1
3
5
10
HOLD TIME
y = -0.1028x + 1.6667
R² = 0.4436 (A)
y = -0.0642x + 1.1797
R² = 0.7968 (B)
y = 0.0325x + 1.8345
R² = 0.3649 (C)
70-C
70-A
70-B
Linear (70-C)
Linear (70-A)
Linear (70-B)

(i)


(BI*/BI₀*) Absorbance 420nm
2.5
2.0
1.5
1.0
0.5
0.0
0
1
3
5
10
HOLD TIME
y = -0.088x + 1.6126
R² = 0.4605 (A)
y = -0.0256x + 1.1257
R² = 0.3675 (B)
y = 0.0171x + 1.8311
R² = 0.2768 (C)
80-C
80-A
80-B
Linear (80-C)
Linear (80-A)
Linear (80-B)

(ii)

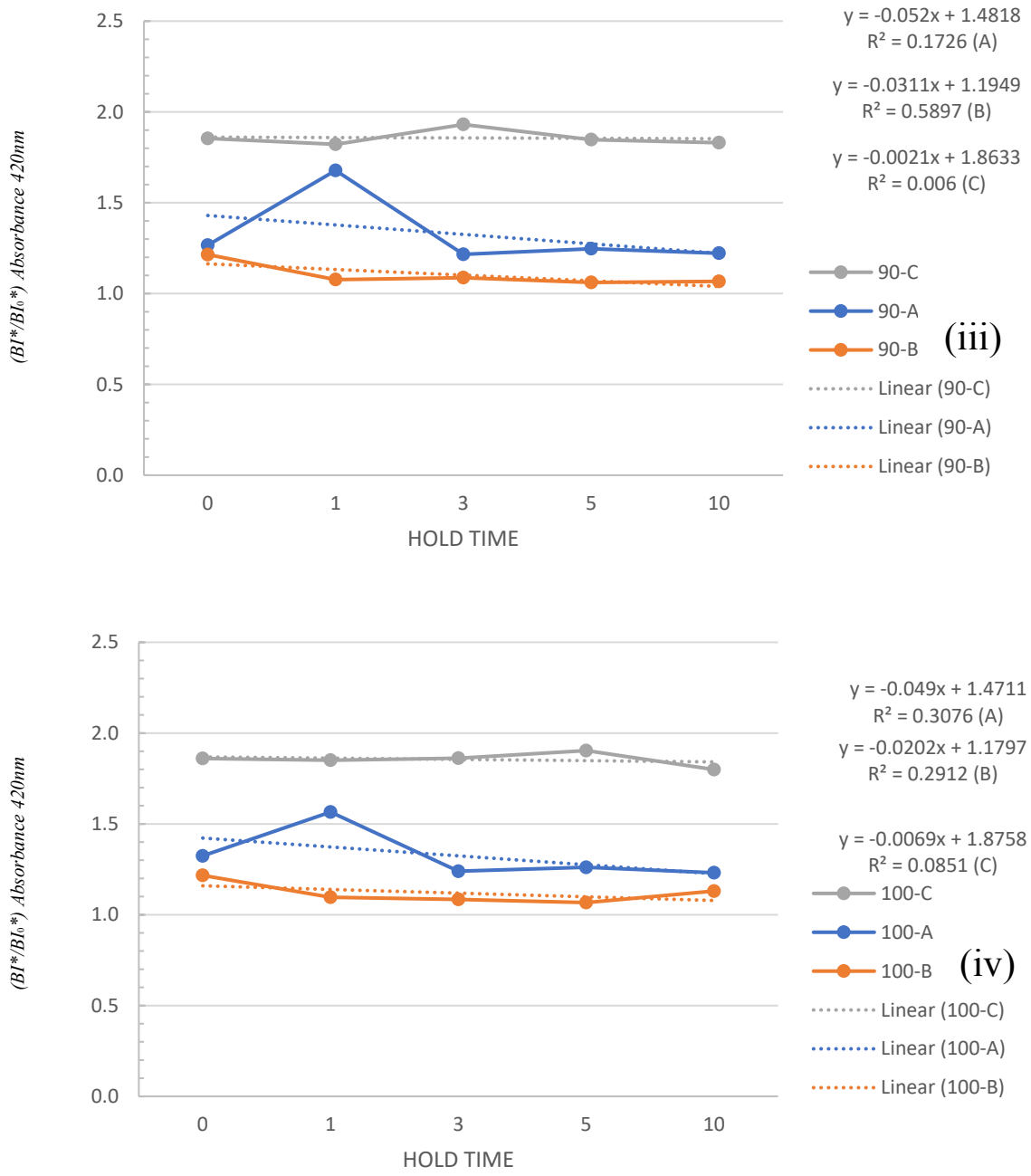


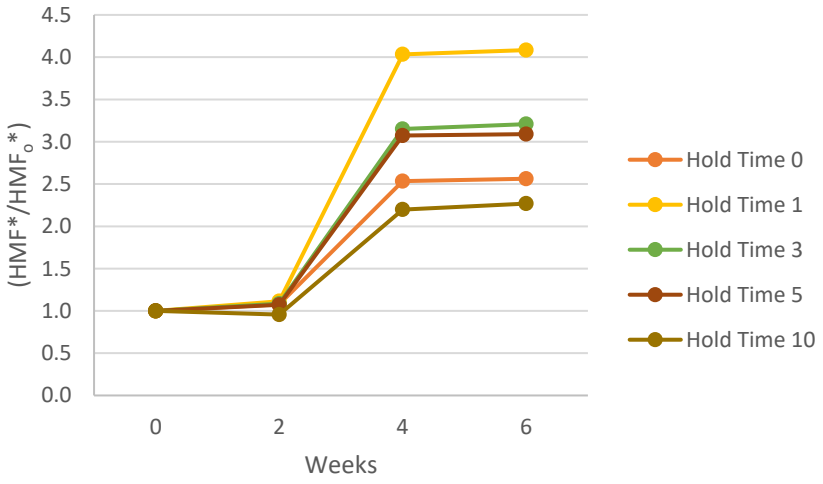
Figure 4.2.4. Relative variation across hold times for all cultivars at final week of storage at 35°C for Browning Index absorbance at 420 nm at 70°C (i), 80°C (ii), 90°C (iii), and 100°.

Table 4.2.4 Relative variations across storage at 35°C between hold times for Cultivar A at 70°C, 80°C, 90°C, and 100°C for Hydroxymethylfurfural absorbance at 443 nm.

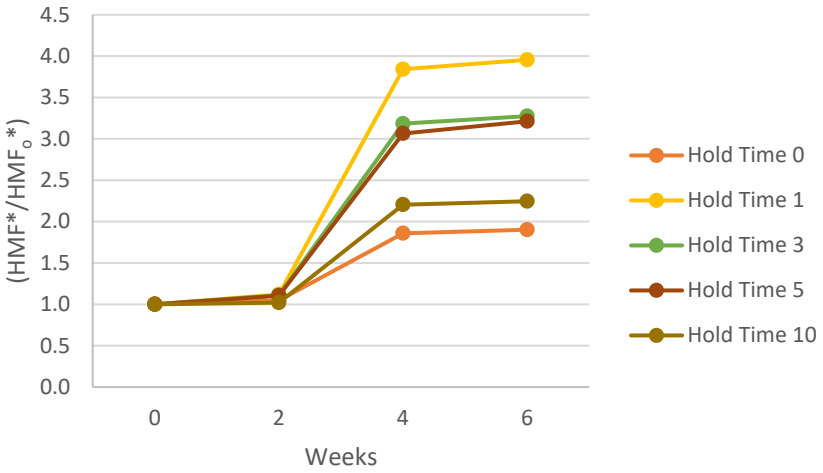
Code	Temperature (C)	Hold Time	0	2	4	6
A	70	0	1.00 $_{B}$	1.08 $_{B}$	2.53 $_{A}$	2.56 $_{A}$
A	70	1	1.00 $_{B}$	1.11 $_{B}$	4.03 $_{A}$	4.08 $_{A}$
A	70	3	1.00 $_{B}$	1.08 $_{B}$	3.15 $_{A}$	3.21 $_{A}$
A	70	5	1.00 $_{B}$	1.07 $_{B}$	3.07 $_{A}$	3.09 $_{A}$
A	70	10	1.00 $_{B}$	0.96 $_{B}$	2.20 $_{A}$	2.27 $_{A}$
A	80	0	1.00 $_{B}$	1.05 $_{B}$	1.86 $_{A}$	1.90 $_{A}$
A	80	1	1.00 $_{B}$	1.12 $_{B}$	3.84 $_{A}$	3.96 $_{A}$
A	80	3	1.00 $_{B}$	1.11 $_{B}$	3.18 $_{A}$	3.27 $_{A}$
A	80	5	1.00 $_{B}$	1.10 $_{B}$	3.07 $_{A}$	3.21 $_{A}$
A	80	10	1.00 $_{B}$	1.02 $_{B}$	2.20 $_{A}$	2.25 $_{A}$
A	90	0	1.00 $_{C}$	1.04 $_{B}$	1.87 $_{A}$	1.89 $_{A}$
A	90	1	1.00 $_{B}$	1.10 $_{B}$	2.75 $_{A}$	2.83 $_{A}$
A	90	3	1.00 $_{C}$	1.43 $_{B}$	3.09 $_{A}$	3.17 $_{A}$
A	90	5	1.00 $_{D}$	1.49 $_{C}$	2.91 $_{B}$	3.00 $_{A}$
A	90	10	1.00 $_{C}$	1.15 $_{B}$	2.19 $_{A}$	2.24 $_{A}$
A	100	0	1.00 $_{D}$	1.04 $_{C}$	1.87 $_{B}$	1.90 $_{A}$
A	100	1	1.00 $_{D}$	1.16 $_{C}$	2.73 $_{B}$	2.87 $_{A}$
A	100	3	1.00 $_{C}$	1.22 $_{B}$	2.64 $_{A}$	2.74 $_{A}$
A	100	5	1.00 $_{C}$	1.52 $_{B}$	2.92 $_{A}$	3.00 $_{A}$
A	100	10	1.00 $_{C}$	1.23 $_{B}$	2.17 $_{A}$	2.22 $_{A}$

*Different letters withing the same row indicate significant difference ($p< 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

(i)


4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
(HMF*/HMF$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

(ii)


4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
(HMF*/HMF$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

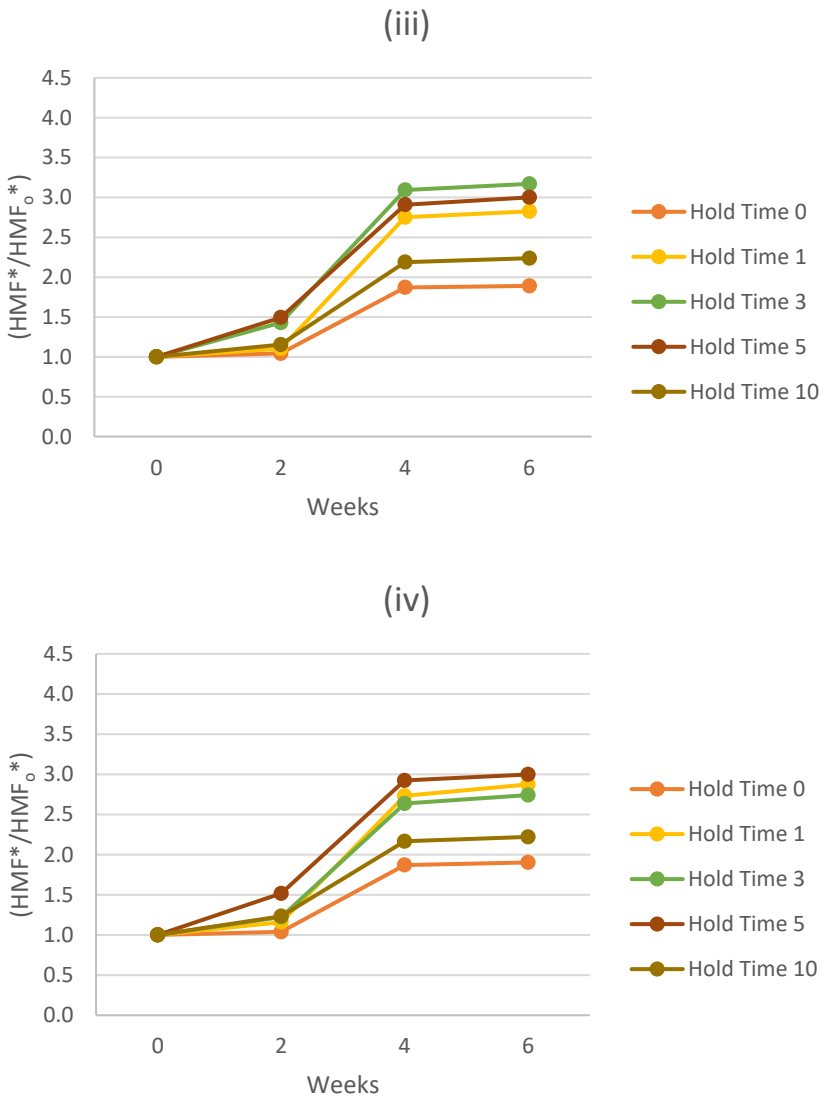


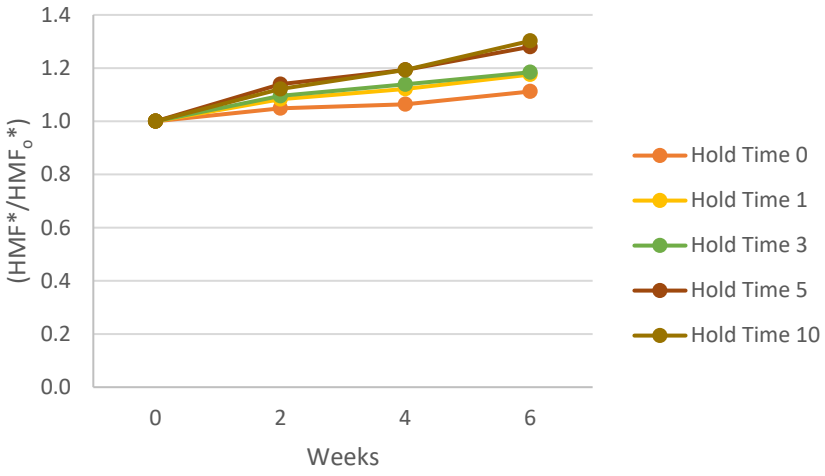
Figure 4.2.5. Relative variations across storage at 35°C between hold times for Cultivar A at 70°C (i), 80°C (ii), 90°C (iii), and 100°C (iv) for Hydroxymethylfurfural absorbance at 443 nm.

Table 4.2.5 Relative variations across storage at 35°C between hold times for Cultivar B at 70°C, 80°C, 90°C, and 100°C for Hydroxymethylfurfural absorbance at 443 nm.

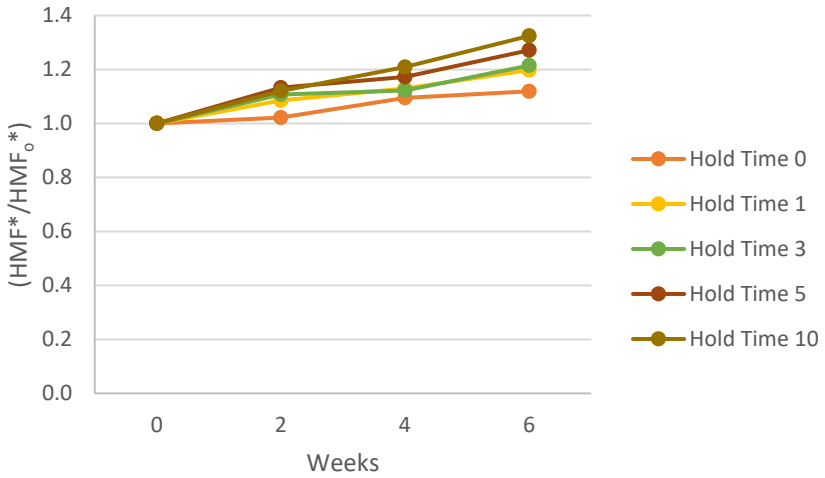
Code	Temperature (C)	Hold Time	0	2	4	6
B	70	0	1.00 $_{D}$	1.05 $_{C}$	1.06 $_{B}$	1.11 $_{A}$
B	70	1	1.00 $_{B}$	1.08 $_{AB}$	1.12 $_{A}$	1.18 $_{A}$
B	70	3	1.00 $_{D}$	1.10 $_{C}$	1.14 $_{B}$	1.18 $_{A}$
B	70	5	1.00 $_{D}$	1.14 $_{C}$	1.19 $_{B}$	1.28 $_{A}$
B	70	10	1.00 $_{D}$	1.12 $_{C}$	1.19 $_{B}$	1.30 $_{A}$
B	80	0	1.00 $_{D}$	1.02 $_{C}$	1.09 $_{B}$	1.12 $_{A}$
B	80	1	1.00 $_{D}$	1.09 $_{C}$	1.13 $_{B}$	1.20 $_{A}$
B	80	3	1.00 $_{C}$	1.11 $_{B}$	1.12 $_{B}$	1.21 $_{A}$
B	80	5	1.00 $_{D}$	1.13 $_{C}$	1.17 $_{B}$	1.27 $_{A}$
B	80	10	1.00 $_{D}$	1.12 $_{C}$	1.21 $_{B}$	1.32 $_{A}$
B	90	0	1.00 $_{D}$	1.02 $_{C}$	1.11 $_{B}$	1.15 $_{A}$
B	90	1	1.00 $_{D}$	1.10 $_{C}$	1.15 $_{B}$	1.24 $_{A}$
B	90	3	1.00 $_{D}$	1.10 $_{C}$	1.15 $_{B}$	1.28 $_{A}$
B	90	5	1.00 $_{C}$	1.14 $_{B}$	1.14 $_{B}$	1.28 $_{A}$
B	90	10	1.00 $_{C}$	1.17 $_{B}$	1.19 $_{B}$	1.28 $_{A}$
B	100	0	1.00 $_{D}$	1.02 $_{C}$	1.17 $_{B}$	1.29 $_{A}$
B	100	1	1.00 $_{D}$	1.03 $_{C}$	1.11 $_{B}$	1.21 $_{A}$
B	100	3	1.00 $_{D}$	1.04 $_{C}$	1.11 $_{B}$	1.24 $_{A}$
B	100	5	1.00 $_{C}$	1.11 $_{B}$	1.12 $_{B}$	1.25 $_{A}$
B	100	10	1.00 $_{D}$	1.16 $_{C}$	1.19 $_{B}$	1.32 $_{A}$

*Different letters withing the same row indicate significant difference ($p < 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

(i)


1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(HMF*/HMF$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

(ii)


1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(HMF*/HMF$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

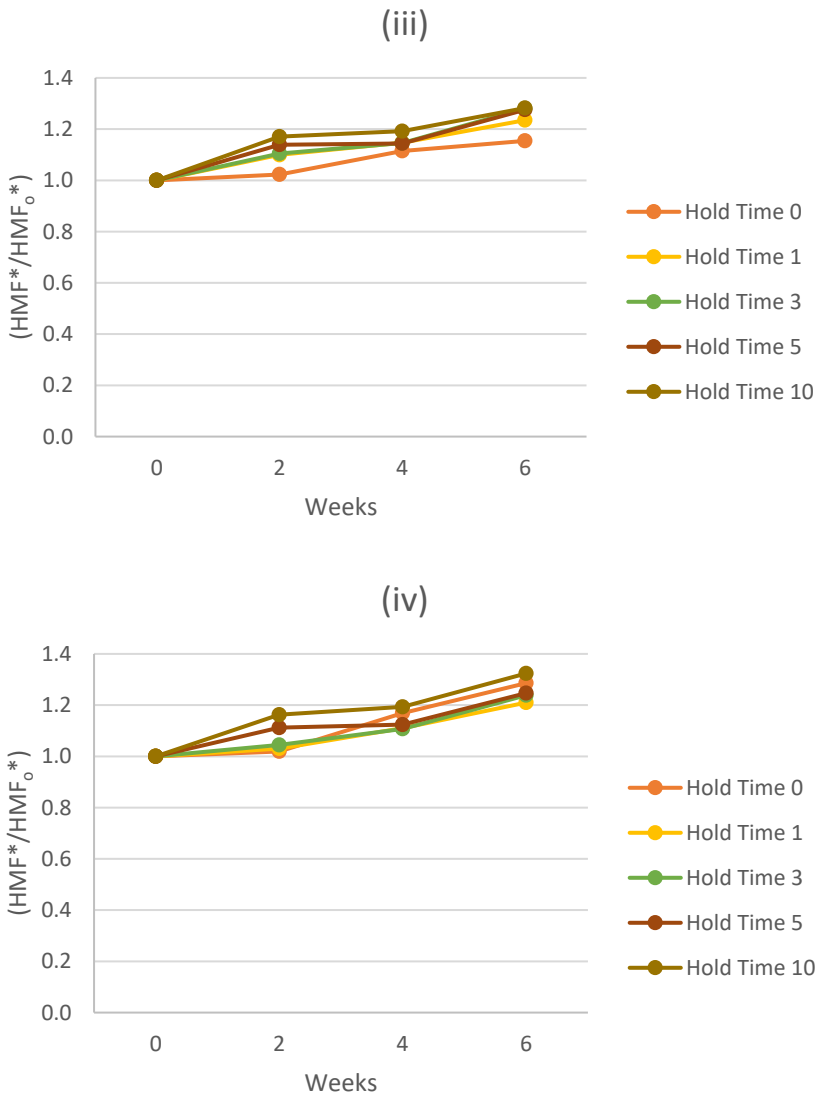


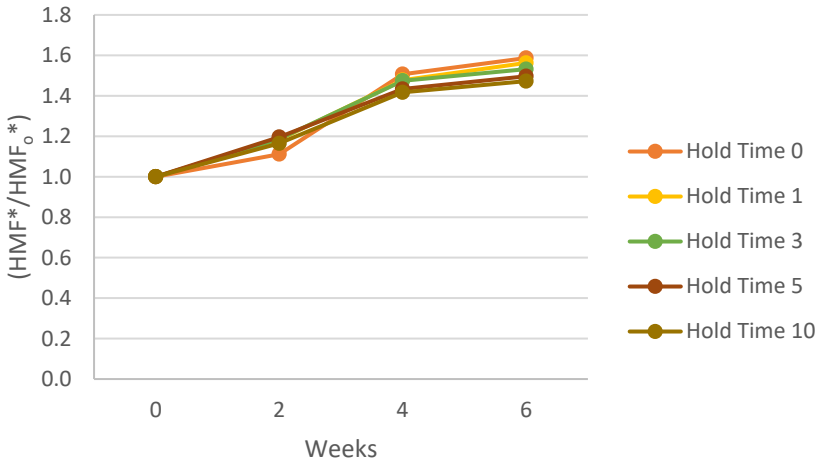
Figure 4.2.6. Relative variations across storage at 35°C between hold times for Cultivar B at 70°C (i), 80°C (ii), 90°C (iii), and 100°C (iv) for Hydroxymethylfurfural absorbance at 443 nm.

Table 4.2.6 Relative variations across storage at 35°C between hold times for Cultivar C at 70°C, 80°C, 90°C, and 100°C for Hydroxymethylfurfural absorbance at 443 nm.

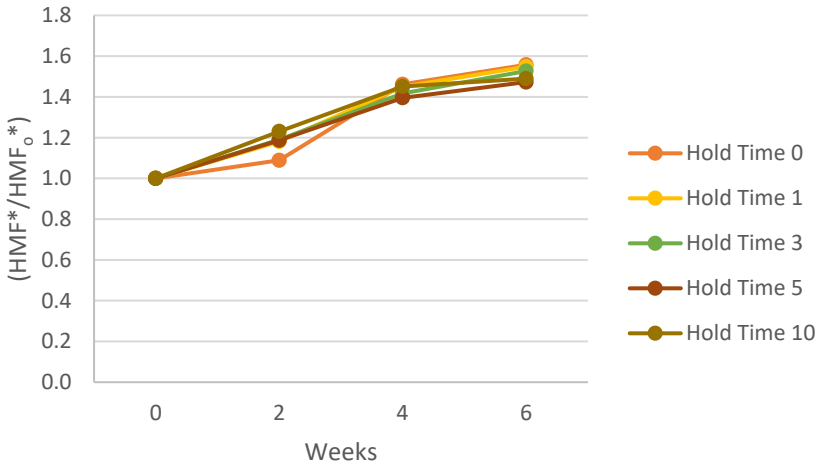
Code	Temperature (C)	Hold Time	0	2	4	6
C	70	0	1.00 $_{D}$	1.11 $_{C}$	1.51 $_{B}$	1.59 $_{A}$
C	70	1	1.00 $_{D}$	1.18 $_{C}$	1.48 $_{B}$	1.56 $_{A}$
C	70	3	1.00 $_{D}$	1.19 $_{C}$	1.47 $_{B}$	1.53 $_{A}$
C	70	5	1.00 $_{D}$	1.20 $_{C}$	1.43 $_{B}$	1.50 $_{A}$
C	70	10	1.00 $_{D}$	1.16 $_{C}$	1.42 $_{B}$	1.47 $_{A}$
C	80	0	1.00 $_{D}$	1.09 $_{C}$	1.46 $_{B}$	1.56 $_{A}$
C	80	1	1.00 $_{D}$	1.18 $_{C}$	1.45 $_{B}$	1.55 $_{A}$
C	80	3	1.00 $_{D}$	1.19 $_{C}$	1.42 $_{B}$	1.53 $_{A}$
C	80	5	1.00 $_{D}$	1.19 $_{C}$	1.40 $_{B}$	1.47 $_{A}$
C	80	10	1.00 $_{D}$	1.23 $_{C}$	1.45 $_{B}$	1.49 $_{A}$
C	90	0	1.00 $_{D}$	1.12 $_{C}$	1.42 $_{B}$	1.52 $_{A}$
C	90	1	1.00 $_{D}$	1.13 $_{C}$	1.39 $_{B}$	1.55 $_{A}$
C	90	3	1.00 $_{D}$	1.15 $_{C}$	1.44 $_{B}$	1.54 $_{A}$
C	90	5	1.00 $_{D}$	1.13 $_{C}$	1.40 $_{B}$	1.47 $_{A}$
C	90	10	1.00 $_{D}$	1.17 $_{C}$	1.42 $_{B}$	1.49 $_{A}$
C	100	0	1.00 $_{D}$	1.19 $_{C}$	1.40 $_{B}$	1.53 $_{A}$
C	100	1	1.00 $_{D}$	1.20 $_{C}$	1.41 $_{B}$	1.62 $_{A}$
C	100	3	1.00 $_{D}$	1.19 $_{C}$	1.39 $_{B}$	1.58 $_{A}$
C	100	5	1.00 $_{D}$	1.14 $_{C}$	1.38 $_{B}$	1.51 $_{A}$
C	100	10	1.00 $_{D}$	1.11 $_{C}$	1.26 $_{B}$	1.36 $_{A}$

*Different letters withing the same row indicate significant difference ($p < 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

(i)


1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(HMF*/HMF$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

(ii)


1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
(HMF*/HMF$_o$*)
0
2
4
6
Weeks
Hold Time 0
Hold Time 1
Hold Time 3
Hold Time 5
Hold Time 10

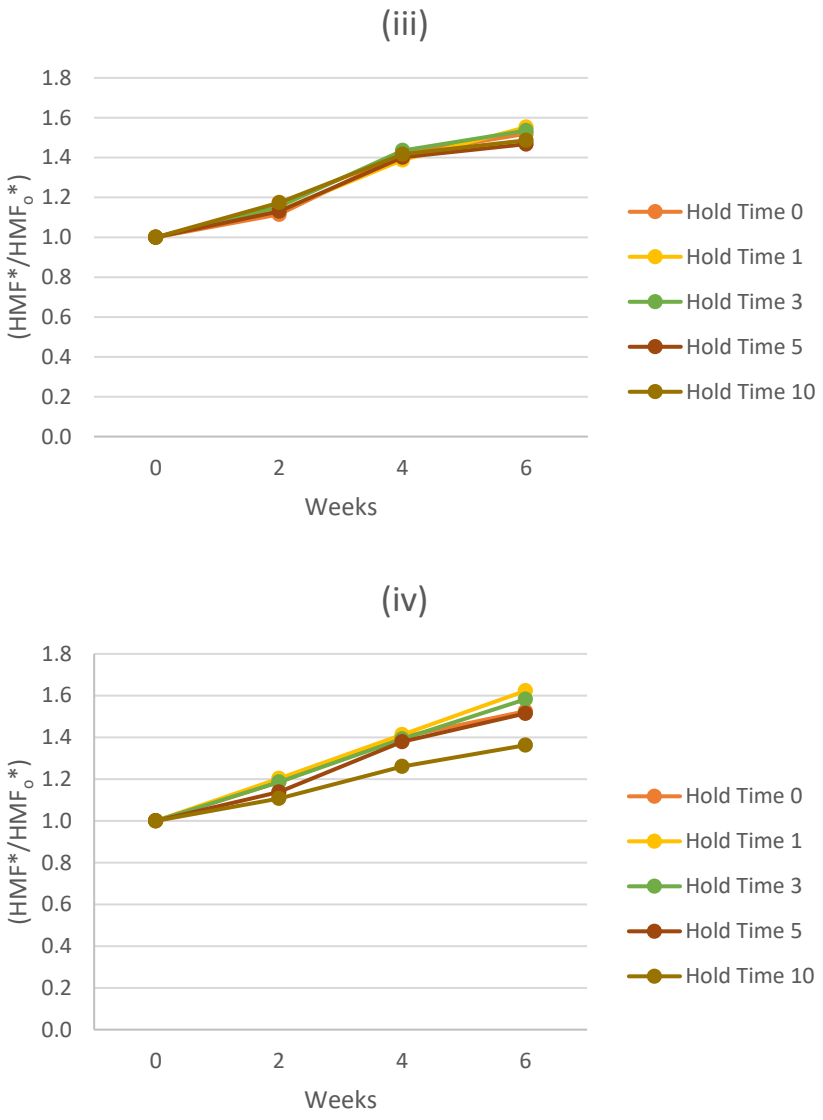
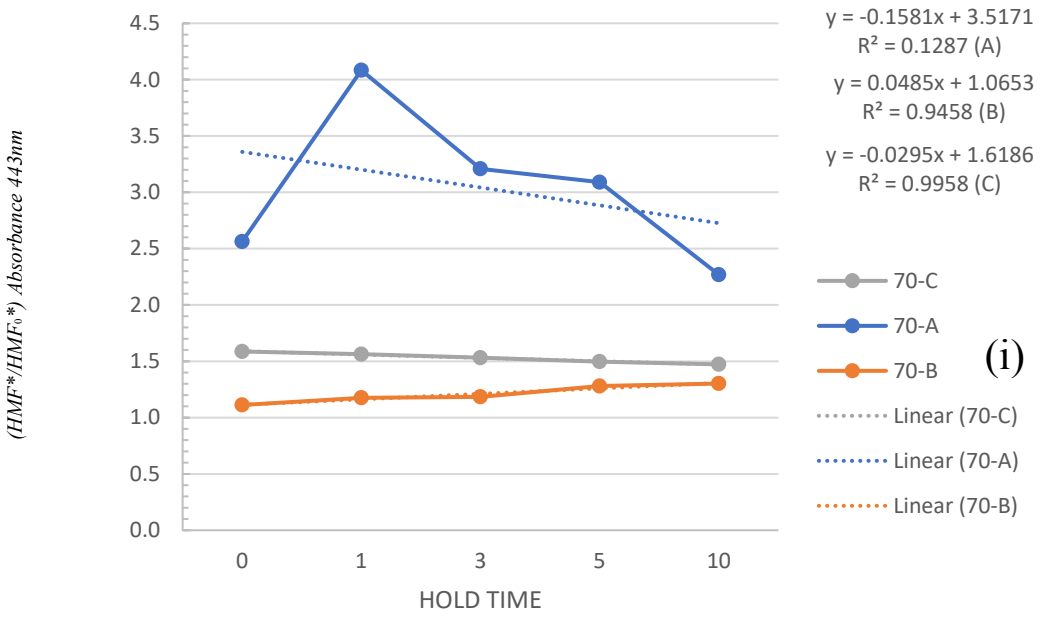
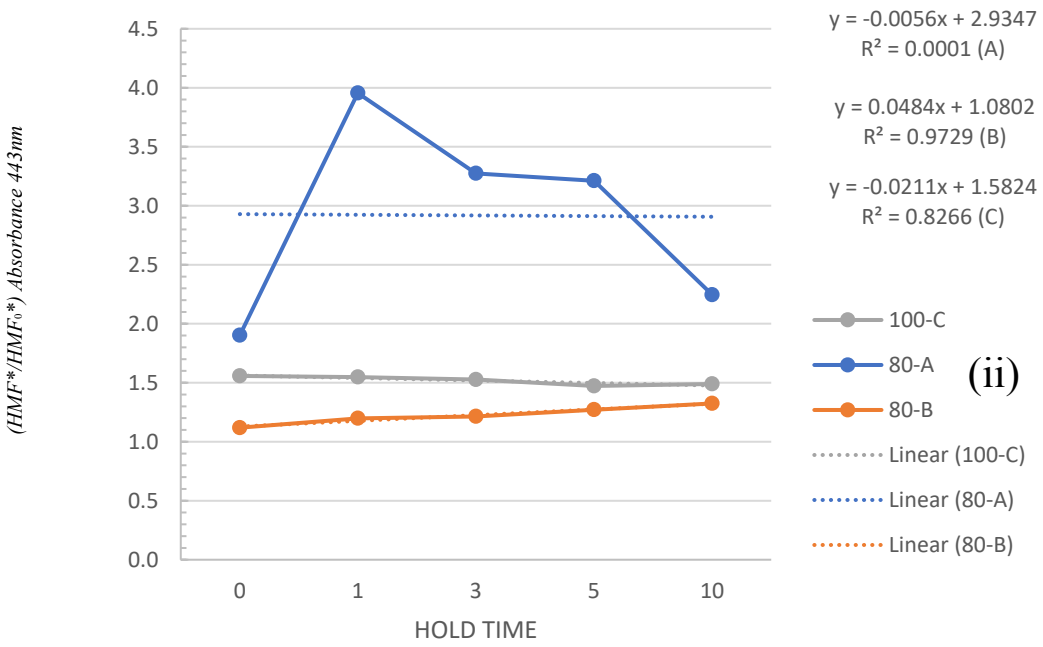


Figure 4.2.7. Relative variations across storage at 35°C between hold times for Cultivar C at 70°C (i), 80°C (ii), 90°C (iii), and 100°C (iv) for Hydroxymethylfurfural absorbance at 443 nm


(HMF*/HMF0*) Absorbance 443nm
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
1
3
5
10
HOLD TIME
y = -0.1581x + 3.5171
R² = 0.1287 (A)
y = 0.0485x + 1.0653
R² = 0.9458 (B)
y = -0.0295x + 1.6186
R² = 0.9958 (C)
70-C
70-A
70-B
Linear (70-C)
Linear (70-A)
Linear (70-B)
(i)


(HMF*/HMF0*) Absorbance 443nm
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
1
3
5
10
HOLD TIME
y = -0.0056x + 2.9347
R² = 0.0001 (A)
y = 0.0484x + 1.0802
R² = 0.9729 (B)
y = -0.0211x + 1.5824
R² = 0.8266 (C)
100-C
80-A
80-B
Linear (100-C)
Linear (80-A)
Linear (80-B)
(ii)

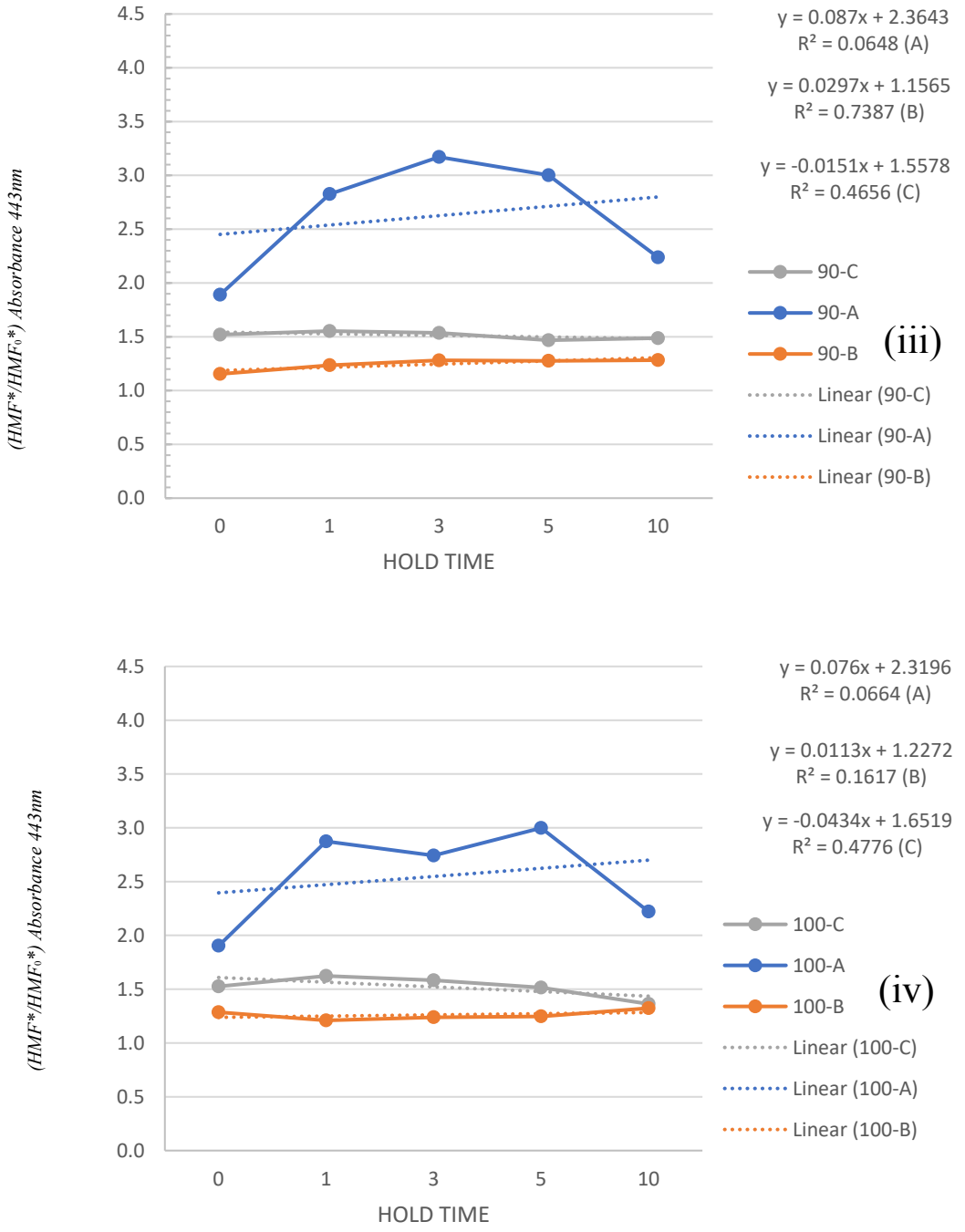


Figure 4.2.8. Relative variation across hold times for all cultivars at final week of storage at 35°C for Hydroxymethylfurfural absorbance at 443 nm at 70°C (i), 80°C (ii), 90°C (iii), and 100° (iv).

For cultivar A, Figure 4.2.1 indicates that BI increased throughout storage at all combinations of time and temperature. Utilizing Beer's law this increase would indicate that the

concentration of brown pigments increased as BI (BI^*/BI_0^*) increased over time in storage. Thus, it is apparent that a darkening of purees for cultivar A was occurring at all combinations of time and temperature confirming conclusions made in the previous research (Saura, Vegara, Martí, Valero, & Laencina 2017). Figure 4.2.5 illustrates increasing hold decreases BI (BI^*/BI_0^*) for cultivar A at all temperatures at the final week of storage. This decrease has not been supported by previous research for peach puree. This decreasing trend may be attributed to human error during processing or testing for cultivar A. Similarly, to BI for cultivar A, HMF ($HMF^*/HMFI_0^*$) increased over storage at all temperatures regardless of hold time, displayed in figure 4.2.6. In accordance with Beer's law, this increase was indicative of an increase in the concentration of HMF throughout storage like the research of by (Saura, Vegara, Martí, Valero, & Laencina 2017). Thus, it is apparent a darkening of puree is occurring via NEB reactions in all purees for cultivar A regardless of occurring at all combinations of time and temperature. Figure 4.2.9 illustrates increasing hold time to decrease HMF (HMF^*/HMF_0^*) at temperatures 70°C and 80°C and an increase at 90°C and 100°C. Thus, data at 70°C and 80°C do not support previous research suggestions about increasing hold time and temperature while 90°C and 100°C do. Overall, for cultivar A, increasing storage time does lead to an increase in BI and HMF while time and temperature data were inconsistent.

For Cultivar B figure 4.2.2 indicates BI (BI^*/BI_0^*) to vary depending on temperature throughout strorage. At 70°C hold times 0,1, and 3 minutes decreased while hold times 5 and 10 increased. According to Beer's law the decrease in BI (BI^*/BI_0^*) at hold times 0,1, and 3 minutes would indicate a decrease in the concentration of brown pigments throughout storage and vice versa the increase was seen at 5 and 10 minutes. Darkening of puree would be said to be occurring at hold times 0 and 5 minutes at 70°C throughout storage. Decreasing values are not supported by

previous research on storage. At 80°C all hold time combinations increased in BI (BI^*/BI_0^*), although inconsistently week to week. This is supported by previous research and according to Beer's law would indicate that brown pigment concentration was increasing over storage. Temperatures 90°C and 100°C consistently increased as storage time increased which confirms previous research by lyu et al. (2018). This increase is correlated to an increase in brown pigment concentration over storage. Figure 4.2.5 shows that increasing hold time correlates to a decrease in BI (BI^*/BI_0^*) for Cultivar B at all temps based on negative trendlines which would not support previous research by lyu et al. (2018). This decreasing trend may be attributed to human error during processing or testing for cultivar B. HMF ($HMF^*/HMFI_0$) data were seen to increase at all temperatures and hold time combinations for cultivar be over storage, displayed in figure 4.2.7. Thus, previous research is confirmed in stating that BI should increase over storage. According to Beer's law, brown pigment concentration was increasing over storage. Figure 4.2.9 indicates that hold time increased so did HMF ($HMF^*/HMFI_0$) at all temps. However, temperature increase was inconclusive in the extent to which it affected HMF.

For cultivar C, Figure 4.2.4 indicates that BI (BI^*/BI_0^*) increased throughout storage. Beer's law this increase would indicate that the concentration of brown pigments increased as BI (BI^*/BI_0^*) increased over time in storage. . Thus, it is apparent that a darkening of purees for cultivar C was occurring at all combinations of time and temperature confirming conclusions made in the previous research (Saura, Vegara, Martí, Valero, & Laencina 2017). Figure 4.2.5 shows that increasing hold time did not increase as BI (BI^*/BI_0^*) based the negative trendline present at all temperatures. This decrease is not supported by previous data on storage time and BI. This decreasing trend may be attributed to human error during processing or testing for cultivar C. Data for cultivar C HMF ($HMF^*/HMFI_0$) are displayed in figure 4.2.8. It can be seen in this figure that

as storage time increased so did HMF ($HMF^*/HMFI_0$) regardless of temperature and hold time combination. This increase according to Beer's law would indicate that the concentration of HMF increased over storage and that a darkening of puree was occurring via NEB reactions at all temperature and hold time combinations. Figure 4.2.9 shows that increasing hold time decreased HMF at all temps, which would not be supported by previous data collected by lyu et al. (2018). Increasing temperature was inconclusive in the extent to which it affected HMF concentration for Cultivar C.

For all cultivars, BI (BI^*/BI_0^*) and HMF ($HMF^*/HMFI_0$) should have been seen to increase throughout storage. Any decrease should be attributed to human error during the processing or testing of puree for all cultivars. Increases seen in any cultivar over storage in BI are likely due to the increase in the presence of glucose and fructose, which are reducing sugars used in Maillard Browning reactions (NEB) (Saura, Vegara, Martí, Valero, & Laencina 2017). The increasing trend in HMF over storage can be linked to the oxidation of vitamin C even though NEB reactions do not directly utilize oxygen or due to the spontaneous degradation of AA into HMF under anaerobic conditions (Lyu, Liu, Bi, Wu, Zhou, Ruan, Zhao, Jiao, 2018; Pham, Bazmawe, Kebede, Buvé, Hendrickx, & Van Loey, 2019; Lavelli, Pompei, & Casadei, 2008). Both vitamin C and AA are inherently present in all peach puree and sealing of pouches containing puree provides the optimal anaerobic environment for AA to degrade spontaneously. BI increase could have also been attributed to an increase in polyphenol oxidation during the processing of puree and sealing. Oxidized Polyphenols have a much higher antioxidant capacity which according to Crooptova et al. (2016), can be directly correlated to melanoidins of NEB reactions in fruit products.

4.3. Evaluation of Soluble Solids (°Brix) Content

Table 4.3.1 Relative variations across storage at 35°C between hold times for Cultivar A at 70°C, 80°C, 90°C, and 100°C for Soluble Solids (°Brix).

Code	Temperature (C)	Hold Time	0	2	4	6
A	70	0	12.2 $_{A}$	12.1 $_{A}$	10.6 $_{B}$	12.4 $_{A}$
A	70	1	11.7 $_{A}$	11.7 $_{A}$	10.8 $_{B}$	11.9 $_{A}$
A	70	3	11.1 $_{B}$	11.7 $_{A}$	11.1 $_{B}$	11.8 $_{A}$
A	70	5	11.1 $_{B}$	11.1 $_{B}$	11.5 $_{B}$	12.8 $_{A}$
A	70	10	11.1 $_{B}$	11.3 $_{B}$	10.4 $_{C}$	12.0 $_{A}$
A	80	0	12.0 $_{B}$	11.8 $_{B}$	10.5 $_{C}$	12.3 $_{A}$
A	80	1	12.2 $_{A}$	12.8 $_{A}$	12.2 $_{A}$	12.9 $_{A}$
A	80	3	12.3 $_{A}$	12.2 $_{A}$	12.2 $_{A}$	12.9 $_{A}$
A	80	5	12.5 $_{B}$	12.5 $_{B}$	12.5 $_{B}$	13.0 $_{A}$
A	80	10	12.3 $_{A}$	12.2 $_{A}$	12.3 $_{BC}$	13.0 $_{A}$
A	90	0	11.6 $_{B}$	10.8 $_{C}$	13.3 $_{A}$	13.2 $_{A}$
A	90	1	12.2 $_{B}$	12.8 $_{A}$	12.8 $_{A}$	12.4 $_{B}$
A	90	3	11.9 $_{C}$	13.2 $_{A}$	12.6 $_{B}$	12.4 $_{B}$
A	90	5	12.2 $_{C}$	12.8 $_{A}$	12.6 $_{B}$	12.7 $_{AB}$
A	90	10	11.9 $_{C}$	13.4 $_{A}$	13.4 $_{A}$	13.7 $_{B}$
A	100	0	10.9 $_{A}$	10.8 $_{A}$	10.5 $_{A}$	12.0 $_{B}$
A	100	1	10.8 $_{B}$	11.1 $_{AB}$	11.5 $_{A}$	11.7 $_{AB}$
A	100	3	11.9 $_{A}$	11.7 $_{A}$	11.5 $_{AB}$	12.2 $_{C}$
A	100	5	11.8 $_{A}$	11.9 $_{A}$	11.8 $_{A}$	12.3 $_{A}$
A	100	10	11.8 $_{AB}$	11.6 $_{B}$	11.8 $_{AB}$	12.0 $_{A}$

*Different letters withing the same row indicate significant difference ($p< 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

Table 4.3.2 Relative variations across storage at 35°C between hold times for Cultivar B at 70°C, 80°C, 90°C, and 100°C for Soluble Solids (°Brix).

Code	Temperature (C)	Hold Time	0	2	4	6
B	70	0	13.3 $_{B}$	13.1 $_{B}$	13.8 $_{AB}$	14.0 $_{A}$
B	70	1	12.1 $_{AB}$	12.1 $_{B}$	12.9 $_{AB}$	13.0 $_{A}$
B	70	3	12.9 $_{AB}$	12.2 $_{B}$	12.8 $_{AB}$	13.1 $_{A}$
B	70	5	12.8 $_{C}$	14.0 $_{A}$	13.8 $_{B}$	14.5 $_{A}$
B	70	10	13.4 $_{A}$	13.1 $_{A}$	13.3 $_{A}$	13.7 $_{A}$
B	80	0	12.7 $_{AB}$	12.3 $_{B}$	11.1 $_{C}$	13.0 $_{A}$
B	80	1	12.8 $_{B}$	13.2 $_{A}$	11.9 $_{C}$	13.8 $_{A}$
B	80	3	11.7 $_{C}$	12.8 $_{B}$	13.2 $_{A}$	13.5 $_{A}$
B	80	5	12.7 $_{B}$	12.3 $_{C}$	11.8 $_{D}$	14.0 $_{A}$
B	80	10	11.7 $_{C}$	12.4 $_{B}$	12.3 $_{B}$	14.4 $_{A}$
B	90	0	12.8 $_{AB}$	12.8 $_{AB}$	12.6 $_{B}$	13.1 $_{A}$
B	90	1	13.2 $_{A}$	12.2 $_{C}$	12.6 $_{B}$	13.6 $_{A}$
B	90	3	12.3 $_{A}$	12.7 $_{A}$	13.0 $_{A}$	13.0 $_{A}$
B	90	5	12.6 $_{B}$	13.0 $_{A}$	12.9 $_{A}$	13.5 $_{A}$
B	90	10	13.0 $_{AB}$	13.2 $_{A}$	13.0 $_{B}$	13.2 $_{A}$
B	100	0	12.0 $_{B}$	13.4 $_{A}$	12.7 $_{AB}$	13.1 $_{A}$
B	100	1	12.7 $_{A}$	13.2 $_{A}$	13.3 $_{A}$	13.2 $_{A}$
B	100	3	11.6 $_{B}$	13.1 $_{A}$	12.9 $_{A}$	12.4 $_{AB}$
B	100	5	12.8 $_{A}$	12.9 $_{A}$	13.2 $_{A}$	13.5 $_{A}$
B	100	10	12.9 $_{A}$	12.5 $_{A}$	12.7 $_{A}$	13.1 $_{A}$

*Different letters withing the same row indicate significant difference ($p < 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

Table 4.3.3 Relative variations across storage at 35°C between hold times for Cultivar C at 70°C, 80°C, 90°C, and 100°C for Soluble Solids (°Brix).

Code	Temperature (C)	Hold Time	0	2	4	6
C	70	0	12.2 $_{D}$	12.6 $_{C}$	14.1 $_{A}$	13.5 $_{B}$
C	70	1	12.2 $_{B}$	12.1 $_{B}$	12.8 $_{A}$	12.6 $_{A}$
C	70	3	11.9 $_{C}$	11.5 $_{D}$	12.7 $_{A}$	12.5 $_{B}$
C	70	5	11.7 $_{B}$	11.4 $_{B}$	12.7 $_{A}$	12.9 $_{B}$
C	70	10	11.6 $_{B}$	11.6 $_{B}$	12.4 $_{A}$	12.8 $_{A}$
C	80	0	12.4 $_{A}$	11.6 $_{A}$	11.9 $_{A}$	12.7 $_{A}$
C	80	1	11.9 $_{BC}$	11.6 $_{C}$	12.0 $_{B}$	12.4 $_{A}$
C	80	3	11.9 $_{AB}$	11.4 $_{B}$	12.2 $_{A}$	12.5 $_{A}$
C	80	5	11.7 $_{B}$	11.1 $_{C}$	12.2 $_{A}$	12.4 $_{A}$
C	80	10	11.3 $_{C}$	11.2 $_{C}$	12.3 $_{B}$	12.7 $_{A}$
C	90	0	12.6 $_{A}$	12.2 $_{AB}$	11.6 $_{B}$	12.9 $_{A}$
C	90	1	11.6 $_{A}$	11.7 $_{A}$	12.0 $_{A}$	12.0 $_{A}$
C	90	3	11.8 $_{B}$	11.7 $_{B}$	11.7 $_{B}$	12.3 $_{A}$
C	90	5	12.0 $_{A}$	11.6 $_{A}$	11.5 $_{A}$	12.1 $_{A}$
C	90	10	11.6 $_{AB}$	11.4 $_{B}$	11.6 $_{AB}$	11.8 $_{A}$
C	100	0	12.2 $_{A}$	11.4 $_{A}$	11.2 $_{A}$	12.3 $_{A}$
C	100	1	12.2 $_{A}$	11.4 $_{B}$	11.0 $_{B}$	12.6 $_{A}$
C	100	3	12.1 $_{A}$	11.6 $_{A}$	11.6 $_{A}$	12.4 $_{A}$
C	100	5	10.9 $_{B}$	11.8 $_{AB}$	11.7 $_{AB}$	12.5 $_{A}$
C	100	10	11.7 $_{A}$	11.6 $_{A}$	11.5 $_{A}$	11.9 $_{A}$

*Different letters withing the same row indicate significant difference ($p< 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

Typically, the lowest acceptable SSC content of peaches is 10 °Brix (Falguera, Gatius, Pascual, Villar, Cubero, Ibarz, & Rufat, 2012). All cultivars and combinations of temperature were greater than the suggested minimum of 10 °Brix throughout storage. All cultivars increased regardless of hold time and temperature combination from the initial week of testing to the final week. The increase in °Brix seen in all cultivars over time can be attributed to the breakdown of sucrose (reducing sugar) via hydrolysis into glucose and fructose. Although the concentration of sucrose was not examined in the study Saura et al. (2017) noted that sucrose concentration decreased over storage while glucose and fructose concentration increased. Some variation is present week to week meaning there was not a traditional linear relationship for °Brix present even though an increase was seen from week 0 to week 6. This variation could be attributed to inherent variation between each peach as well as due to human error. However, °Brix is only accurate for solutions entirely of sucrose (Skrypec, 2020). Thus, the breakdown of sucrose to glucose and fructose may have led to a skew in the data in tables 4.3.1, 4.3.2, and 4.3.3. Despite this Bassi et al. (2016), notes that °Brix as a measure of SSC is adequate when used to examine peach puree.

4.4. Evaluation of pH Concentration

Table 4.4.1 Relative variations across storage at 35°C between hold times for Cultivar A at 70°C, 80°C, 90°C, and 100°C for pH concentration.

Code	Temperature (C)	Hold Time	0	2	4	6
A	70	0	3.22 $_{D}$	3.28 $_{C}$	3.70 $_{A}$	3.42 $_{B}$
A	70	1	3.20 $_{B}$	3.30 $_{B}$	3.82 $_{A}$	3.82 $_{A}$
A	70	3	3.35 $_{B}$	3.47 $_{B}$	3.37 $_{B}$	3.62 $_{A}$
A	70	5	3.20 $_{B}$	3.47 $_{A}$	3.54 $_{A}$	3.54 $_{A}$
A	70	10	3.22 $_{B}$	3.51 $_{A}$	3.43 $_{AB}$	3.52 $_{A}$
A	80	0	3.26 $_{C}$	3.60 $_{B}$	3.60 $_{B}$	3.89 $_{A}$
A	80	1	3.29 $_{C}$	3.53 $_{A}$	3.41 $_{B}$	3.57 $_{A}$
A	80	3	3.35 $_{C}$	3.62 $_{A}$	3.38 $_{BC}$	3.47 $_{B}$
A	80	5	3.35 $_{C}$	3.61 $_{A}$	3.39 $_{BC}$	3.41 $_{B}$
A	80	10	3.26 $_{B}$	3.60 $_{A}$	3.70 $_{A}$	3.46 $_{AB}$
A	90	0	3.47 $_{C}$	3.67 $_{A}$	3.60 $_{B}$	3.63 $_{AB}$
A	90	1	3.52 $_{D}$	3.65 $_{B}$	3.70 $_{A}$	3.60 $_{C}$
A	90	3	3.52 $_{A}$	3.65 $_{A}$	3.60 $_{A}$	3.43 $_{A}$
A	90	5	3.52 $_{D}$	3.63 $_{B}$	3.84 $_{A}$	3.60 $_{C}$
A	90	10	3.47 $_{C}$	3.63 $_{B}$	3.83 $_{A}$	3.62 $_{B}$
A	100	0	3.58 $_{A}$	3.69 $_{A}$	3.37 $_{B}$	3.70 $_{A}$
A	100	1	3.58 $_{B}$	3.69 $_{A}$	3.60 $_{B}$	3.71 $_{A}$
A	100	3	3.59 $_{B}$	3.73 $_{A}$	3.59 $_{B}$	3.74 $_{A}$
A	100	5	3.57 $_{B}$	3.74 $_{A}$	3.51 $_{B}$	3.78 $_{A}$
A	100	10	3.59 $_{B}$	3.75 $_{A}$	3.59 $_{C}$	3.81 $_{A}$

*Least Squares Means Students t-Test
*Different letters withing the same column indicate significant difference ($p < 0.05$)

Table 4.4.2 Relative variations across storage at 35°C between hold times for Cultivar B at 70°C, 80°C, 90°C, and 100°C for pH concentration.

Code	Temperature (C)	Hold Time	0	2	4	6
B	70	0	3.61 $_{A}$	3.60 $_{A}$	3.88 $_{A}$	3.80 $_{A}$
B	70	1	3.70 $_{C}$	3.82 $_{B}$	3.47 $_{D}$	3.94 $_{A}$
B	70	3	3.65 $_{C}$	3.70 $_{B}$	3.47 $_{D}$	3.95 $_{A}$
B	70	5	3.65 $_{B}$	3.62 $_{C}$	3.63 $_{D}$	3.91 $_{A}$
B	70	10	3.63 $_{B}$	3.64 $_{B}$	3.58 $_{B}$	4.03 $_{A}$
B	80	0	3.76 $_{B}$	3.96 $_{A}$	3.66 $_{C}$	3.62 $_{C}$
B	80	1	3.64 $_{B}$	3.86 $_{A}$	3.67 $_{B}$	3.63 $_{B}$
B	80	3	3.82 $_{A}$	3.66 $_{B}$	3.62 $_{C}$	3.65 $_{B}$
B	80	5	3.82 $_{A}$	3.77 $_{B}$	3.59 $_{D}$	3.70 $_{C}$
B	80	10	3.81 $_{A}$	3.77 $_{B}$	3.63 $_{D}$	3.70 $_{C}$
B	90	0	3.77 $_{A}$	3.73 $_{AB}$	3.56 $_{C}$	3.62 $_{BC}$
B	90	1	3.76 $_{A}$	3.64 $_{B}$	3.64 $_{B}$	3.65 $_{AB}$
B	90	3	3.64 $_{A}$	3.66 $_{A}$	3.64 $_{A}$	3.66 $_{A}$
B	90	5	3.83 $_{A}$	3.69 $_{B}$	3.59 $_{C}$	3.67 $_{B}$
B	90	10	3.88 $_{A}$	3.71 $_{B}$	3.63 $_{C}$	3.67 $_{BC}$
B	100	0	3.63 $_{B}$	3.86 $_{A}$	3.56 $_{B}$	3.64 $_{B}$
B	100	1	3.82 $_{A}$	3.77 $_{A}$	3.54 $_{C}$	3.63 $_{B}$
B	100	3	3.86 $_{A}$	3.76 $_{B}$	3.71 $_{C}$	3.65 $_{D}$
B	100	5	3.77 $_{A}$	3.63 $_{B}$	3.61 $_{B}$	3.67 $_{B}$
B	100	10	3.89 $_{B}$	4.03 $_{A}$	3.38 $_{D}$	3.67 $_{C}$

*Different letters withing the same row indicate significant difference ($p< 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

Table 4.4.3 Relative variations across storage at 35°C between hold times for Cultivar C at 70°C, 80°C, 90°C, and 100°C for pH concentration.

Code	Temperature (C)	Hold Time	0	2	4	6
C	70	0	3.58 $_{B}$	3.63 $_{A}$	3.56 $_{B}$	3.45 $_{C}$
C	70	1	3.59 $_{B}$	3.67 $_{A}$	3.57 $_{B}$	3.47 $_{C}$
C	70	3	3.63 $_{AB}$	3.67 $_{A}$	3.58 $_{AB}$	3.53 $_{B}$
C	70	5	3.63 $_{A}$	3.62 $_{A}$	3.60 $_{B}$	3.52 $_{C}$
C	70	10	3.64 $_{A}$	3.58 $_{B}$	3.61 $_{B}$	3.59 $_{B}$
C	80	0	3.62 $_{BC}$	3.73 $_{AB}$	3.60 $_{C}$	3.83 $_{A}$
C	80	1	3.73 $_{B}$	3.61 $_{C}$	3.60 $_{C}$	3.83 $_{A}$
C	80	3	3.66 $_{A}$	3.56 $_{A}$	3.62 $_{A}$	3.61 $_{A}$
C	80	5	3.64 $_{B}$	3.71 $_{A}$	3.63 $_{B}$	3.59 $_{B}$
C	80	10	3.66 $_{AB}$	3.69 $_{A}$	3.64 $_{BC}$	3.63 $_{C}$
C	90	0	3.53 $_{B}$	3.55 $_{B}$	3.63 $_{A}$	3.51 $_{B}$
C	90	1	3.53 $_{B}$	3.61 $_{AB}$	3.63 $_{A}$	3.66 $_{A}$
C	90	3	3.37 $_{D}$	3.58 $_{B}$	3.64 $_{A}$	3.56 $_{C}$
C	90	5	3.50 $_{C}$	3.58 $_{B}$	3.66 $_{A}$	3.51 $_{C}$
C	90	10	3.58 $_{B}$	3.57 $_{B}$	3.67 $_{A}$	3.54 $_{B}$
C	100	0	3.60 $_{A}$	3.56 $_{A}$	3.15 $_{B}$	3.53 $_{A}$
C	100	1	3.57 $_{A}$	3.60 $_{A}$	3.32 $_{C}$	3.46 $_{B}$
C	100	3	3.50 $_{B}$	3.58 $_{A}$	3.42 $_{C}$	3.51 $_{AB}$
C	100	5	3.48 $_{B}$	3.67 $_{A}$	3.02 $_{C}$	3.51 $_{B}$
C	100	10	3.60 $_{A}$	3.66 $_{A}$	3.35 $_{B}$	3.60 $_{A}$

*Different letters withing the same row indicate significant difference ($p< 0.05$) based on ANOVA followed by Fishers Least Significant Difference Test

pH was utilized as a parameter to ensure that no microbial interaction was taking place post-processing of puree. MacNaughton (2008), states that any product with a pH< 4.6 is from

microbial activity that may be detrimental to human health or may cause degradation to product quality when processed using hot-fill or pasteurization. Being that all cultivars were pasteurized and regardless of time and temperature combination had pH values less than 4.6 no interaction between the peach purees and microbes was possible. Over storage, all cultivars regardless of hold time and temperature were relatively consistent. Any variation week to week can be attributed to inherent variation between each peach used to create purees as well as to the variation given within the pH meter.

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CHAPTER FIVE

CONCLUSION

This study focused on the effects of thermal processing on the quality of peach puree quality of three different cultivars using color parameters [L^* (lightness), a^* (redness), and b^* (yellowness)]; two brown pigment measures [spectrophotometric absorption at 420 nm (Browning Index) and 443 nm (Hydroxymethylfurfural)]; °Brix; and pH). It can be concluded that all purees are darkening based on the results of the analysis of relative lightness, relative BI and HMF absorption throughout storage. However, the effect of increasing temperature and time on relative lightness, relative BI and HMF absorption were inconclusive in the final week of testing. Data on relative redness and relative yellowness varied regardless of temperature and hold time combination for all cultivars throughout storage. Moreover, the effect of increasing temperature and time on redness and relative yellowness was also inconclusive in the final week of testing. Inherent cultivar differences may have played a role in how peach purees responded to the stress related to thermal processing. Additionally, increasing trends of SSC were observed suggesting that sucrose hydrolysis contributed to the formation reducing sugars related to browning and the increase in SSC. The pH was consistent throughout storage never reaching a pH level conducive to the growth of microbial or spoilage related organisms. Thus, darkening of purees was not due to an interaction with microbes rather that browning is occurred via browning pathways. With that being said, the accumulation of brown pigments may not only be due to non-enzymatic pathways. Rather enzymatic browning played a role in puree darkening of puree throughout storage. The creation of the puree, filling, and sealing, may have allowed for the enzymatic browning process to occur.

Overall, the inconsistency of results and data for all color parameters *L*, a*,* and *b** and spectrophotometric absorption at 420 nm (BI) and 443 nm could have been improved by breaking the cultivars into individual studies, increasing the sample number, and by elongating the period of testing. Further studies should also include more testing parameters including Chroma (°C), Hue (°h), and ΔE^*, activation energies, and a measurement for ascorbic acid throughout storage. Imploring and implementing a different container, filling, and sealing method may also improve the consistency of data as well as limit enzymatic browning from occurring.