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By

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ABSTRACT

METHODOLOGY TO ASSESS QUALITY OF FRESH-CUT FRUIT, AS AFFECTED BY PACKAGE DESIGN, SIZE OF FRUIT DICE AND TRANSPORTATION

By

Koushik Saha

Fresh produce sales boosted from $3.3 billion in 1994 to $11 billion in 2005. The Fresh-cut Fruit (FCF) industry currently accounts for approximately a $1 billion. Once fruits are harvested and undergo a cutting process, there is a loss in quality. The loss in quality is primarily due to water loss, respiration, ripening, enzymatic discoloration of cut surfaces, microbial degradation and mechanical damage. Therefore, the success and expansion of fresh-cut fruit quality will be dependent on continual marketing of quality products. Several postharvest and post cutting techniques are implemented in combination to maintain quality of FCF during storage. The most common form of packaging used in the FCF industry currently is rigid containers made from Polyethyleneterephthalate (PET) and Oriented Polystyrene (OPS). Rigid containers come in different shapes and sizes, depending on the serving size and utility (on-the-go, club store quantity); fresh-cut fruit can be packaged accordingly. It is known that during the cutting operation and transportation, surface tissues get wounded making FCF highly susceptible to sensorial and physiological degradation compared to whole fruits. Therefore, while preparing fresh-cut fruits it is necessary to consider the dice size (cube size) and rigid

container design for packaging.This study aims to evaluate quality of fresh-cut fruit as affected by container dimensions, size of fresh-cut fruit and transportation.

Locally available whole cantaloupe (*Cucumis melo*) was used to prepare fresh-cut fruit. Cantaloupes were cut into 2.5 and 1.5 cm cubes following proper sanitization and post cut treatment. FCF was packaged in three PET containers designated as 'Container A', 'Container B' and 'Container C' of varying dimensions. These containers were subjected to random vibration spectrum for 60 and 120 minutes described in ASTM D4169 for Assurance Level II. A 6-member trained panel evaluated melons on a 1-15 unstructured scale for aroma, color, sweetness, texture and overall quality at days 1, 4, 7 and 10. Total soluble solids, headspace gas composition (O_2 and CO_2), color CIE L*, a* & b* values, flesh firmness and olfactory response of an electronic nose, were determined at Days 1, 4, 7 and 10. The change in color and texture properties were attributed to vibration movement observed by the FCF. Fresh-cut fruit prepared to a cube size of 2.5cm and packaged in 'Container B' showed best sensory evaluated fruit quality and minimal mechanical damage. Longer vibration test times representing longer shipping distances produce a significantly higher release of aroma (E-Nose) in FCF after controlled refrigerated storage. The longer shipped fruit was therefore was rated lower by the sensory panel due to both loss of texture and excessive release of off odors. It should be noted that a different fruit size may have a better result in a different container shape. The way to determine this would be by conducting a series of tests as described in this research study.

This dissertation is dedicated to

My parents Krishna Lal Saha and Chhanda Saha, and my brother Angshuman Saha

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1.INTRODUCTION

The United States Department of Agriculture (USDA) and Food and Drug Administration (FDA) describe 'fresh' and 'minimally processed' fruits as products that have been freshly cut, washed, packaged and maintained with refrigeration. Initially the food service industry was the main customer for fresh-cut products, but in the past decade fresh-cut products have become increasing popular in restaurants, supermarkets and warehouse stores. Food service and restaurants prefer fresh-cut products because the man power needed for preparation and waste handling is eliminated and product can be delivered at short notice. This makes fresh-cut products convenient with the added benefit of reduced waste for retail consumers as an item. Fresh produce has been growing rapidly in U.S. supermarkets. Fresh-cut sales rose from \$3.3 billion in 1994 to \$11 billion in 2005 and the Fresh-cut Fruits (FCF) industry is at approximately \$1 billion category (IFPA, 2004). Once fruits are harvested and undergo the cutting process, there is loss in quality. The loss in quality is primarily due to water loss, respiration, ripening, and enzymatic discoloration of cut surfaces, microbial degradation and mechanical damage. Therefore the success and expansion of fresh-cut will be dependent on continual marketing of quality products.

Over the last several years consumers have become very conscious of the nutritional value of their daily diet. They recognize that fresh-cut fruits are not only convenient but adding it to their daily diet will provide them the additional nutrition required to maintain good health. Fruits and vegetables are a major source of vitamins (Vitamin C, Vitamin A, Vitamin B_6, thiamin and niacin), minerals and dietary fiber, which reduce the risk of cancer, heart disease and degenerative diseases, along with carotenoids, flavonoids and other phenolics (Doll, 1990, Rimm et al., 1996, Tee 1992, Grassmann et al., 2002, Gaziano & Hennekens, 1993). Therefore, it is important that the post cutting operations are optimized such that there is minimal loss in nutrients during storage of fresh-cut fruits.

Besides nutritional wholesomeness, some of the key attributes which make fresh-cut fruits an appealing food category are aroma, flavor, color and texture. If these attributes are maintained at a level which is acceptable by consumers then the likelihood that consumers will buy the same fresh-cut product increases. The primary reasons for rapid deterioration of cut fruit quality is biochemical and physiological changes during processing, storage, transportation and handling. Therefore, it is an ongoing challenge to maintain a certain level of quality. Various postharvest and post cutting techniques have been implemented to achieve these goals, such as treating fresh-cut fruits with anti-browning solution, anti-microbial agents, controlled atmosphere storage, modified atmosphere packaging, irradiation, osmotic dehydration and ethanol vapor treatment (Gonzalez et al., 2000, Beaudry, 2000, Qi and Watada, 1999, Lerici et al., 1985) . Depending on the type of fruit characteristics the above mentioned techniques can be implemented in combination to achieve the desirable level of quality.

The most common packaging used in the fresh-cut fruit industry are rigid containers made from Polyethyleneterephthalate (PET) and Polystyrene (PS).

These containers may have a rigid lid, non-perforated film or perforated film as a closure, depending on the packaging requirements of the fresh-cut fruit. Rigid containers come in different shapes and sizes, depending on the serving size and utility (on-the-go, club store quantity), so fresh-cut fruit can be packaged accordingly. Single serve rigid containers used for packing fresh-cut fruits have varying heights causing fruit dices to be packed either in a single layer or multiple layers or oriented randomly in the container. These fruit dices packed in rigid containers will experience physical movement and repetitive impacts during transportation. Fruit pieces will tend to move into voids within the container, causing frictional damage of surface tissue and leading to quality degradation. It is expected that fruit dices which are packed in layers will experience relatively lesser physical movement than randomly oriented fruit dices in a container during transportation. The intensity of the impact and physical movement is dependent on the location of the rigid container on a unitized load of fresh-cut fruit in corrugated boxes. Rigid containers located on the top layer of the unitized load will experience more physical movement due to vibration caused during transportation. This is due to magnification of vibration forces with increasing stack height resulting in maximum bouncing of in the top layers. The severity of the surface tissue damage can be dependent on the rigid container design. A rigid container with straight side walls may restrict fruit dice movement more effectively than a container with a sloping side wall. Similarly, ribbed faces of a rigid container may contribute to the severity of surface tissue damage caused by repetitive impacts on the ribbed bottom face or side wall. These factors make it essential to consider the container design in a fresh-cut fruit packaging operation.

It is known that during the cutting operation, surface tissue is wounded and is highly susceptible to sensorial and physiological degradation compared to the whole fruit (Gorny et al., 2000). This can be magnified when a product is transported over a considerable travel distance for distribution to a retail market (Chonhenchob and Singh, 2006). The fruit dice size can be an important factor to consider during the cutting operation. The size of the fruit dice plays an important role during the filling operation. Smaller dices will have larger surface area to volume ratio than a larger dice, making it more susceptible to surface tissue damage during transportation. Similarly, during the filling operation a cube shape fresh-cut fruit piece can be more effectively packed in layers than a randomly shaped fruit piece. The randomly shaped fresh-cut fruit piece will experience more physical movement during transportation compared to a cube shape fresh-cut fruit piece, resulting in surface tissue and quality degradation. Therefore, it is pertinent to know during the cutting operation the recommended shape and fruit dice size that can withstand transportation abuses without compromising the quality of fresh-cut fruit.

Upon reviewing several research studies performed over the past decade, it is observed that a considerable amount of research effort has been focused on maintaining the quality of fresh-cut fruits. Most of the research work has been focused on understanding to maintain quality, nutritional value and extending shelf life of fresh-cut fruits through various available post harvest techniques and post cutting treatments. There has not been a study which develops a methodology to assess the quality of fresh-cut fruit affected by fruit dice size, container design and transportation.

This study selected three PET container designs, where Container A, square shaped, had straight side walls with a shallow height (1.75 inches). Container B rectangular shaped, had a sloping side wall with a medium height (2.625 inches) and Container C parfait cup shaped, which had a wide mouth, sloping side wall transitioning to a straight side wall with a tall height (3.1 inches). Similarly, the two dice sizes selected for this study were 2.5cm and 1.5 cm cubes. It was hypothesized that a smaller fruit dice packaged in a taller container with sloping side walls will reduce the quality of fresh-cut fruit during transportation.

2. LITERATURE REVIEW

2.1 Fresh-cut Fruit and Quality

The International Fresh-cut Produce Association (IFPA) defines fresh–cut produce as fruits or vegetables that have been trimmed and/or peeled and/or cut completely into usable product that is either bagged or packaged to provide consumers with convenience, high nutrition and flavor while still maintaining its freshness (Lamikanra, 2002). Fresh-cut produce acquired a marketplace in the retail industry during the 1990s, lettuce, cabbage, and carrots among other vegetables (Brody, 2002). These products were made available to consumers as 'ready to eat' product after sanitization, cleaning and distribution in controlled refrigeration thus making it a popular healthy food choice (Ahvenainen, 1996). A similar approach has been adopted in the fresh-cut fruit industry, where similar processing technologies are utilized to make available minimally processed fresh-cut fruits. Fresh-cut produce has been a rapidly growing industry in the U.S. Fresh-cut sales rose from $3.3 billion in 1994 to $11 billion in 2004 (IFPA, 2004). The Fresh-cut fruits (FCF) industry is currently (approximately) $1 billion (IFPA, 2004). This category has not yet reached its potential market share of the fresh-cut industry. However, there are several challenges in maintaining the quality of such fresh-cut fruit products.

Quality is a term often used in postharvest and food packaging but it is rarely defined. There are several perspectives and concepts of quality in postharvest handling and distribution. The two primary concepts that define quality are the 'Product-Oriented Quality' and 'Consumer-Oriented Quality'

(Shewfelt, 1999). Product-oriented quality is often used by postharvest researchers, producers and handlers and consumer-oriented quality is used by consumers, marketers and economists. Product-oriented quality is described as quality changes of specific attributes that can be quantified and plotted as a function of time and directly related to physiological changes (Shewfelt, 1999). The specific attributes are package headspace O_2 and CO_2 composition, firmness, color, and total soluble sugar, which are measured with analytical instruments and results can be analyzed and reproduced. The accuracy and precision of the data analyzed provides internal validity of a scientific study (van Trijp and Schifferstein, 1995). A product oriented quality evaluation is best suited for assessing cultivar selection, harvest techniques and post harvest treatments with an emphasis on appearance leading to extended shelf life. Consumer oriented quality is defined by consumer behavior and product performance in a marketplace providing external validity of product performance in a market place. This involves understanding consumer attitudes by using consumer panels to determine acceptability/unacceptability and willingness to purchase. The results can be utilized in identifying quality attributes that drive acceptability, and in conjunction with sensory descriptive analysis, the critical quality attributes can be verified (Conner, 1994; Shewfelt et al., 1997). Consumer oriented quality is better suited to produce a distribution system that is sensitive to consumer needs with an emphasis on flavor at the expense of appearance leading to shorter shelf life (Shewfelt, 1999). In view of these two quality concepts, it is essential to design a postharvest and packaging study where it considers appearance, flavor and texture to be of equal importance to meet both consumer and distributor needs.

In fresh-cut fruits the greatest hurdle to commercial marketing is its limited shelf life, which is due to excessive tissue softening and cut surface browning. The primary reason is the rapid deterioration of cut-fruit quality due to biochemical and physiological changes during processing, storage, transportation and handling (IFPA 2005). Mechanical operations like cutting, peeling, and coring reduce the shelf life of fresh-cut fruit commodities. Wounding tissues results in metabolic activation which increases respiration rate and in some cases ethylene production (Varoquaux & Wiley,1997) leading to post-climacteric stage ripening. These changes adversely affect fruit flavor, texture, appearance, nutrient retention and increase safety concerns. Since fresh-cut fruits are more perishable than intact fruits (Watada et al., 1996), research efforts are being directed towards developing better approaches in processing, handling, packaging and storage to minimize their impact on cut fruit quality. Consumers have also become more critical of the use of synthetic additives to preserve food or enhance characteristics such as color and flavor (Bruhn, 2000). This has led to adopting minimal processing techniques in place of traditional methods of preservation while retaining nutritional and sensory quality (Ohlsson, 2002).

As mentioned earlier, fresh-cut fruits have been gaining popularity in the past decade as consumers recognize their convenience and added benefit of nutritional value. Is the same level of nutrition maintained in fresh-cut fruits compared to whole fruits? A major benefit to high fruit intake is the increase consumption of vitamins, minerals and dietary fibers (Doll, 1990, Rimm et al., 1996, Tee 1992, Grassmann et al., 2002, Gaziano & Hennekens, 1993). Postharvest processing can lead to nutritional loss in quality. This is observed in the case of Vitamin C. It is affected by physical damage, extended storage, high temperatures, and low relative humidity (Nunes et al., 1998, Lee & Kader, 2000, Kader 2002, Hussein et al., 2000). Similarly, the antioxidant properties of a cut fruit can be depleted by surface exposure due to cutting and oxidation (Klein, 1987, Huxsoll et al.,1989 Wright & Kader, 1997). Gil et al., 2006 studied the change in quality and nutrition retention in fresh-cut fruits compared to whole fruits during storage. The study included pineapples, mangoes, cantaloupes, watermelons, strawberries and kiwis. It was found that the antioxidant properties of fresh-cut fruits did not vary much more than whole fruits during processing and storage. However there was a reduction in Vitamin C content in the case of fresh-cut fruits compared to whole fruits during storage and processing. On the basis of visual quality, the fresh-cut fruits studied were unacceptable by day 6 or 9 depending on the fruit.

When purchasing a fresh-cut fruit product, a consumer considers a blend of attributes. They consider the appearance, texture and flavor of the product before making a purchase. The value of such a product to a consumer is a combination of the above mentioned attributes. The relative importance of each quality attribute depends upon the fruit. Consumers judge quality of fresh-cut fruit on the basis of appearance and freshness at the time of purchase. However, subsequent purchase is dependent on the quality of flavor, aroma and texture of the product. Researchers utilize these parameters to design research and gauge the quality of minimally processed cut fruits. There are several sets of criteria used to assess the quality of a product. A practical approach to assess quality is to determine acceptability of a product compared to a criterion, the quality limit. Below this limit, the product is rejected (Tijkens,2000). The acceptance limit is defined principally by psychological and economic factors, whereas quality of a product is mostly defined by the intrinsic properties (e.g. aroma, appearance, flavor and texture). Once these intrinsic properties have fallen below the acceptance limit the product is considered to have reached the end of its shelf life under standard storage conditions (Tijskens, 2000).

Consumers take product appearance into consideration as a primary criterion (Kays, 1999). Color is considered to have a key role in food choice, food preference and acceptability. It can substantially influence the threshold for taste and aroma perception (Clydesdale, 1993) Appearance is the size, color, gloss and visual defects of a whole or cut fruit. In the case of whole fruits, appearance can be flawed due to insect infestation, disease and bruising due to physical forces. Cut fruit can experience tissue browning caused by polyphenol oxidase that catalyzes the oxidation of phenolic compounds to produce brown pigments. Consumers perceive a firm and juicy texture to be highly desirable while consuming minimally processed fruits and associate it with freshness and wholesomeness (Bourne, 2002; Fillion & Kilcast, 2002). Texture includes firmness, crispiness, juiciness and toughness depending on the fruit. Soft fruits cannot be shipped long distances without proper handling and packaging due to mechanical injuries. Therefore various fruits are harvested at a maturity level where it may not have reached its optimum flavor quality but can withstand such abuses during transit. The factors which include flavor descriptors are sweetness, sourness, bitterness, aroma and off-flavor. These factors are perceptions of various compounds in fruits. The sugar content influences sweetness as organic acids influence sourness. Similarly, certain off-flavors and odors can be a result of pre or post cut treatment and chemical degradation of fruit. It is important that these factors are quantified through extensive sensory testing to determine the minimum level of consumer acceptance. Also, with growing health concerns, consumers are resorting to more nutritional options like cut fruits in their diet (IFPA,2004). Since fruits are a good source of vitamins, mineral and dietary fibers, it is essential they are not depleted of these nutrients. Nutrient depletion can be a result of improper post harvest, post cut treatment or physical damage. Therefore it is very essential for a consumer to purchase a FCF product without any defects and in its finest condition (Watada and Qi,1999). However subsequent purchase of the same product depends on the consumers' satisfaction of its flavor and textural properties upon consuming the product. Thus one of the on-going challenges is to protect and extend the shelf life of these highly perishable and minimally processed FCF.

Quality of whole fruits is dependent on cultivars, cultural practices and climatic conditions, maturity at harvest and harvesting methods (Solomos, 1997). These factors consequently impact cut-fruit quality. The state of maturity of processed fruit has been shown to influence the damage inflicted during mechanical operations on the cut fruit surface. Studies performed previously have shown that the more advanced the ripeness the more susceptible the fruit is to wounding during processing (Gorny et al., 2000, Gorny et al., 1998). On the contrary it has been observed that ethylene production doubled in apple slices from partially ripened apples stored in passive modified atmosphere in the first week compared to ripe apples (Solvia-Fortuny et al., 2003).

Additional factors which affect FCF quality are method of preparation, temperature, humidity, package atmosphere and sanitation (Watada et al.,1996). Some studies have reported that blunt cutting blades used during the cutting operation led to a slight increase in respiration and the ethylene production rates of fresh-cut melon (Portela and Cantwell, 2001). Similarly, cutting direction appears to play an important role in the wounding response of many fruits. It has been observed in bananas that a 1 cm-thick transverse section produced less ethylene and showed the lowest respiration rates (Abe et al., 1998). Some research has shown that wound induced ethylene production can be reduced by treating whole fruit or cut fruit with 1-Methylcyclopropene (1-MCP) treatments, as in the case of apples (Jiang and Joyce, 2002). The study showed that 1-MCP will bind itself to the superficial cell receptors and block ethylene from its binding site, thereby reducing ethylene induced ripening and its effect on intact climacteric fruit quality. Similarly at temperatures between 10-20°C respiration rates and Q_{10} values were observed to be higher than 0-10°C for several cut fruits (Watada et al., 1996). This can deteriorate product appearance, flavor and aroma. Therefore, it is recommended that FCF should be stored at lower temperatures unless there is a risk of chilling injury. Similarly, very low levels of oxygen in the package induces anaerobic respiration in fresh-cut fruits, which can lead to the development of undesirable anaerobic respiratory volatiles and growth of anaerobic micro-organisms growth (Watada et al., 1996). Therefore, it is necessary to maintain CO_2 and O_2 levels in specific ranges to avoid deterioration of FCF quality and has been recommended in several studies that 3-5% O_2 and 5-10% CO_2 is optimum for fresh fruits and vegetables storage (Paul and Clarke,2002; Lee et al. 1996).

2.2 Respiration

Minimally processed vegetables and fruits are living tissues even after cutting. Damaged plant tissues exhibit an increase in respiratory rate (Theologis and Laties, 1978). It has been shown that tissues with high respiratory rates have shorter postharvest lives (Eskin, 1990). The process of respiration involves combining O_2 in the air with organic molecules in the tissue (usually a sugar) to form various intermediate compounds and eventually CO_2 and water. The energy produced by the series of reactions comprising respiration can be captured as high energy bonds in compounds used by the cell in subsequent reactions, or lost as heat. Little can be done to alter the internal factors affecting respiration of harvested fruits and vegetables, since they are largely a function of the commodity itself once harvested. However, a major part of postharvest technology is devoted to reducing respiration and other metabolic reactions associated with quality retention by manipulating the external environment. Modifying the atmospheric composition in which the fresh-cut fruits are stored is usually done to slow down the respiration rate, reduce metabolic rate and maturation (Kader, Zagory, & Kerbel, 1989) and losses in fresh weight (Bottcher et al., 2003). The headspace composition is modified by altering the O_2 and CO_2 concentration which affects the metabolic state of the product in turn affecting the quality of the fresh-cut product. Respiration rates can then be evaluated by monitoring the composition of O_2 and CO_2 in the headspace of the packages (Del Nobile et al., 2006) to ensure optimum level of gas composition. Adequate O_2 levels are required to maintain aerobic respiration. The exact level of O_2 that reduces respiration while still permitting aerobic respiration varies with commodity. In most fruits and vegetables, an O_2 level around 2 to 3% produces a beneficial reduction in the rate of respiration and other metabolic reactions. Levels as low as 1% improve the storage life of some fruits, such as apples, when stored in optimal temperature conditions. At higher storage temperatures, the demand for ATP may outstrip the supply and promote anaerobic respiration. The need for adequate O_2 should be considered in selecting various postharvest handling procedures, such as waxing and other surface coatings, film wrapping, and packaging. Unintentional modification of the atmosphere in packaging can result in production of undesirable fermentative products and development of foul odors. Increasing the CO_2 level of some commodities reduces respiration, delays senescence and retards fungal growth. In low O_2 environments, increased CO_2 levels may trigger anaerobic respiration with the production of undesirable metabolite and other physiological disorders (Oms-Oliu et al., 2002; Zager & Kader, 1988). Some commodities tolerate brief (a few days at low temperatures) storage in a pure N_2 atmosphere, or in very high concentrations of CO_2.

2.3 Factors Affecting Respiration

Respiration is affected by a wide range of environmental factors that include light, chemical stress such as fumigants, radiation stress, water stress, growth regulators, and pathogen attack (Biale and Young, 1981) . The most important postharvest factors are temperature, atmospheric composition, and physical stress (Kays, 1991).

2.3.1 Temperature

Without a doubt, the most important factor affecting postharvest life is temperature. This is because temperature has a profound affect on the rates of biological reactions, such as metabolism and respiration. Increased temperatures cause an exponential rise in respiration (Biale and Young, 1981). The Van't Hoff Rule states that the velocity of a biological reaction increases 2 to 3-fold for every 10 °C (18 °F) rise in temperature (Salveit, 1996).

The temperature quotient for a 10 °C interval is called the Q_{10}. The Q_{10} can be calculated by dividing the reaction rate at a higher temperature by the rate at a 10 °C lower temperature, i.e., $Q_{10} = R_2/R_1$ (Biale and Young, 1981). The temperature quotient is useful because it allows us to calculate the respiration rates at one temperature from a known rate at another temperature. However, the respiration rate does not follow ideal behavior, and the Q_{10} can vary considerably with temperature (Biale and Young, 1981). At higher temperatures, the Q_{10} is usually smaller than at lower temperatures. Typical rates for Q_{10} are:

Table 1. Q_{10} rates at different temperatures

Temperature	Q10
0 to 10 °C	2.5 to 4.0
10 to 20 °C	2.0 to 2.5
20 to 30 °C	1.5 to 2.0
30 to 40 °C	1.0 to 1.5

(Salveit, 1996)

Although respiration is normally reduced at low, but non-freezing temperatures, certain commodities, chiefly those originating in the tropics and subtropics, exhibit abnormal respiration when their temperature falls below 10 to 12 °C (50 to 53.6 °F). Typically Q_{10} is much higher at these low temperatures for chilling sensitive crops than it would be for chilling tolerant ones. Respiration may increase dramatically at the chilling temperatures or when the commodity is returned to non-chilling temperatures (Biale and Young, 1981). This enhanced respiration presumably reflects the cells' efforts to detoxify metabolic intermediates that accumulated during chilling, as well as to repair damage to membranes and other sub-cellular structures (Kays, 1991). Enhanced respiration is only one of many symptoms that signal the onset of chilling injury.

As the temperature rises beyond the physiological range, the rate of increase in respiration falls. It becomes negative as the tissue nears its thermal death point, when metabolism is disorderly and enzyme proteins are denatured (Biale and Young, 1981). Many tissues can tolerate high temperatures for short periods of time and this property is used to advantage in killing surface fungi on some fruits. Continued exposure to high temperatures causes phytotoxic symptoms, followed by complete tissue collapse (Biale and Young, 1981). However, conditioning and heat shock, such as short exposure to potentially injurious temperatures, can modify the tissue's responses to subsequent harmful stresses.

2.3.2 Physical Stress

Even mild physical stress can perturb respiration. Physical abuse can cause a substantial rise in respiration that is often associated with increased ethylene evolution. The signal produced by physical stress migrates from the site of injury and induces a wide range of physiological changes in adjacent, non-wounded tissue (Biale and Young, 1981, Kays, 1991, Abeles et al., 1992). Some of the more important changes include enhanced respiration, ethylene production, phenolic metabolism and wound healing (Kays, 1991). Wound-induced respiration is often transitory, lasting a few hours or days. However, in some tissues wounding stimulates developmental changes, such as promotion of ripening that result in a prolonged increase in respiration (Barberan, 1997). Ethylene stimulates respiration and stress-induced ethylene may have many physiological effects on commodities besides stimulating respiration (Abeles et al., 1981).

2.3.3 Stage of Development

Respiration rates vary among and within commodities. Storage organs such as nuts and tubers have low respiration rates. Tissues with vegetative or floral meristems such as asparagus and broccoli have very high respiration rates (Biale and Young, 1981). As plant organs mature, their rate of respiration typically declines. This means that commodities harvested during active growth, such as many vegetables and immature fruits, have high respiration rates (Biale and Young, 1981).

After harvest, the respiration rate typically declines; slowly in non-climacteric fruits and storage organs and rapidly in vegetative tissues and immature fruits. The rapid decline presumably reflects depletion of respirable substrates that are typically low in such tissues (Biale and Young, 1981). An important exception to the general decline in respiration following harvest is the rapid and sometimes dramatic rise in respiration during the ripening of climacteric fruit (Biale and Young, 1981). This rise, which has been the subject of intense study for many years, normally consists of four distinct phases: 1) pre-climacteric minimum, 2) climacteric rise, 3) climacteric peak, and 4) post-climacteric decline.

Several fresh-cut fruits have shown higher respiration rates than whole fruits (Watada et al,1990;Cantwell, 1992). It has been shown that wounding a fruit induces a change in the mitochondrial structure as well as increases their numbers. This explains the higher respiration rates due to higher aerobic mitochondrial respiration (Asahi,1978). Higher respiration rates has been linked to shorter shelf life (Kader,1987). It is assumed that cutting fruits will shorten their shelf life (Rolle and Chism,1987). Respiration in cut fruits is also influenced by storage temperature. Higher respiration rates are more prevalent in cut fruits stored at higher temperature (Watada et al,1996). Shredded cabbage had the lowest respiration rate at a storage temperature of 2.5°C followed by 5°C, 7.5°C and 10°C (Cantwell 1992). Similarly sliced green tomatoes stored at 8°C had a

40% increase in their respiration rate, compare to that of an intact tomato (Mencarelli et al.,1989). Increased respiration rate in cut fruit can be also be a result of anaerobic respiration. If cut fruit is stored at high temperature and at oxygen levels which are below the threshold to induce anaerobic metabolism, then the cut fruits will sustain high respiration rates (Lakakul et al., 1999). Therefore, it is essential to control temperature and package atmosphere to inhibit anaerobic respiration as it can lead to accumulation of anaerobic metabolites producing off-flavors (Ke et al., 1991)

Several studies have been devoted to fresh-cut physiology (Watada et al, 1990, Brecht 1995, Watada et al 1996). The fundamental principle behind fresh-cut quality is that they are living tissues, as a consequence if they are abused during post harvest handling, processing and distribution it will result in certain physiological responses (e.g. browning and purging). Microbial growth on cut fruits is influenced by the physiology of the minimally processed product therefore maintaining low microbial numbers is an essential part of maintaining the quality of fresh-cut fruit.

2.4 Ethylene Production

It is well known that wounding a plant tissue leads to ethylene production. Ethylene production as a consequence of cutting has been observed in tomato (Lee et al.,1999), strawberry (Abeles et al., 1992) and papaya (Paull and Chen,1997). There are some fruits which do not produce ethylene or have reduced ethylene upon cutting, like pear (Gorny et al,2000; Rosen and Kader

1989). Whereas cantaloupe melon has shown both high and low ethylene release upon cutting (Hoffmann and Yang,1982 ; Luna-Guzman et al.,1999). A possible explanation to this contradiction is that the melon was cut at two different stages of maturity. If the melon was cut pre-climacteric stage then it will show high ethylene release, whereas cutting at post-climacteric stage it showed low ethylene release. Therefore, it is crucial to be aware of fruit maturity before starting a fruit cutting operation as it may influence cut fruit quality with time. One successful method to suppress ethylene production is to store fresh-cut fruits at temperatures between 0 - 2.5°C (Madrid and Cantwell).

2.5 Preservative Treatments

The color of fresh-cut fruits is probably the main quality attribute considered by consumers. One of the most limiting factors on the shelf-life of minimally processed fresh-cut fruits is browning. The aroma and texture attributes of fresh-cut fruit are secondary factors which a consumer considers before buying a FCF product. Several studies have been conducted to reduce or control browning in fresh-cut fruits, maintain desirable level of aroma volatiles and texture during storage. The common practice to reduce browning in fresh-cut fruit is post cutting treatment of fruits with anti-browning agents. Anti-browning agents administered could be synthetic (1-Methylcyclopropene, sulfites) or naturally occurring compounds and derivatives found in plants (Methyl jasmonate, 4-hexylresorcinol) (Gonzalez et al., 2001 and Monsalve-Gonzalez et al.,1995). There has also been a report of study performed using mild heat treatment of whole fruit prior to the cutting operation to maintain desirable aroma characteristics in cantaloupe (Lamikanra et al., 2005).

Gonzalez et al., 2000 studied the effect of anti-browning agents on fresh-cut mangoes. The anti-browning agents used were 4-hexylresorcinol (HR), potassium sorbate (KS) and D-isoascorbic acid (ER). They also studied the effectiveness of a combination of these anti-browning agents to inhibit browning. The combination solutions investigated in this study were HR (0.001M) + KS (0.05M), HR(0.001M) +ER (0.5M) + KS(0.05M), ER(0.5M)+ KS(0.05M) and HR(0.001M) + KS(0.05M). It was discovered that the two best performing solutions were HR(0.001M) + KS (0.05M) and HR(0.001M) +ER (0.5M) + KS(0.05M). Fresh-cut mangoes treated with these solutions produced a reduction in color change (L^*,a^*,b^*) and microbial growth while maintaining the sensory characteristics of fresh-cut mangoes. Fresh-cut mangoes treated with these two solutions retained high levels of citric acid, the main organic acid in mango fruit. It was also observed that there was an increase in fructose and glucose during storage. The combination HR+ER+KS was reported to be the most effective in extending the shelf life of fresh-cut mangoes to 14 days. The study showed that the combination of several browning inhibitors was more effective than those applied individually.

The use of 1-methylcyclopropene (1-MCP) induces beneficial effects such delay in physio-chemical changes related to fruit ripening, reduction of decay, color properties and weight loss (Blankenship and Dole, 2003). Valero et al., 2004 studied the effectiveness of 1-MCP treatment on plums packaged in bulk and small card-board boxes. It was found that 1-MCP inhibited the typical climacteric peak and delayed the change in properties related to fruit ripening. 1-MCP treated plums packaged in small card-board boxes showed significantly lower fruit softening, decreased in titrable acidity and delayed color changes compared to plums treated in bulk. Packaged plum in small card-board boxes was more responsive to 1-MCP treatment as there was better gas diffusion over the entire surface of the fruit enabling 1-MCP to block receptors more effectively. Thus, parameters related to plum ripening, such as color chroma, TSS, fruit acidy and softening was delayed compared to 1-MCP bulk treated plums. The study showed that plum packaged in well aerated boxes and treated with 1-MCP had an increased shelf-life compared to plums treated with 1-MCP in bulk.

One of the key problems in fresh-cut pineapple was browning after 6 days of storage at 4°C (O Connor et al., 1994). Gonzalez et al., 2003 studied the effect of different concentration of ascorbic acid (AA), isoascorbic acid (IAA) and acetyl cysteine (AC) to delay browning in fresh-cut pineapple packaged in polystyrene trays stored at 10°C. The anti-browning agents reduced browning and decay significantly. Isoascorbic acid was most effective in preserving the visual appearance, firmness and reduced changes in L* and b* values of the pineapple slices followed by acetyl cysteine and ascorbic acid. The pineapple slices treated with IAA, AA and AC effectively increased the shelf-life up to 14 days at 10°C.

By processing FCF with anti-browning agent it provides a protective layering over the exposed tissue. Several studies have reported that ascorbic acid in combination with $CaCl_2$ is an effective anti-browning agent (Chohenchob and Singh, 2005). A commercially available anti-browning agent NatureSeal™ is a calcium ascorbate powder used extensively in the fresh-cut industry. Ascorbic acid functions as a reducing agent to deter surface browning (Whitaker, 1994). Calcium chloride treatment provides tissue firming and has been reported to reduce browning (Drake and Spayd, 1983; Hopfinger et al.,1984).

2.6 Sensory Evaluation

Sensory analysis is a branch of food science in which a structured and codified methodology is adopted to evaluate physical and organoleptic properties of a food product. In basic terms it can be understood as a human response interpreted by the person's brain to a physical stimulus (Meilgaard et al, 1999). Physical stimulus could be through any of the 5 senses a human possess (smell, vision, taste, touch and auditory). The four main sensory attributes that are generally evaluated for food products are appearance, aroma/odor, texture (consistency and/or firmness) and flavor (Meilgaard et al, 1999). A subject's perception of each of these attributes is integrated during sensory evaluation of a product. Unless the subject is trained to provide independent evaluation of each attribute prior to the sensory evaluation of the product (Meilgaard et al., 1999). Essentially there are three different types of sensory tests. They are discriminative tests, descriptive tests and affective tests. Discriminative tests are performed to identify if there is a difference between samples. The intensity and nature of difference is determined by performing a descriptive test. An affective test is performed to determine a panelist's preference, acceptance or degree of liking between samples. The results are a subjective representation of a panelist's attitude towards a product (Meilgaard et al, 1999). Sensory analysis is an affective tool to detect off-odor and off-flavors caused by a compound having a low threshold level, which can go undetected by instrument analysis (Peled and Mannheim, 1977).

A study was performed by Schieberle and Hofmann, 1997, to evaluate the odor impact of certain volatiles in model strawberry juices. They identified twelve odor active volatiles which were representative of fresh strawberry juice from a previous study (Schieberle, 1994). A group of six trained panelists determined the intensity of eight odor qualities as detected in fresh strawberry juice compared to a model strawberry juice with the odor active volatiles. It was found that the flavor profile of the model juice was very similar to that of fresh strawberry juice. To gain better insight into their model juice as to how much of an impact each of the odor active volatiles presented, they prepared 11 model juices with one missing odor active volatile of the twelve odor active volatiles a typical strawberry juice is expected to contain. A triangle test was performed in which they used the complete mixture of twelve odorants as a control. It was determined that lack of 4-hydroxy-2,5-dimethyl-3(2H furanone and (Z)-3-hexenal caused a clear change in the overall strawberry like odor, thereby showing that both are character impact odorants in strawberry flavor (Schieberle and Hofmann, 1997). Such systematic approach to identify key odorants in food can assist in developing a product where strawberry flavor is desired.

Sensory evaluation can be used to determine an acceptable level of acid and sugar levels in diced tomatoes to ensure consumer acceptability and freshness impact on flavor. A study was performed to determine the affect on diced tomato taste and impact on freshness affected by six different ratios of sugar and acid levels (Malundo et al., 1995). Descriptive analysis was conducted to understand the effect on sweet, sour and fresh tomato impact and a consumer test was conducted to rate acceptability of diced tomatoes. The sugar and acid levels affected the tomato taste (sweet and sour) but did not significantly affect the descriptive ratings for fresh tomato impact, as it is more a function of volatile compound concentrations than sugar and acid levels (Kader et al., 1977). The results indicated that when tomato has a pH of about 3.74 or 0.80% TA, increasing the sugars can lead to an improved flavor quality (as per the consumer acceptability test). However, beyond these levels of pH and TA increasing acid levels affected negatively on the consumer acceptability rates for a given concentration of sugar. This study demonstrates that sensory evaluation and particularly consumer testing is an effective tool to determine the affect of taste components on flavor perception, independent of volatile aroma compounds, thus paving a way to improve the quality of fresh tomatoes.

Instrument analysis may sometimes not correlate well with sensory measurements, in particular off-odor/ aroma with low threshold levels stimulating a response in a panelist, but undetectable by way of instrument analysis. It is necessary to discover a relationship between sensory measurements and instrument analysis where possible for certain attributes, such as texture. Harker et al. (2002) investigated the relationship between sensory and instrument measurements of apple texture. A group of trained panelists was directed to evaluate a wide range of texture attributes (eight texture attributes) for different cultivars, maturity and ripeness of apples. Similarly, three instrument tests were performed to predict sensory response, which were puncture, twist and chewing sound. It was discovered that the puncture test was better at predicting sensory measurements than the other two methods. It was reported that for a panelist to detect a difference in texture there should be a firmness difference of 6 newtons (N) between samples (Harker et al., 2002). Such a finding facilitates researchers in postharvest technology to make decisions on pre/postharvest treatments with some level of confidence. However, it has been suggested that conventional sensory analysis by trained/untrained panelists should not be replaced by instrument analysis as some of the textural attributes (mealiness) is not predictable by instrument analysis.

Flavor, aroma and texture are the key indicators of fresh-cut fruit quality (Shewfelt, 1999) and it is a challenge to maintain these attributes at a level for consumer acceptability level (Shewfelt, 1999). Sensory analysis is often conducted to determine if there is a detrimental effect of postharvest processing techniques in order to maintain the quality of fresh-cut fruit (Gonzalez et al., 2000 and Gonzalez et al., 2004). Similarly, sensory analysis techniques can be implemented to determine the level of maturity that a fruit should reach before it is harvested to prepare fresh-cut fruits with the desirable levels of sensory properties. Sensory characteristics of fresh-cut cantaloupe are affected by the harvest maturity of the whole fruit (Beaulieu et al., 2004). It was established that descriptive analysis by a trained sensory panel that fresh-cut cantaloupe cubes prepared from 1/4 slip mature cantaloupe were significantly firmer than 1/2, 3/4 and full slip matured fruit. Correspondingly, 1/4 slip cubes had significantly lower fruit and sweet aromatic flavor than 1/2, 3/4 and full slip maturities (Beaulieu et al., 2004). The study suggested in order to achieve the desirable sensory characteristics, fresh-cut cantaloupe should be prepared from fruits which are greater than equal to 1/2 slip mature.

Sensory analysis techniques have been implemented to determine quality of fresh-cut fruit as affected by cutting tools (Cantwell and Portela, 2001) and shape of cut fruit (Lopez et al., 2005). Cantwell and Portela, 2001 found that cantaloupe pieces prepared using sharp borers maintained a marketable quality for 6 days compared to those prepared with blunt borers which were unacceptable after 6 days. Pieces prepared with a blunt blade show higher surface translucency scores making it visually unacceptable. However, blade sharpness did not affect aroma and off-odor scores. Similarly, Lopez et al., (2005) discovered that papaya cubes had a better overall quality index than slices stored at 5°C. It is evident that sensory evaluation is a critical component in determining the quality of fresh-cut fruits.

2.7 Electronic Nose Technology

The electronic nose is defined as an instrument comprised of electronic chemical sensors with partial specificity and an appropriate pattern recognition system, capable of recognizing simple or complex odors (Gardner and Barlett, 1993).

The electronic nose system generates headspace gas a over the sample being tested, exposes the headspace gas to the sensors, records the sensors' response, and analyzes the data. Different types of sensors are commercially used in electronic noses, and include metal oxide sensors, conducting polymers, and quartz crystals. Metal oxide sensors are made from zinc or tin oxide. These sensors are operated between two electrodes at 300 °C. The aroma compounds get oxidized on the surface of the sensor and change the resistance of the sensor. Conducting polymer sensors are obtained by electro-polymerization of a thin film of polymer across the gap between gold-plated electrodes. The electrical conductance of the film changes according to the odor compounds adsorbed on its surface. In the quartz crystal category, two different types of sensors are used. One is based on sensing the mass of the aroma compound adsorbed into the stationary phase coated on the crystal surface. The adsorption changes the frequency of vibration of the crystal, due to change in mass. These sensors are called quartz microbalances. The second type of sensor is a surface acoustic wave device. It operates similarly to quartz microbalance, apart from the fact that a surface wave is used to measure the absorbed quantity of aroma compound (Cutler,1999).

As reviewed by Schaller et al (1998), there is another type of metal oxide semi-conductor sensor used in the commercial electronic noses, known as a metal oxide semiconductor field-effect transistor (MOSFET) sensor. A MOSFET sensor is comprised of three layers: a silicon semiconductor, a silicon oxide insulator, and a catalytic metal such as palladium, platinum, iridium or rhodium. The catalytic metal is also called gate. The applied voltage on the gate and contact creates an electrical field, which alters the conductivity of the transistor. Hence when polar, odor compounds interact with the metal gate and the electric field is modified, which eventually modifies the current flowing through the sensor.

The electronic nose is an analytical instrument that can recognize flavors, odors and volatile compounds. It has many advantages over the subjective sensory panel evaluation of odors and flavors as it eliminates the fatigue factor, inconsistency, and the high cost involved in human sensory analysis. An electronic nose is composed of a chemical sensing system including as a sensor array and a pattern recognition system. Each sensor is sensitive to a certain volatile compound and generates a signature or pattern characteristic of the vapor. Different chemicals can be presented to the sensor array, which is then used to build a database of signatures. Such a database can be used to train the pattern recognition system of the electronic nose (Giese,2000).

Cutler (1999) pointed out that analytical measurement techniques such as GC-MS can detect individual components in a volatile vapor, but such components do not necessarily represent the combined sensory effect of the s

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vapor. Moreover, trained human subjects are not always available to perform sensory analysis.

Schaller et al (1998) pointed out that the electronic nose has been successfully used as a quality control tool to evaluate quality of various food products such as meat, grains, coffee, beer, mushroom, cheeses, sugar, fish, blueberry, orange juice, cola, and alcoholic beverages. It is also being widely used to analyze off-flavors in food due to packaging.

Henio and Ahvenainen (2002) used the E-nose to analyze the taints caused by pigments of printed solid boards. The objective of the experiment was to determine the effect of printing inks on the sensory properties of the packaging material, using the E-nose, which was correlated with human sensory evaluation and other headspace methods such as GC-MS. Twenty samples were studied, which included unprinted solid board, lacquered solid board, offset printed solid board with 14 different colors, and offset printed, lacquered solid board with 4 colors. The E-nose was found to successfully discriminate the different board samples based on their coloring agents or lacquering. The results also were correlated with the off-flavor perceived during sensory evaluation. Winquist et al (1993) used E-nose to study the quality of ground beef and pork and also estimate storage time in a refrigerator, based on the organoleptic property of the meat after storage. The electronic nose used consisted of a gas sensor array combined with a pattern recognition routine. Samples of ground beef and pork, stored in a refrigerator, were studied. The E-nose was successful in identifying the type and quality of meat.

Benedetti et al (2002) explored the use of an electronic nose to study the shelf life of ripened Taleggio cheese packaged in paper. The electronic nose used for the study had an array of 10 MOFSET sensors and 12 MOS sensors. The E-nose was found to effectively classify and discriminate among cheese samples based on differences in their storage time and temperature. The different storage times and temperatures influenced the aroma characteristics of the cheese, which was sensed by 6 of the 22 sensors, with good discrimination power.

Van Deventer and Mallikarjunan (2002) analyzed and compared the performance of three electronic nose systems as a quality control tool, to detect retained printing solvents in packaging. Metal oxide semiconducting sensors, conducting polymer sensors, and quartz microbalance sensors. Each system was used to test 3 different film classes, with varying retained solvents. It was concluded that E-nose with conducting polymer sensor technology had the highest discriminatory power. However, all the electronic noses were found to be capable of discriminating among the film samples at different levels of retained solvents.

Willing et al (1998) used an electronic nose to measure odors from paperboard, intended for packaging applications. Nine different paperboards from a wide range of board grades were analyzed using the electronic nose. The electronic nose was equipped with 10 MOFSET sensors, 4 Tagushi sensors, and 1 carbon dioxide sensor. The partial least squares regression (PLS) method was used to correlate electronic sensor responses with sensory panel descriptors.

Some electronic sensor responses correlated well with a selected number of panel descriptors, while others did not fit with panel descriptors.

Electronic nose technology is in a continuous development process, both with respect to hardware and software technology. It still has some disadvantages. It cannot provide sufficient quantitative information for certain aroma differences (Harper, 2001). In addition, the electronic nose system is prone to sensor drift, which occurs due to degradation of individual sensors. Drift results in a gradual change in output over time without any significant change in input. Thus, it hinders the reproducibility of the system. Calibration of sensors and sensor replacement after a fixed time interval can help in minimizing this problem (Maneesin,2001). Moreover, the sensors are sensitive to moisture. Conducting polymer sensors are more sensitive to moisture than the metal oxide sensors, which is minimized by using a filter and an air conditioning unit (Culter,1999).

2.8 Packaging

Packaging plays an important role in containing and maintaining quality of perishable products. Several technologies have been developed to maintain quality of fresh-cut fruits by way of post harvest treatments, such as anti-browning treatments, anti-microbial treatments, irradiation, and mild heat treatment (Gonzalez et al., 2000, Beaulieu, 2007, Ferrer & Harper, 2005, Lamikanra et al., 2005). In the past decade modified atmosphere packaging (MAP) has played an increasingly important role in the perishable product industry. An important goal in modified atmosphere packaging is to maintain a sufficiently low O_2 concentration to influence metabolism of the product to extend it's shelf life (Beaudry, 2000). In some cases altering the CO_2 concentration in the package headspace positively influences the shelf life of fruits and vegetables (Qi et al.,1998 and Aguayo et al., 2004).

By itself, modified atmosphere packaging to extend shelf life of fresh-cut fruits may not be enough to achieve the goal to maintain quality of cut fruits. Optimal storage temperature and appropriate post cutting treatments are necessary to meet these goals. Marrero and Kader, 2005 studied the optimal temperature required to enhance keeping quality of fresh-cut pineapples in modified atmosphere package. They established that storing fresh-cut pineapples in modified atmosphere package at 10°C resulted in a shelf life of 4 days, whereas the shelf life of cut pineapples stored at 2.2°C and 0°C was found to be over 14 days.

Similarly, another study conducted by Zhang et al., 2006 showed that MAP of strawberries prolonged shelf-life by 4-6 days. However, application of edible coating on strawberries prior to packaging extended the shelf-life by 8-10 days. Micro-perforated films are being used for modified atmosphere packaging to maintain a desirable O_2/CO_2 concentration in the package headspace (Welt and Abdellatief, 2007). This study showed, however, that micro-perforated film may not be suitable for all types of fresh-cut vegetables. They discovered that non-perforated films would satisfy MAP requirements for rutabaga, sweet potato, yellow squash, and 50/50 blend of yellow squash and zucchini. Whereas, microperforations were only suitable for fresh-cut sweet potato to satisfy MAP requirements. Modified atmosphere packaging was used to maintain the quality of fresh-cut mango (Buta et al.2000; Beaulieu and Lea, 2003, Chohenchob et al., 2006), cantaloupe melon and pineapple (Chohenchob et al., 2006). Currently, the common packaging material used are PET (Polyethyleneterephthalate) and PS (Polystyrene) for rigid containers. Such rigid containers are non-biodegradable which contributes substantially towards solid waste in a landfill. To combat this issue a biodegradable material known as PLA (Poly lactic acid) is being used to make rigid containers. Rigid containers made from PLA are slowly becoming popular in the fresh-cut fruit industry to replace PET and PS rigid containers. However, it is yet to be verified if PLA containers are capable of maintaining the quality of FCF during storage and transportation in a cold chain distribution system. Thus, it is necessary to determine the effect of an anti-browning agent on minimally processed cantaloupe packaged in rigid containers made from PLA, as affected by transportation (Chohenchob et al., 2006).

2.9 Distribution of Fresh Fruits

Distribution and marketing of fresh fruits and produce comprise multiple processes, including storage handling and transportation over land or sea to various markets, sometimes over 1000 miles away from the orchards or farm, where it is grown. Fruits and vegetables can be distributed as whole or minimally processed to various distribution centers and retail outlets. Consumers in urban areas have high per capita income and can afford to spend it on premium quality pre-packaged ready to eat cut fruits. This is evident in the fresh-cut fruit industry, which is reported to be a $1 billion market (IFPA, 2004). These products need to be in premium condition at retail outlets so that consumers get maximum value for the price. To ensure quality, expensive sophisticated operations including cleaning, disinfecting, processing, packaging and controlled atmosphere cold storage is practiced. Modern produce houses generally have a packing house located near the growing area. Without proper packaging fruits at such maturity levels can be easily bruised and abused which can lead to deteriorating quality in downstream operations. It is in individual grower's prime interest to send out the maximum amount of produce to a produce house. Even though quality inspection practices are in place it may not be enough to ensure that the highest quality of products are being distributed. To ensure quality, marketing organizations have quality control schemes and reward the growers as per the quality of their products. To assist in these efforts research and development is dedicated to understanding the produce distribution system and analytically to determine the best solution to maintain high quality and standards for such products. The goal of research and development is to have an interdisciplinary approach that considers the bio-chemical behavior and processing of fruits and vegetables, along with packaging and distribution systems.

It is well known that whole fruits like mango, banana, tangerine and papaya get bruised and quality deteriorates very rapidly. Such spoilage is dependent on road conditions and type of trucks used to transport fruits (Chohenchob and Singh, 2005). Since fresh-cut fruits have exposed tissue, highly perishable (Watada et al., 1996) and even more susceptible to damages during transportation.

Jarimopas, Singh and Saengril studied the effects of vibration in truck shipments on packaged tangerines in Thailand. (2005). A part of this study measured the effect of road conditions on the vibration levels. The study measured laterite, asphalt and concrete road surfaces. Results showed that the effect of road condition and trailer speed makes a big impact on the vibration produced and this affects bruising of fruit. The highest damage was produced on unpaved roads (laterite) road surfaces. These surfaces are usually formed from clay and pebbles.

The raw vibration data for different type of shipments is usually measured as a time-acceleration history and is sampled periodically using data recorders. The data is then analyzed to form power density spectrums (PDS). These are plotted on a log-log scale with power density (PD) along the y-axis and frequency in the x-axis. The average PD within a band of frequencies is calculated as root mean square acceleration measured in g's at any instant within a 1 hertz (Hz) bandwidth (BW), and N is the number of instant samples for a given segment of vibration.

Figure 1 shows a typical Power Density Spectrum. This spectrum is from the composite truck spectrum shown and described in American Society of Testing and Materials (ASTM) D4169 for an Assurance Level II. This is the most widely used vibration spectrum for random vibration testing internationally. The FDA also recommends the use of this spectrum for validation of all pharmaceutical and food products. Packaging engineers use this spectrum to program vibration test equipment in accordance with ASTM D4728 to conduct random vibration tests.

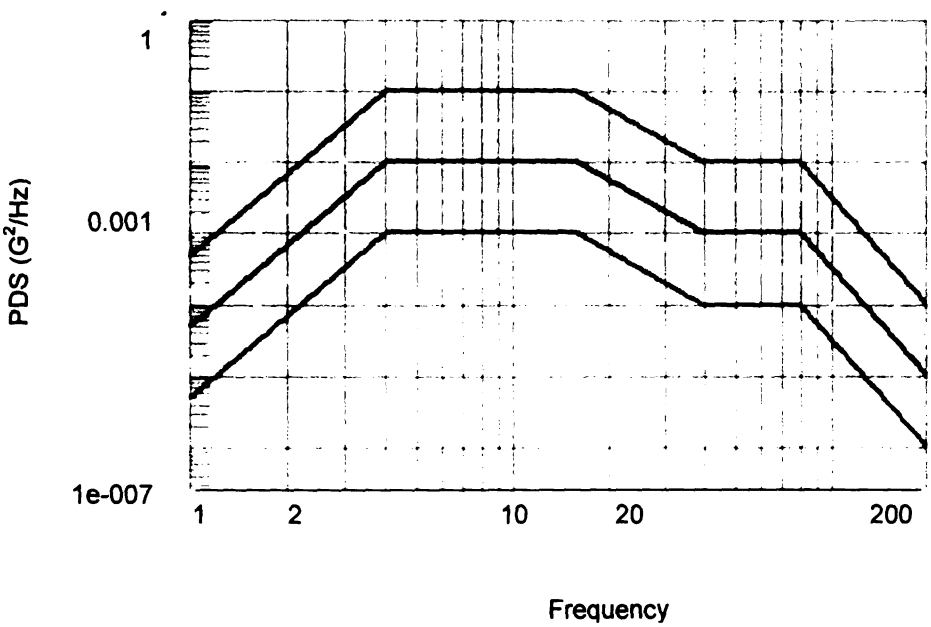

Figure 1. Power density spectrum as described in ASTM 4169 assurance level II

It should be noted that it is almost impossible and usually extremely expensive and time consuming to recreate the exact measured vibration levels in a laboratory. The reason is that vibration testers are not capable of large displacements that may with large potholes or uneven surface irregularities. As a result, various test method developing organizations have developed PD "composite" spectrums that combine various spectrums from road travel, speed, and truck types and then use accelerated levels to reduce test time. The ASTM D4169 Assurance Level II is the most widely accepted vibration spectrum representing vibration in a steel spring suspension trailer traveling in the United

States. International Safe Transit Association (ISTA) has developed a correlation of test time to travel time. ISTA Test Method 3E recommends correlating 30 minutes of test time in a random vibration test to 300 miles. A 1500 mile trip therefore reflects a 180 minute or 3 hour test. ASTM D4169 allows a range between 30 minutes to 6 hours to represent domestic and international shipments.

3. MATERIALS AND METHODS

3.1 Phase-1

Effect of Anti-browning Agent and Transport Vibration

3.1.1 Fresh-cut Processing

This part of the study was performed to identify a suitable anti-browning solution for post cutting treatment. Whole cantaloupe was purchased from a local supermarket. The whole cantaloupe was washed and dipped in a commercial sanitizer- Fruit & Vegetable Wash (SC Johnson Professional, Sturtevant, WI) (100-ppm chlorine) for 5 minutes. They were then stored in a 4°C± 0.3°C in walk-in chamber for a period of 12 hours prior to cutting. Once cantaloupes equilibrated to the desirable temperature, they were cut in 22°C± 4°C environment which has been cleaned and sanitized. After removing seeds and peels, the cantaloupes were cut into 1-inch cubes using a sharp stainless steel knife cleaned in a 100pm chlorine solution (Figure 2). Cantaloupe pieces were dipped in two anti-browning solutions: Treatment-A (2% ascorbic acid + 1% calcium chloride + 0.5% citric acid) and Treatment-B (3% NatureSeal™ containing calcium ascorbate) for 2 minutes. Following, 180 ± 5grams of cantaloupe pieces were packaged in bio-based clamshell containers (19.1 x 16.5 x 4.4 centimeters) made from polylactide (PLA) (Figure 3) procured from Wilkinson Industries, Nebraska.

Corrugated boxes were designed using ArtiosCad 7.6 (EskoArtwork, Gent, Belgium) and an ArtiosKornsberg Premiumline 1930 cutting table (EskoArtwork, Gent, Belgium) was used to make the corrugated boxes. The corrugated box were made of C-flute; brand FEFCO 0306 AB the dimensions- were 48.9 x 40.6 x 15.6 cm. Twelve cantaloupe filled containers were packaged in these corrugated fiberboard boxes, 6 containers per layer, and subjected to random vibration as described in ASTM D4169 at an Assurance Level II for 60 minutes to represent approximately 500 miles of truck travel in the United States. The vibration table (Lansmont Model 10000-10, Inc, Monterey, CA, USA) shown in Figure 4 was used to generate a power density spectrum in accordance with ASTM D4728. The cantaloupe filled containers were stored at 4°C± 0.3°C for 12 hours before further evaluation and testing. These cantaloupe filled PLA containers were compared to "control" samples (anti-browning solution + non-vibrated samples) packaged and stored under identical conditions for the same period of time as the tested (Figure 5).

Figure 2. Minimally processed fresh-cut cantaloupe (size: 1 in^3) before transport vibration

Figure 3. Cantaloupe filled containers packaged in corrugated box

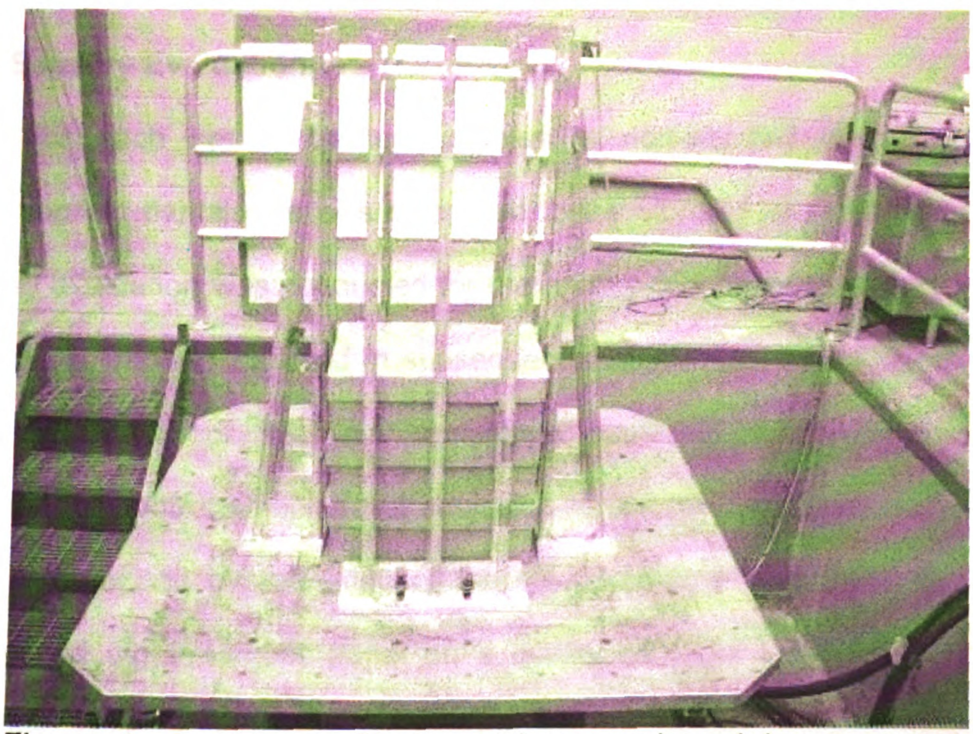

Figure 4. Cantaloupe filled containers packaged in corrugated boxes subjected to random vibration.

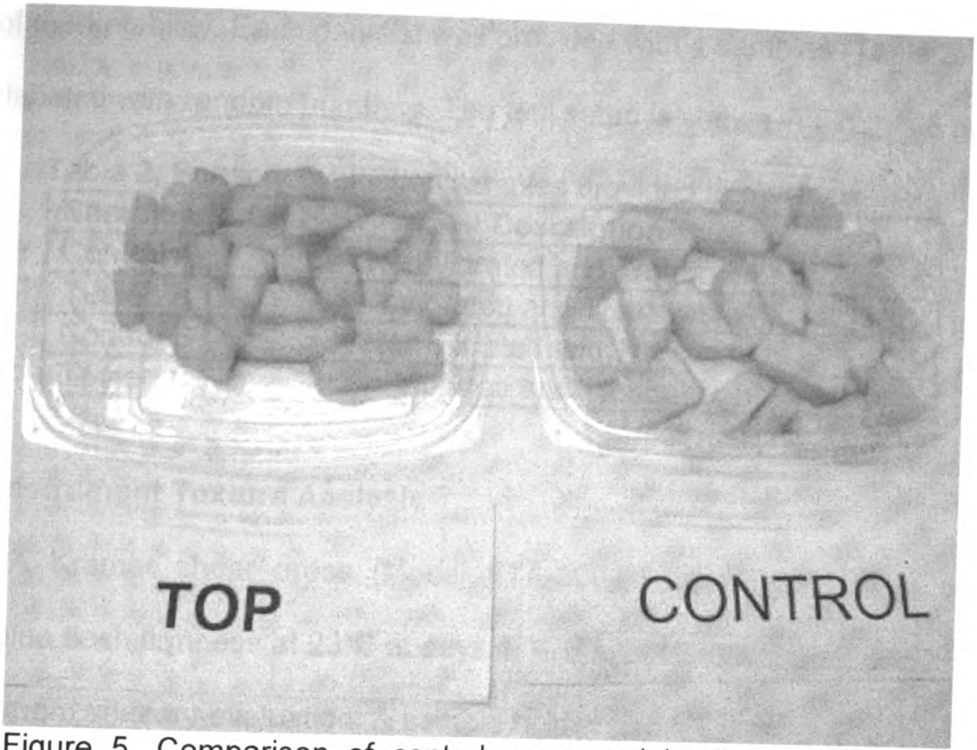

Figure 5. Comparison of control versus minimally processed fresh-cut cantaloupe after transport vibration

3.1.2 Sensory Evaluation

For each set of treated samples, a non-vibrated control container containing cut cantaloupe was compared to the vibrated and treated samples. Sensory evaluation was conducted for preliminary screening for the type of anti-browning solution to be used in subsequent studies. Also, to determine overall effect on quality of fresh-cut cantaloupe subjected to transport vibration compared to control samples not subjected to transport vibration. Appearance, flavor, texture and overall liking of the cut cantaloupe were evaluated by an experienced eight-member panel on a quality scale of 1-9 hedonic (9= Like extremely, 7=like moderately, 5= neither like nor dislike, 3=dislike moderately, 1=dislike extremely) for days 1, 4, 7 and 10. A score of 5 was determined as the limit of marketability. Each panelist was provided with 4 samples (Table 2) in 2 oz cups labeled with random numbers. The test setup is shown in Figures 6 and 7.

Table 2. Sensory evaluation samples provided to panelists

Samples	Description
Control A	Non-vibrated and Treatment A
Tested A	Vibrated and Treatment A
Control B	Non-vibrated and Treatment B
Tested B	Vibrated and Treatment B

3.1.3 Instrument Texture Analysis

A Kramer shear press (Model FTA-300,FTC,Stering,VA) was used to determine flesh firmness at 23°C at days 1, 4, 7 and 10 to compare it with texture scores from sensory evaluation. A sample holder (6.6 x 6.6 x 6.4 cm) was loaded with 60 grams of cut cantaloupe cubes. Upon placing the sample holder in the test cell 10 movable blades were lowered at 20 cm/min, compressing the cut samples to a distance of 10.2 cm. The force required to compress the test sample was recorded.

3.1.4 Statistical Analysis

The data was analyzed using statistical software Minitab 13.1 (Minitab Inc, State College,PA, USA). Analysis of variance was performed on sensory and firmness data and the means were separated using Fisher's LSD at significance level of $p \leq 0.05$.

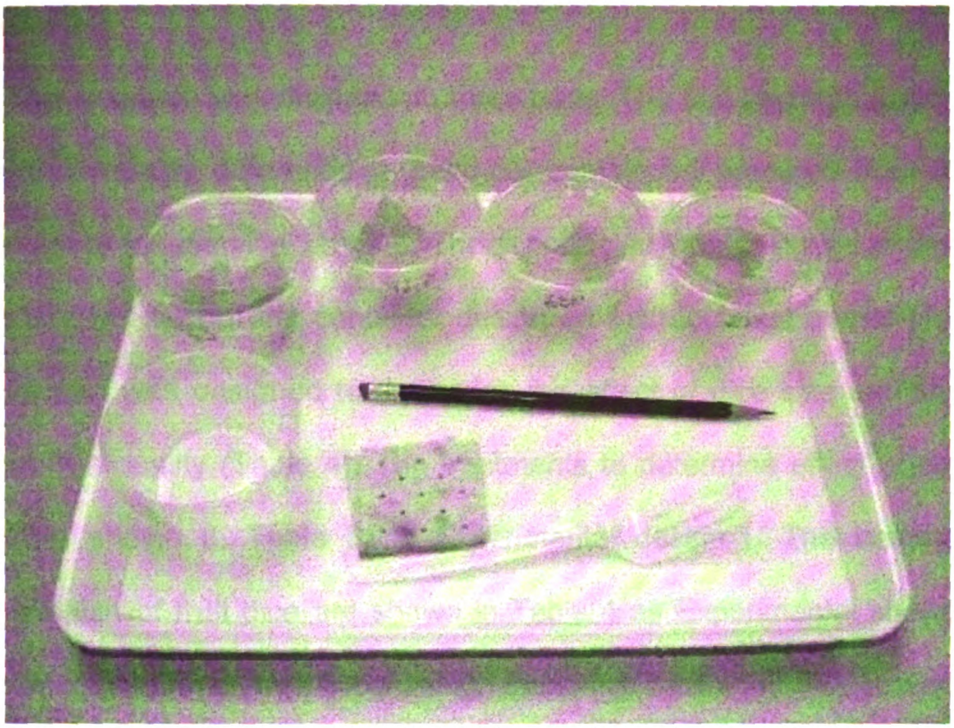

Figure 6. FCC samples coded with 3 digit random number on a tray for a panelist

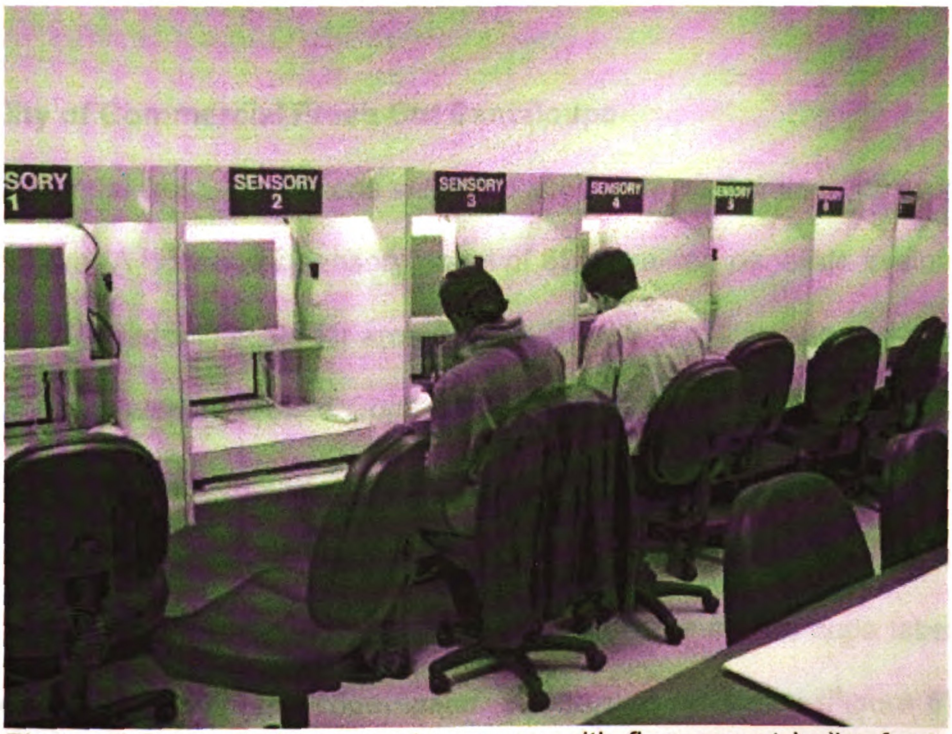

Figure 7.Controlled temperature room with fluorescent bulbs for taste testing fresh-cut cantaloupe

3.2 Phase 2

This research was divided into three parts. The first part was to determine if there is a quality difference in fresh-cut cantaloupe procured from different commercial or foodservice vendors. The second part was designed to determine if there is any effect of the container design on fresh-cut fruit quality (Table 3). The third part was designed to determine the effect of dice size and shape on fresh-cut fruit quality (Table 4). The treatments to determine effect of container design are shown in Table 3 as Experimental design-1. The treatments to determine size of fruit dice are shown in Table 4 as Experimental shown-2. An illustration of fresh-cut fruit processing, preparing packaged FCC, quantitative descriptive and physiochemical analysis to determine effect of container design and effect of dice size is shown in Figures 9 and 10.

3.2.1 Quality of Commercial Fresh Cut Cantaloupe

Commercial fresh-cut melons were procured from six commercial or food service vendors. A consumer sensory panel of 65 untrained panelists evaluated melons on a 1-9 hedonic scale for aroma, color, sweetness, firmness and overall quality. Panelists were recruited from MSU students, staff and faculty of both sexes. The consumer sensory panel testing was conducted under fluorescent bulbs and in a temperature controlled room (23°C±3) dedicated to sensory testing. Panelists were provided with three blind samples in 2oz cups labelled with a specific 3 digit random code, water and cracker on a tray (Figure 6). A LabScanXE colorimeter, (Hunter Associates Laboratory, Inc, Virginia,USA) was used to determine fruit color (CIE L*, a* & b* values), total soluble solids was measured using hand refractometer Atago PAL-1 (Atago Co., Ltd., Tokyo, Japan), pH and titrable acidy (malic acid) was analyzed and data was collected at days 1, 4, 7 and 10. A TA-XT2i (Texture Technologies Corporation, New York) texture analyzer equipped with a probe diameter 50 mm was used to determine flesh firmness value to compare it with texture score from sensory evaluation.

3.2.2 Effect of Container Design and Dice Size on Fresh-Cut Cantaloupe

The whole cantaloupe was washed and dipped in a commercial sanitizer (100-ppm chlorine) for 2 minutes. After removing seeds and peels, melons were cut into Size-2.5cm and Size-1.5 cm cubes. Melon pieces were dipped in a commercially available anti-browning solution (NatureSeal^{TM}) for 2 minutes and drained in a colander for 2 minutes then packaged in 3 PET containers (A, B and C) of different dimensions. The pictures of the 3 container design can be seen in Figure 8. Container A is a square shaped (4.75 inches x 4.75 inches x 1.75 inches) (Appendix A), Container B is a rectangular shaped (5.25 inches x 4.75 inches x 2.625 inches) (Appendix B) and Container C is a parfait cup (diameter: 4.7 inches height: 3.1 inches) (Appendix C). Nine PET containers of each container design were packaged in a customized corrugated boxes constructed for each container design. Corrugated boxes were designed using ArtiosCad 7.6 (EskoArtwork, Gent, Belgium) and an ArtiosKornsberg Premiumline 1930 cutting table (EskoArtwork, Gent, Belgium) was used to make the corrugated boxes. The corrugated boxes were made of C-flute; brand FEFCO 0306 AB. The dimensions for the corrugated box to package 'Container A', Container B' and 'Container C' were 15.75 inches x 14.96 inches x 2.16 inches, 16.92 inches x 14.76 inches x 3.34 inches; 14.76 inches x 14.37 inches x 3.54 inches respectively. The corrugated boxes for each container design were stacked to a height of 3 feet, the top two boxes of the stack contained packaged fresh-cut cantaloupe. Vibration forces magnifies with increasing stack height resulting in maximum bouncing of fresh-cut fruits in the top layers. Therefore, the fruit dices were expected to experience repetitive impacts during transportation and loss in quality. The stack of corrugated boxes were placed on an electro-hydraulic vibration table as seen appendices D,E, and F (Lansmont Model 10000-10, Inc, Monterey, CA, USA) to generate a power density spectrum in accordance with ASTM D4728. They were vibrated for two different test times of 60 minutes and 120 minutes (ASTM 4169, Assurance Level II) representing 500 and 1000 mile shipping distance (ISTA 3J,2006)

Six MSU students (24-27 years) were selected with prior cantaloupe eating experience to be part of a 6-member trained panel. Panelists were trained to detect specific attributes including aroma, color, sweetness, firmness and overall quality. All the panelists participated in training over a period of 3 training sessions. The trained panel evaluated melons on a 1-15 unstructured scale for aroma, color, sweetness, firmness and overall quality at days 1, 4, 7 and 10. Panelists were provided a control sample with three blind samples in 2oz cups labelled with a specific 3 digit random code (Figure 6). The trained sensory panel testing was conducted under fluorescent bulbs and in a temperature controlled room (23°C±3). Panelists were provided with three blind samples in 2oz cups labelled with a specific 3 digit random code, water and cracker on a tray. To determine effect of container design on quality of FCC, panelists evaluated samples packaged in either Container A or B or C subjected to the same vibration time and were of the same fruit dice size. To determine effect of fruit dice on quality of FCC, the panelists evaluated dice size 2.5cm and 1.5 cm packaged in the same container design and subjected to the same vibration time.

A TA-XT2i (Texture Technologies Corporation, New York) texture analyzer equipped with a probe diameter 50 mm was used to determine flesh firmness value at 1, 4, 7 and 10 days to compare it with texture score from sensory evaluation. A LabScanXE colorimeter, (Hunter Associates Laboratory, Inc, Virginia,USA) was used to determine fruit color (CIE L*, a* & b* values) at days 1, 4, 7 and 10. A decrease of L* values indicates a loss of brightness, and a more positive a* value indicates increase in redness, whereas a more positive b*indicates increase in yellowness. Total soluble solid contents of fresh-cut fruits were measured using a hand held refractometer Atago PAL-1 (Atago Co., Ltd., Tokyo, Japan) at days 1, 4, 7 and 10. The changes of in-package O_2 and CO_2 concentrations were measured using an headspace analyzer (6600 O_2/CO_2 Headspace Analyzer, Illinois Instrument, Illinois, USA) at days 1,4,7 and 10.

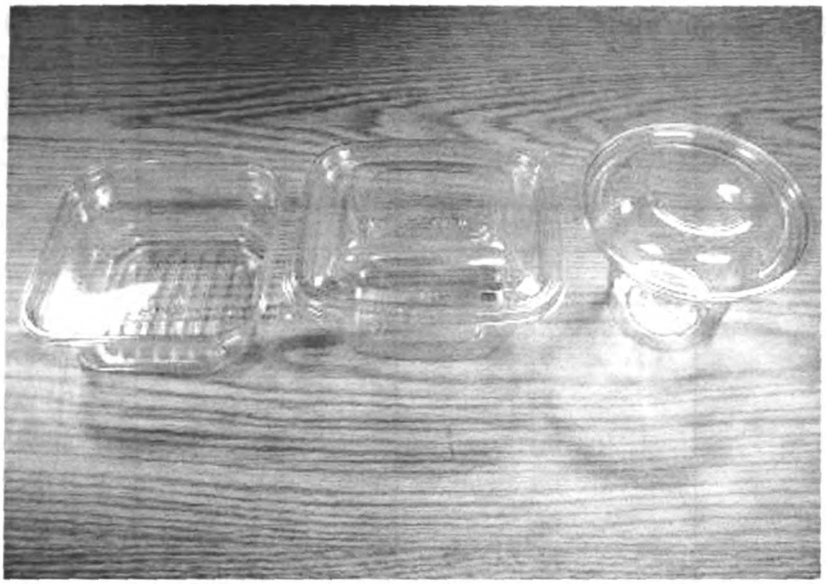

Figure 8. PET containers: left to right Container A; Container B; Container C

Table 3. Experimental design-1 to determine effect of container design on quality of fresh-cut cantaloupe

Treatment	Container Type	Vibration Time (minutes)	Dice Size (cm)
Control-1	A	0	2.5
Control-2	B	0	2.5
Control-3	C	0	2.5
Control-4	A	0	1.5
Control-5	B	0	1.5
Control-6	C	0	1.5
Treatment-1	A	60	2.5
Treatment-2	B	60	2.5
Treatment-3	C	60	2.5
Treatment-4	A	60	1.5
Treatment-5	B	60	1.5
Treatment-6	C	60	1.5
Treatment-7	A	120	2.5
Treatment-8	B	120	2.5
Treatment-9	C	120	2.5
Treatment10	A	120	1.5
Treatment-11	B	120	1.5
Treatment-12	C	120	1.5

Table 4. Experimental design-2 to determine effect of fruit dice size on quality of fresh-cut cantaloupe

Treatment	Dice Size (cm)	Vibration Time (minutes)	Container Type
Control-1	2.5	0	A
Control-2	2.5	0	B
Control-3	2.5	0	C
Control-4	1.5	0	A
Control-5	1.5	0	B
Control-6	1.5	0	C
Treatment-1	2.5	60	A
Treatment-2	2.5	60	B
Treatment-3	2.5	60	C
Treatment-4	1.5	60	A
Treatment-5	1.5	60	B
Treatment-6	1.5	60	C

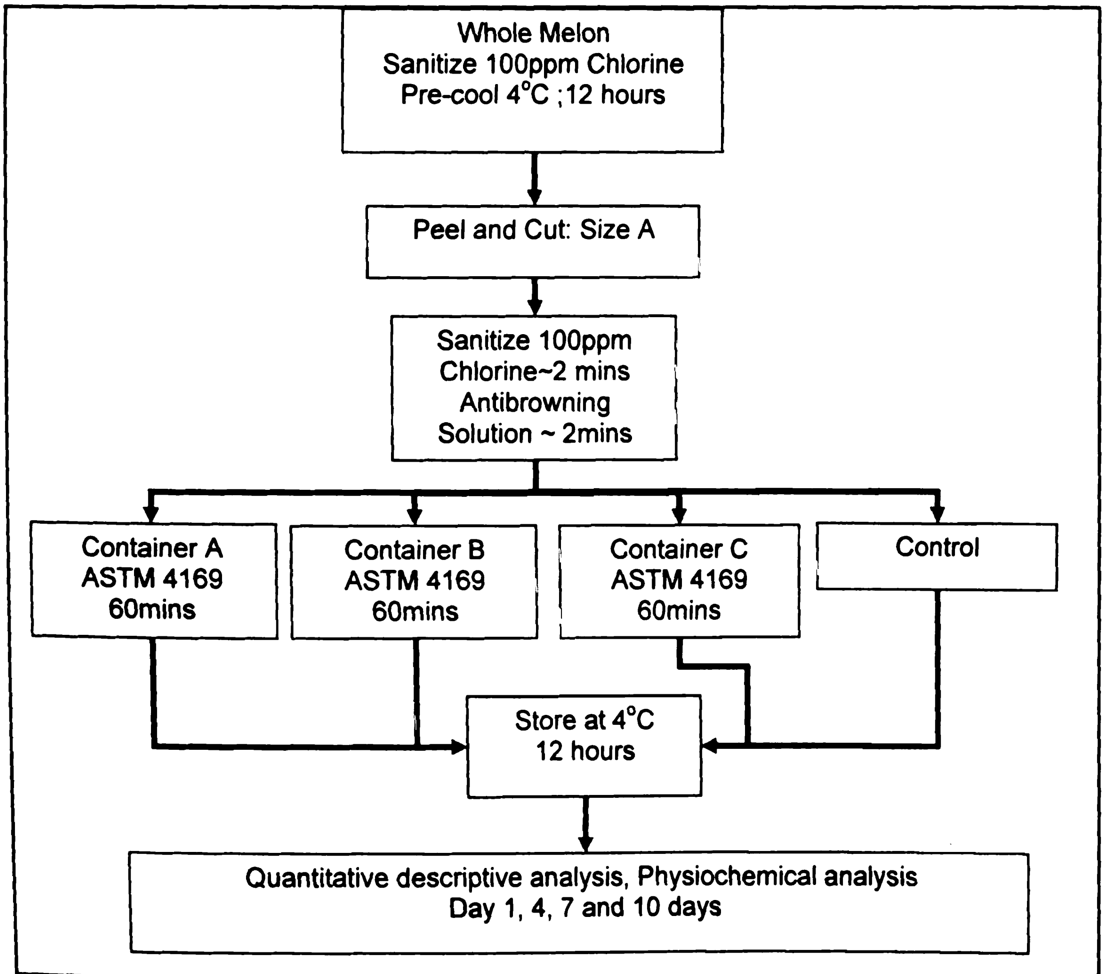

Figure 9. Fresh-cut cantaloupe processing to determine effect of container design on quality of FCC

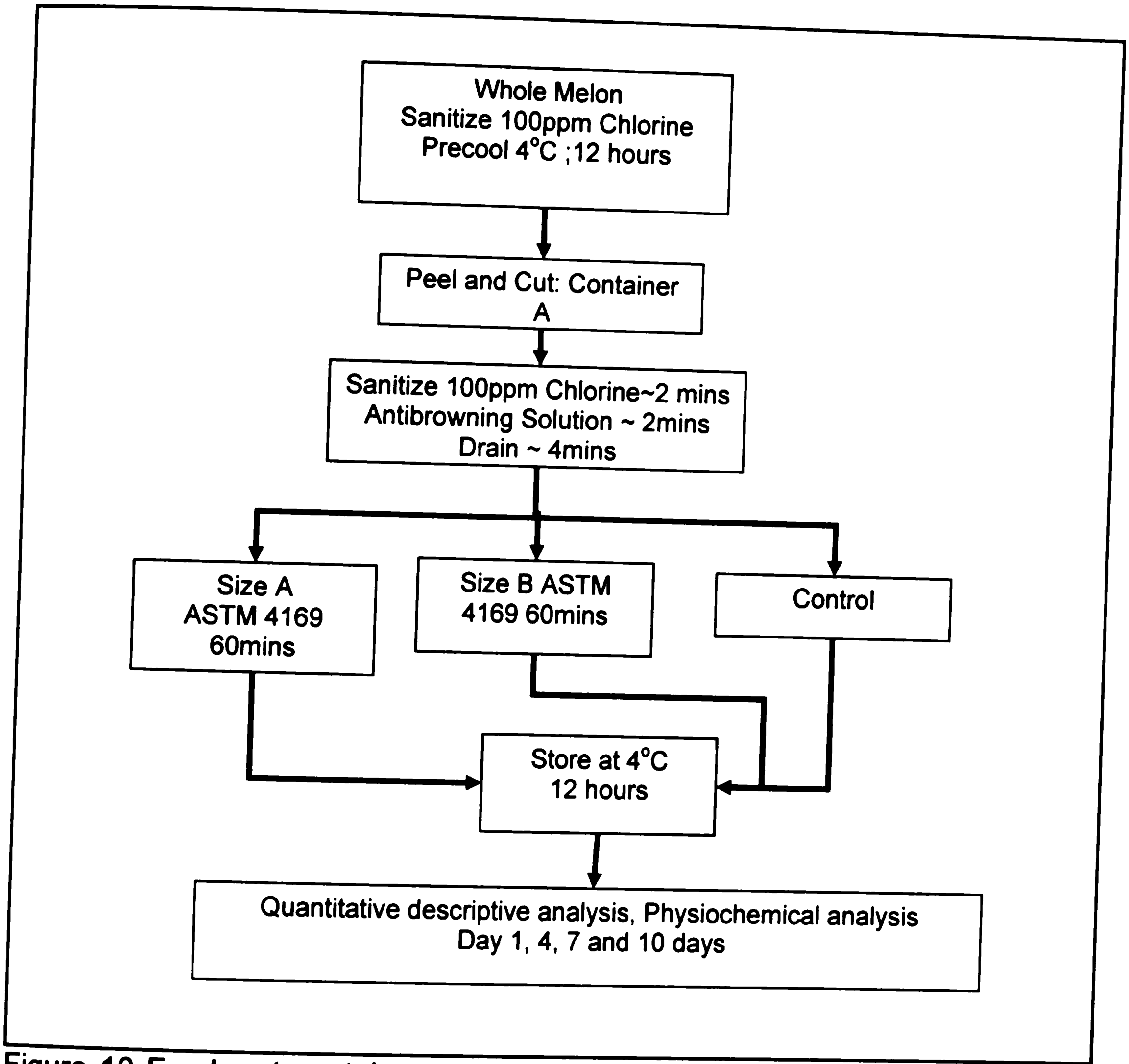

Figure 10 Fresh-cut cantaloupe processing to determine effect of fruit dice size on quality of FCC

3.2.3 Electronic Nose Methodology

In this study, the Fox 3000 E-Nose system was used to analyze the olfactory profiles of commercially available fresh-cut cantaloupe and fresh-cut cantaloupe prepared in the laboratory subjected to various experimental treatments. A fixed quantity of each fresh-cut cantaloupe (2g) was weighed into 10ml glass vial and sealed in triplicate. The samples were loaded in the auto sampler tray of the E-Nose and activated by Alpha-Mos software. During each cycle, each vial was automatically transferred to the oven and agitator, to generate headspace volatiles. The headspace volatiles were collected from the heated vial using a syringe and injected in to the sensor array chamber, to generate the olfactory response profiles. The experimental run conditions are shown in Table 5. The data obtained for the various replicates of fresh-cut cantaloupe samples were analyzed by multivariate statistical methods such as Principal Component Analysis (PCA) and Partial Least Square (PLS) to understand the degree of sample discrimination and correlation with sensory scores of the fresh cantaloupe samples with various treatments.

Table 5. E-Nose system conditions

System Parameters	Run Condition
Sample quantity (g)	1.5
Incubation time (sec)	300
Incubation temperature (^{o}C)	35
Agitation speed (rpm)	500
Syringe type (ml)	5
Syringe fill speed (ul/sec)	500
Syringe temperature (^{o}C)	40
Flushing time	120
Vial type (ml)	10
Injection volume (ul)	5000
Injection speed (ul/sec)	2500
Acquisition time (sec)	600
Acquisition period (sec)	1
Delay (sec)	180
Flow (ml/min)	300

3.2.4 Statistical Analysis

The collected data from sensory, color and texture analysis was analyzed using Minitab 13.1 (Minitab Inc, State College, PA, USA). Analysis of variance was performed on sensory, color and firmness data and the means were separated using Fisher's LSD at significance level of $p \leq 0.05$

4. RESULTS AND DISCUSSION

4.1 Phase 1

Effect of Anti-browning Agent and Transport Vibration

4.1.1 Sensory Evaluation

4.1.1.1 Appearance

Fresh-cut cantaloupes (FCC) treated with 'Treatment A' (2% Ascorbic Acid +1% Calcium Chloride + 0.5% Citric Acid) and 'Treatment B' (3% NatureSeal ™ containing Calcium Ascorbate) packaged in PLA containers and subjected to random vibration for 60 minutes ('Tested A' and 'Tested B'), were evaluated for various sensory attributes. In general the appearance of the FCC deteriorated as function of storage time (Figure 11). One day after processing and vibration there was no significant difference in appearance (Figure 11) between cut cantaloupe processed according to Treatment A and Treatment B. However, cut cantaloupe 'Control B' (6.63a) appeared to be better than 'Control A' (6.25a), 'Tested A' (6.25a) and 'Tested B' (6.25a) at day 1. Even though 'appearance' deteriorated with time (Figure.7) it was observed that the appearance scores for 'Tested B' (6.13a) samples were higher than 'Control A' (5.75a), 'Tested A' (5.75a) and 'Control B' (5.38a) by day 10. This indicates that fresh-cut cantaloupe treated with Natureseal™ and subjected to vibration had the best appearance over a period of 10 days.

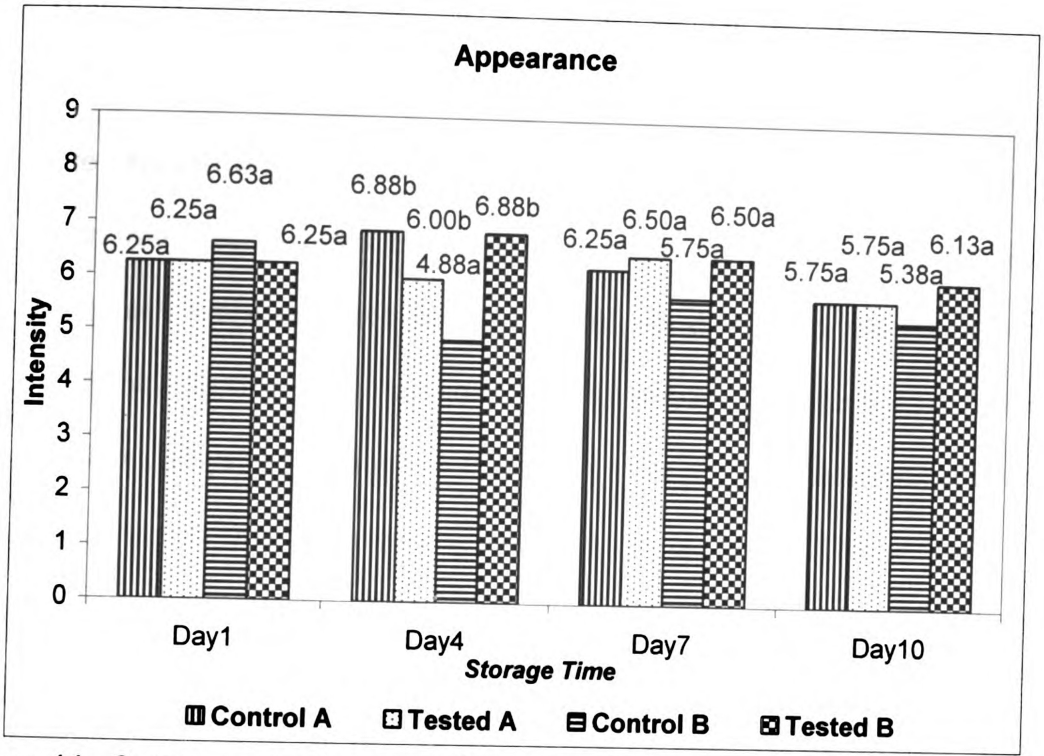

Figure 11. Sensory panel scores for fresh-cut cantaloupe appearance during storage; n=8; 1=dislike extremely; 9= Like extremely
*Mean scores with different letters are significantly different

4.1.1.2 Flavor

It was observed that the day 1 flavor scores compared to Day 4 had lower hedonic scores for all the treatments except for 'Tested B' (7.0a) at day 1. Also, at day 1, 4 and 7 'Tested B' cantaloupe samples had better flavor scores than its 'Control B' samples (Figure.8). Similarly at days 1 and 7 'Tested B' samples had higher flavor scores than 'Control A' (Figure.12). This is possibly due to ripening of cut cantaloupe as a result of higher respiration rate and ethylene induced ripening during storage. Ethylene production as a consequence of cutting has been observed in tomatoes (Lee et al.,1970), strawberries (Abeles et al., 1992) and papayas (Paull and Chen,1997) leading to accelerated ripening. Similarly, cantaloupe has shown high ethylene release upon cutting (Hoffmann and

Yang,1982). Also, several cut fruits have shown higher respiration rates than whole fruits (Watada et al,1990;Cantwell, 1992) leading to shorter shelf life. Therefore accelerated ripening due to increased ethylene production and respiration rate can explain better 'flavor' scores at day 1, 4 and 7 for the samples which were exposed to mechanical vibration. According to Oliu and Fortuny et al. (2007) study an increase in ethylene production accelerated ripening. Also, physical damage to fruits was enhanced by mechanical vibration resulting in a change in quality (Jarimopas et al.,2005). This indicates that vibration during distribution has some positive effects in enhancing flavor of fresh-cut cantaloupes. However at the end of the study 'Control A' samples had the highest flavor scores (Figure.12) (Jarimopas et al., 2005).

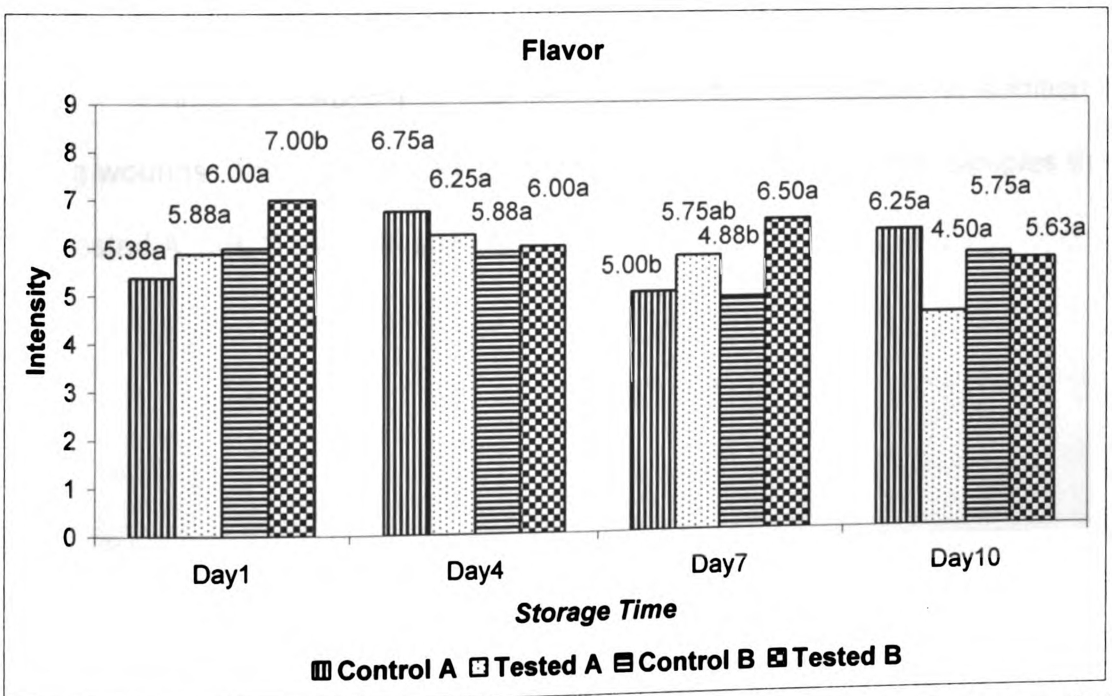

Figure 12. Sensory scores for fresh-cut cantaloupe flavor over storage period; n=8; 1=dislike extremely; 9= Like extremely
*Mean scores with different letters are significantly different

4.1.1.3 Texture

Overall the texture of all the sample treatments deteriorated with time except for 'Control A' samples (Figure 9). 'Control A' samples had the highest texture scores (6.75) at day 4 and day 10 (7.0) compared to day 1 samples (5.75) (Figure 13). Initially, 'Tested B' had the best texture scores but it deteriorated with time from a score of 7.13 at day 1 to 5.88 at day 10. 'Control A' samples had the best texture (7.0) at day 10 compared to the remaining treatments. The texture of 'Tested A' and 'Control B' was observed to be similar at days 1, 4 and 7 (Figure13). At the end of the study the 'Control A' samples (7.0a) were observed to have the best texture followed by 'Control B' (6.0a), 'Tested B' (5.88a) and 'Tested A' (5.38b) samples by day 10. The FCC control samples were wounded by cutting which has an effect on the texture of cut fruit (Lamikanra et al., 2003), the 'Tested A' and 'Tested B samples were subjected to random vibration causing further wounding of the cut surface in addition to cutting wounds. This explains the better texture of the FCC control samples than the 'Tested A' and 'Tested B' samples.

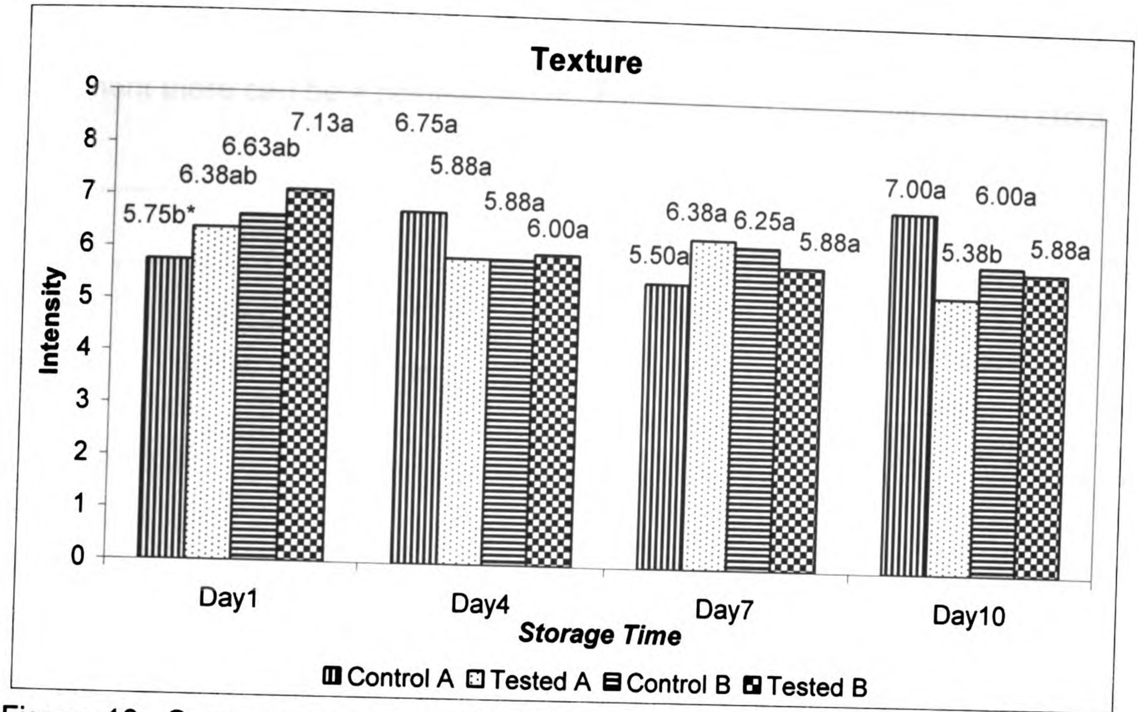

Figure 13. Sensory scores for fresh-cut cantaloupe texture over storage;n=8 period;1=dislike extremely; 9= Like extremely

*Mean scores with different letters are significantly different

4.1.1.4 Overall-liking

Initially it was observed that 'Tested B' samples had the highest overall-liking score of 7.0 at day 1 followed by 'Control B' (6.5ab), 'Tested A' (5.75ab) and 'Control A' (5.63b) (Figure.10). At day 4 'Control A' samples were rated to have the highest overall score of 7.13. 'Tested A' samples were preferred over 'Control A' samples at day 7. Similarly, 'Tested B' samples had higher overall scores than 'Control A' at day 1, 4, 7 and 10 (Figure.14). According to Bai et al., (2001) fresh-cut cantaloupe had a shelf life of 9 days in naturally modified atmosphere packaging. An overall acceptability score of greater than or equal to 5 was deemed acceptable in this study. Therefore, 'Tested A' reached the end of shelf life by day 10. However, the control samples and 'Tested B' samples were still acceptable at the end of day 10. This indicates that with proper post cutting treatment there can be a positive effect of vibration on fruit quality during storage.

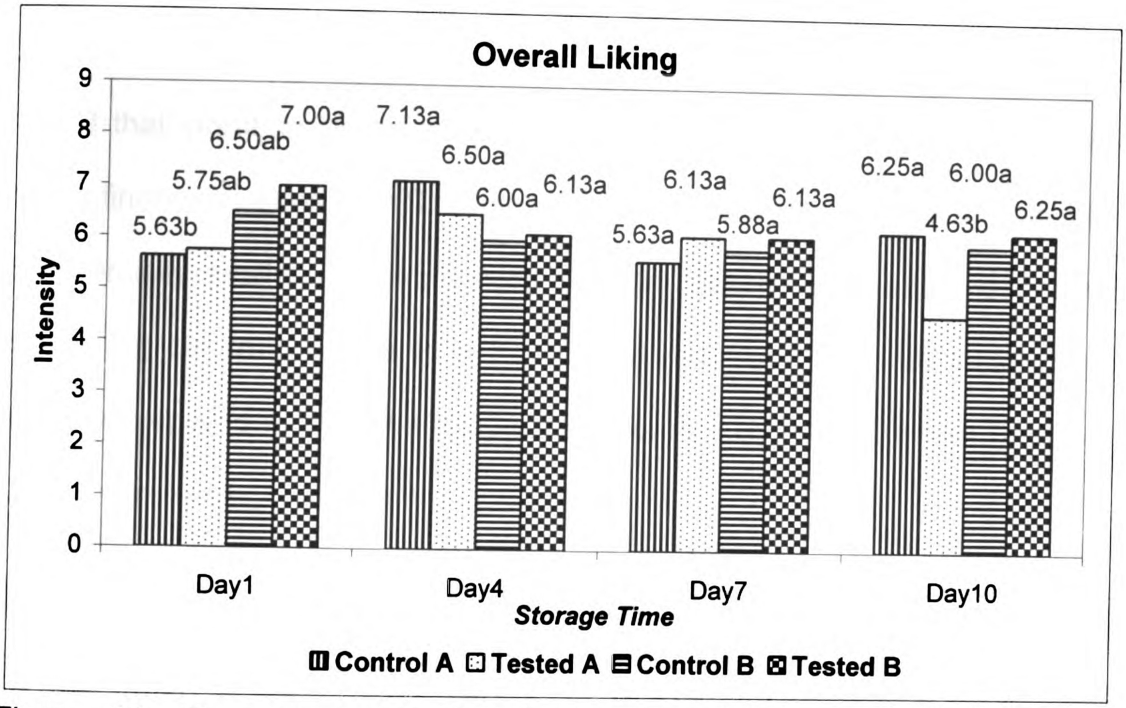

Figure 14. Sensory scores for fresh-cut cantaloupe overall liking over storage;n=8; period; 1=dislike extremely; 9= Like extremely
*Mean scores with different letters are significantly different

4.1.2 Firmness Measurements

A general trend in firmness value was not observed as a function of storage time. By day 10, the firmness values for 'Control A' samples (178.23 lb) were observed to be the highest followed by 'Tested B' (159.20b), 'Control B' (149.20b),and 'Tested A' (94.02c).Comparing this trend to texture scores as observed at day 10 by the panelists (Figure13), it can be seen that cut fruit firmness is related to its texture during storage. Also, the firmness of the cut cantaloupe was observed to decrease somewhat from day 1 to day 10 for 'Tested A' and 'Tested B' samples (Figure 15). Thus, there is a distinct effect of vibration on firmness values during transportation. Hence, softening of cantaloupe flesh can be expected as these samples are subjected to vibrational forces during the transportation. This is due to wounding of surface tissue caused by repeated impacts during vibration (Jarimopas et al., 2005). It was interesting to find that vibration tested cut cantaloupe with 'Treatment B' (159.20 lb) had higher firmness values than 'Treatment A' (94.02 lb) at day 10. This indicates that commercially available anti-browning solution Natureseal™ performs better in preserving cut fruit texture in a transport environment than an anti-browning solution prepared in the laboratory (2% Ascorbic Acid +1% Calcium Chloride + 0.5% Citric Acid).

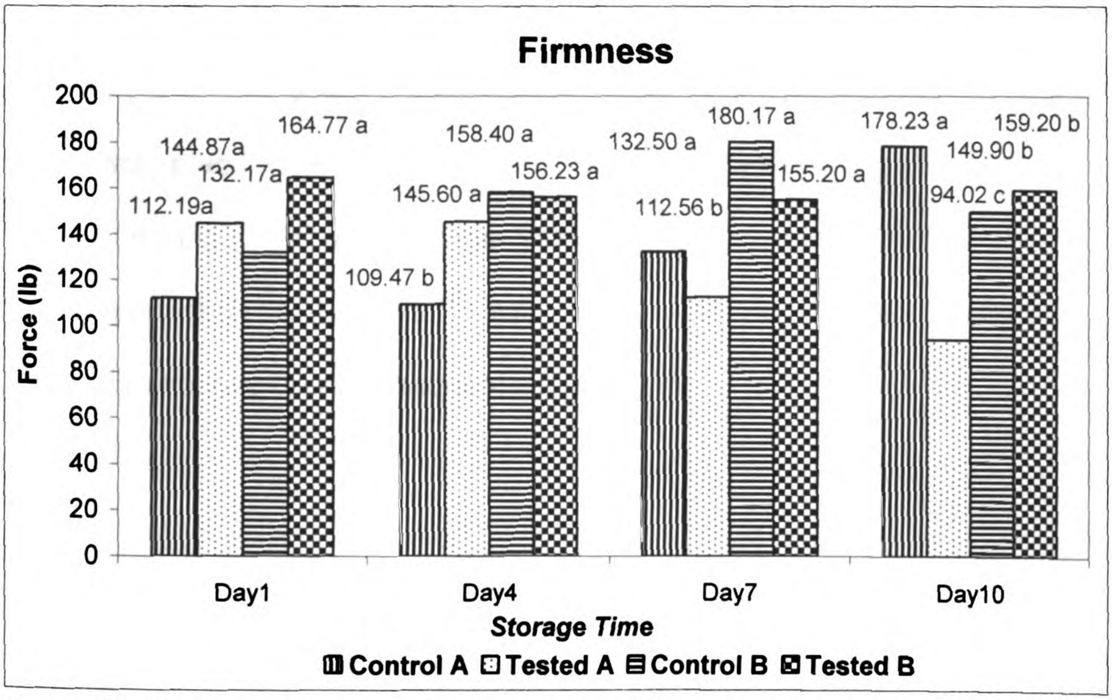

Figure 15. Kramer firmness of fresh-cut cantaloupe over storage period;n=8;
*Mean scores with different letters are significantly different

4.1.3 Key Findings of Phase 1

Vibration of fresh-cut-cantaloupe packaged in sample containers had a positive effect on the flavor and overall acceptability. The 'overall-liking' scores were higher than a quality score of 5 (like slightly) for all samples except for vibrated-Treatment-A. The texture of vibrated cut-cantaloupe (Treatment A) deteriorated with time. There was some evidence of correlation between texture scores and firmness values at day 10 (Figures 12 & 15), which shows that flesh firmness and texture scores at the end of the storage period was better in control samples compared to vibration tested samples. Thus, it can be said that vibrational forces during transportation has an effect on texture quality of cut cantaloupe. Treatment-B ('NatureSeal™') fresh-cut-cantaloupe subjected to vibration performed better than Treatment-A for appearance, flavor, texture and overall acceptability. No sliminess or mold growth was observed in any of the samples during a 10-day storage study. Based on these findings, the anti-browning solution 'NatureSeal™' was selected as a post cutting treatment of fresh-cut cantaloupe for subsequent experiments.

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4.2 Phase 2

4.2.1 Quality of Commercial Fresh-cut Cantaloupe

This part of the overall project was performed to understand consumer desires for fresh-cut cantaloupe, by researching what was currently available from various commercial sources. The methodologies developed in this study were used to train sensory panelists in the succeeding studies. Also, information from this study was used in selecting package for the study. Fresh-cut Cantaloupe (FCC) was procured from 6 different commercial retail and food service vendors (Meijer Inc., Kroger Co., L&L Food Center Inc., Sysco Corp., Coastal Produce Distributor and Del Monte Corp.). Fresh-cut cantaloupe was packaged in various sizes of rigid containers. There was no uniformity in dice sizes between commercial suppliers. It was found that Meijer and Kroger performed the fresh-cut operation in their backroom using whole fruits that were on the shelf in the store and which were harvested 1-2 weeks prior to reaching the store. A consumer panel of 65 untrained panelists evaluated these samples on a hedonic scale 1-9 for aroma, color, sweetness, firmness and overall quality.

Upon completion of the sensory analysis of the fresh-cut cantaloupe, it was found that aroma characteristics of Sysco FCC were rated the highest by the consumers followed by Meijer, Del Monte, Kroger, L&L and Coastal (Figure 16). Sysco FCC was rated the highest (7.54) and the lowest was Coastal FCC (6.30) (Figure 16.). Aroma ratings for Sysco and Meijer FCC were significantly higher than Del Monte, Kroger, L&L and Coastal FCC. Significantly higher aroma ratings for Sysco and Meijer FCC could be attributed to the harvest maturity and/or the p

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post harvest shelf life of the whole fruit. It is possible the whole fruits used by Sysco and Meijer were harvested at or more than 1/2 slip maturity, which could explain the higher level of sweet aromatic volatile compounds in the package headspace (Beaulieu et al., 2004). Similarly, it is possible that the whole cantaloupe fruit was from traditional shelf life category, which has been reported to have higher total volatile content than long shelf life and extended shelf life cantaloupe cultivar (Lamikanra et al., 2003).

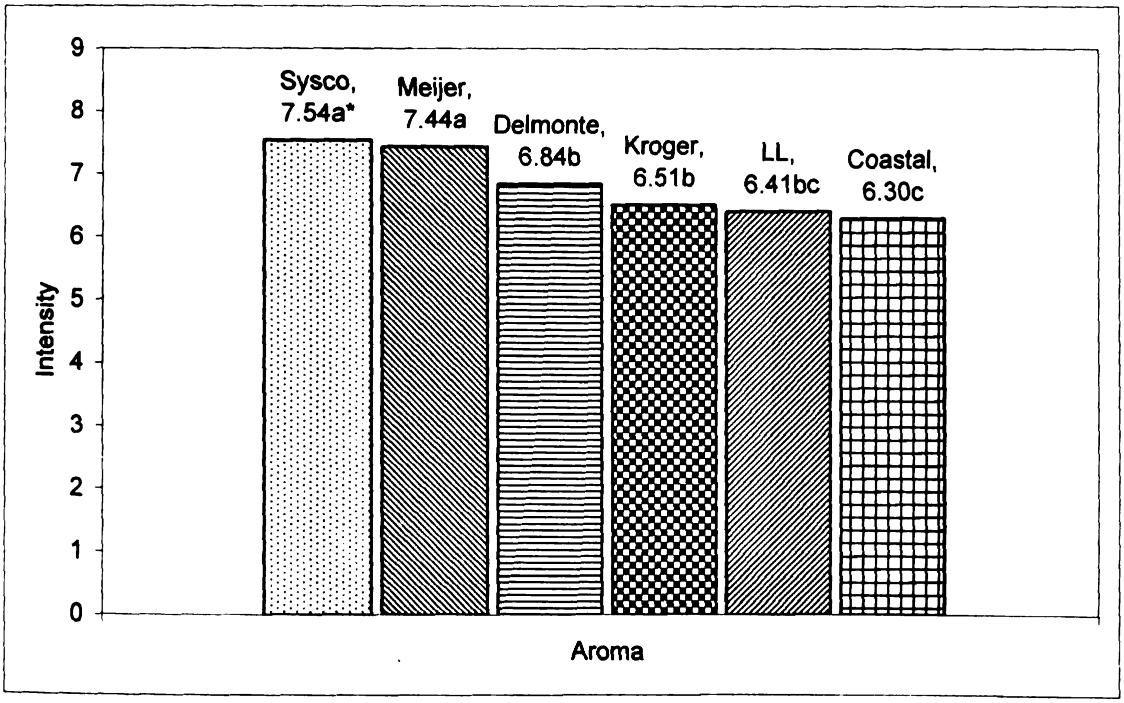


Figure 16. Consumer panel (n=65) mean aroma scores for commercially available fresh-cut cantaloupe
*Mean scores with different letters are significantly different (p<0.05)

The color characteristics of Meijer FCC were rated the highest by consumers followed by Del Monte, Sysco Kroger, L&L and Coastal (Figure 17). Meijer FCC was rated the highest (7.88) compared to Coastal FCC (7.31) (Figure 16.). Color ratings for Coastal FCC were significantly the lower than Meijer and

Del Monte FCC. Consumers ratings indicated that panelists liked the orangish-yellow color that was more evident in the Meijer and Del Monte FCC compared to Coastal FCC (Figure 17). This is supported by the color values L* ,a *and b* as seen Figures 22,23 & 24. In Figure 22 it can be seen that Del Monte FCC had significantly lower L* values than Coastal FCC, indicating that Coastal FCC was lighter and more translucent compared to Del Monte FCC. Similarly, Del Monte FCC had significantly lower b* values (Figure 24) compared to all the FCC samples, which indicates that Del Monte FCC had a orangish color, which the consumers seemed to like.

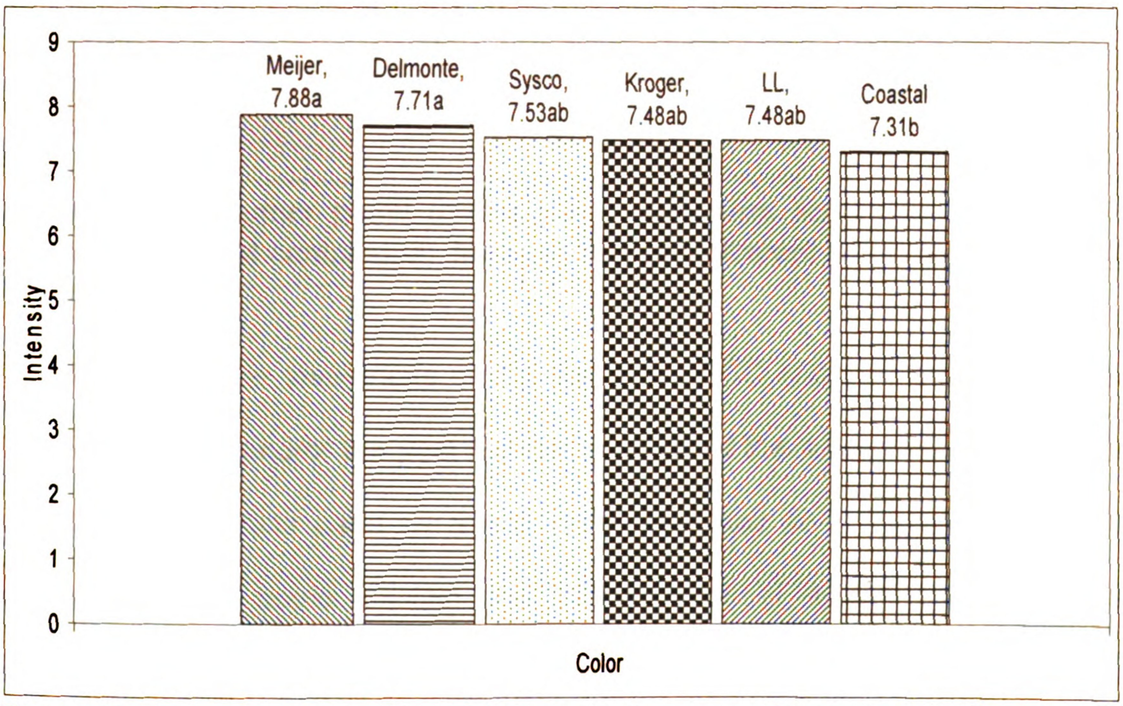


Figure 17. Consumer panel (n=65) mean color scores for commercially available fresh-cut cantaloupe
*Mean scores with different letters are significantly different (p<0.05)

According to the consumer panel, Sysco FCC was rated to have the highest sweetness ratings (7.59) and was significantly different than the remaining FCC procured from the different sources (Figure 18). This is supported by the total soluble solids results showing that Sysco TSS had the highest compared concentration to the other FCC products (Table 6).

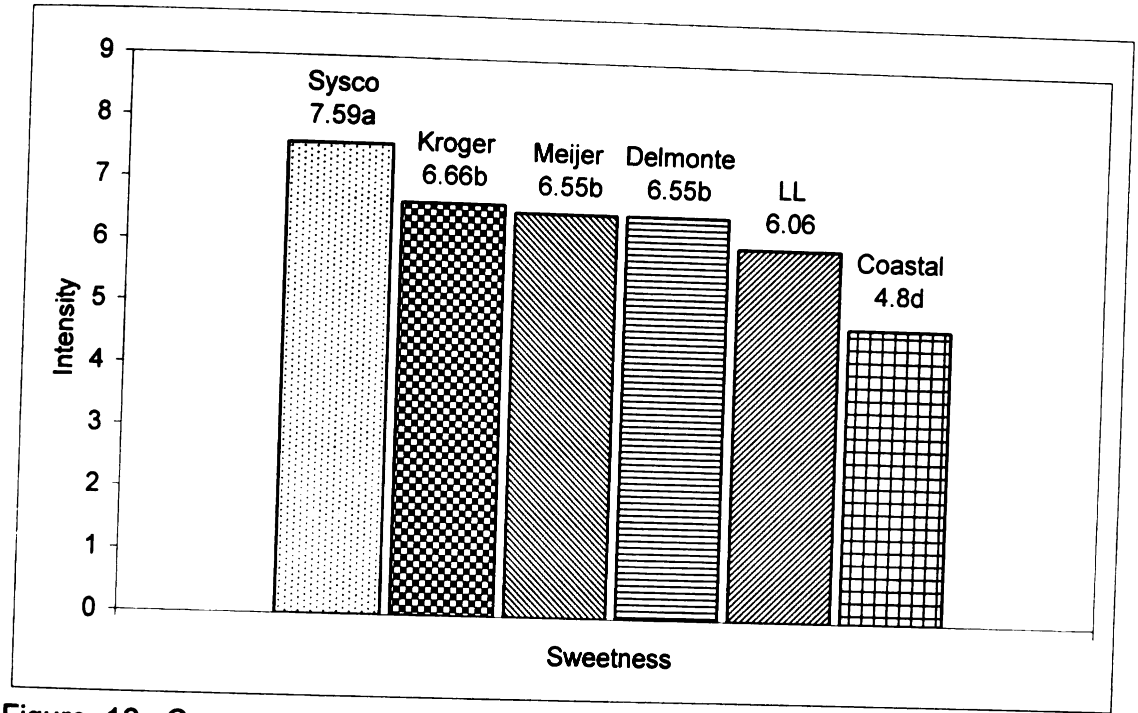


Figure 18. Consumer panel (n=65) mean sweetness scores for commercially available fresh-cut cantaloupe; *Mean scores with different letters are significantly different ($p<0.05$)

Significantly higher sweetness ratings for Sysco FCC could be attributed to the harvest maturity and/or the post harvest shelf life of the whole fruit. It is possible that the whole fruits used by Sysco were harvested at or more than 1/2 slip maturity, which could explain the higher level of sweet aromatic flavor compounds (Beaulieu et al., 2004). Similarly, it is possible that the whole cantaloupe fruit cultivar was from a traditional shelf life category, which is expected to be sweeter (Lamikanra et al., 2003). Titratable acidity and pH did not seem to play a significant role in the sweetness ratings of the FCC samples (Table 6).

Table 6. Difference in pH, Titrable acidity and total soluble solid concentration of commercial fresh-cut cantaloupe

	pH	TA	TSS
Meijer	7.1	0.0223	8.0
Kroger	6.8	0.0603	8.0
LL	7.4	0.0313	8.5
Sysco	7.1	0.0357	10.8
Coastal	6.6	0.0715	8.0
Delmonte	6.9	0.0737	7.8

Consumers were not able to distinguish a significant difference in texture or firmness between the FCC samples (Figure 19). However, Sysco FCC had the highest firmness rating (6.83) and Coastal FCC had the lowest firmness rating. Variability within the FCC samples using untrained panelists could have led to indistinguishable texture results. However, the texture analysis values obtained from the texture analyzer, shows that Sysco had the highest firmness value of 168.86 N followed by Kroger, L&L, Coastal, Del Monte and Meijer FCC (Figure.21).

Overall, the consumers rated Meijer FCC as the best followed by Sysco, Kroger, Del Monte, L&L and Coastal FCC (Figure 20). Overall quality was a collective response of aroma, color, sweetness and texture of the sample. Meijer and Sysco FCC samples were consistently rated to have aroma, color, sweetness and firmness ratings in the top 3 compared to the remaining FCC samples. The sensory, color and firmness results from this part of the study were used to train panelists in the succeeding part of this research study.

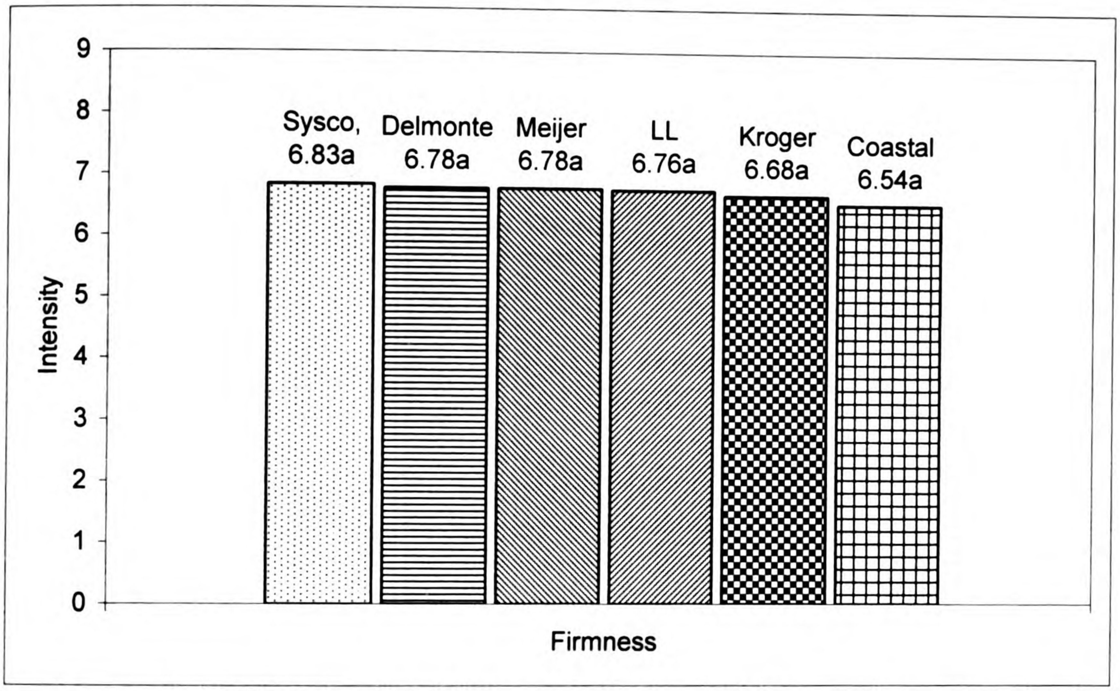


Figure 19. Consumer panel (n=65) mean firmness scores for commercially available fresh-cut cantaloupe
*Mean scores with different letters are significantly different ($p<0.05$)

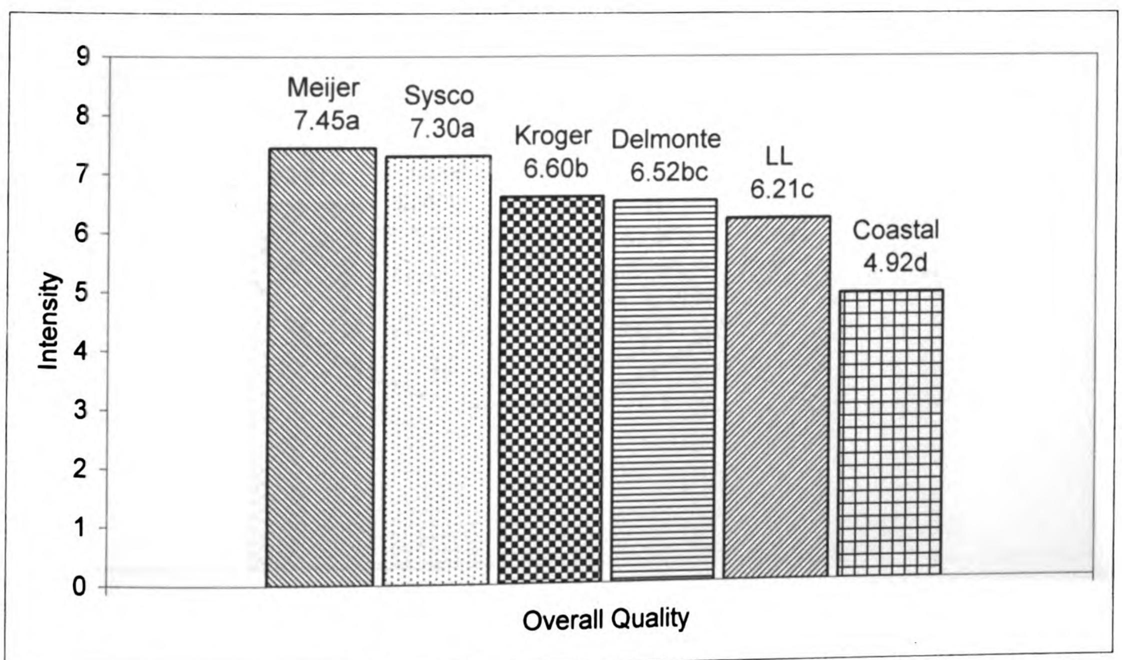


Figure 20. Consumer panel (n=65) mean overall quality scores for commercially available fresh-cut cantaloupe. *Mean scores with different letters are significantly different ($p<0.05$)

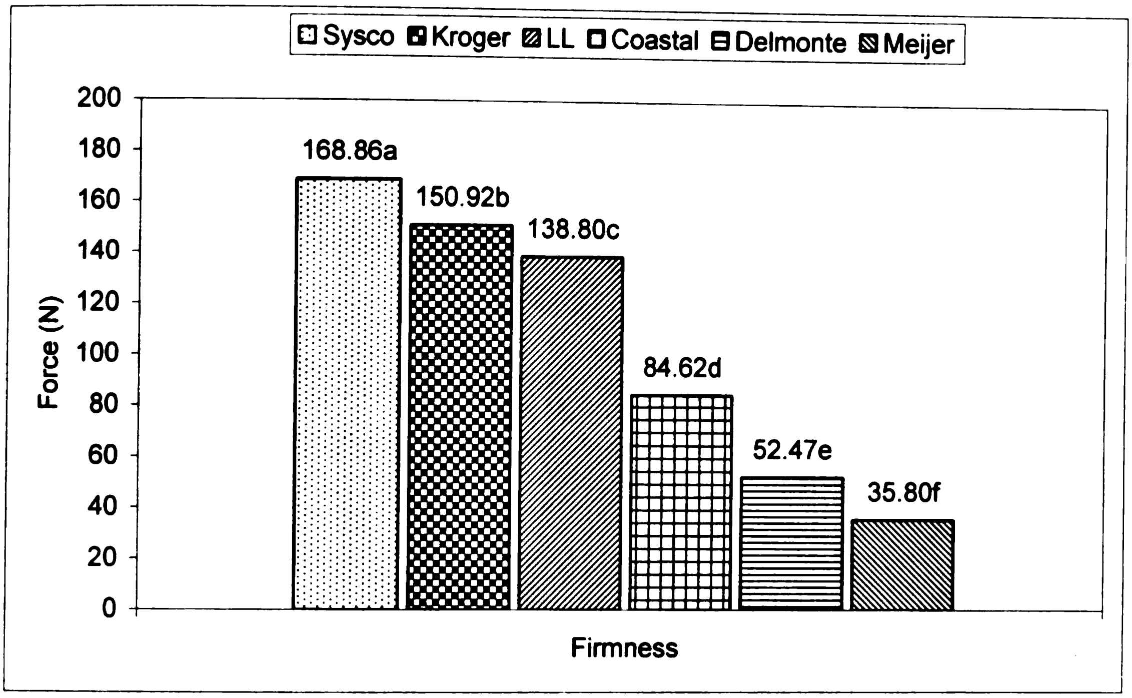


Figure 21. Mean firmness measurements for commercially available fresh-cut cantaloupe *Mean scores with different letters are significantly different ($p<0.05$)

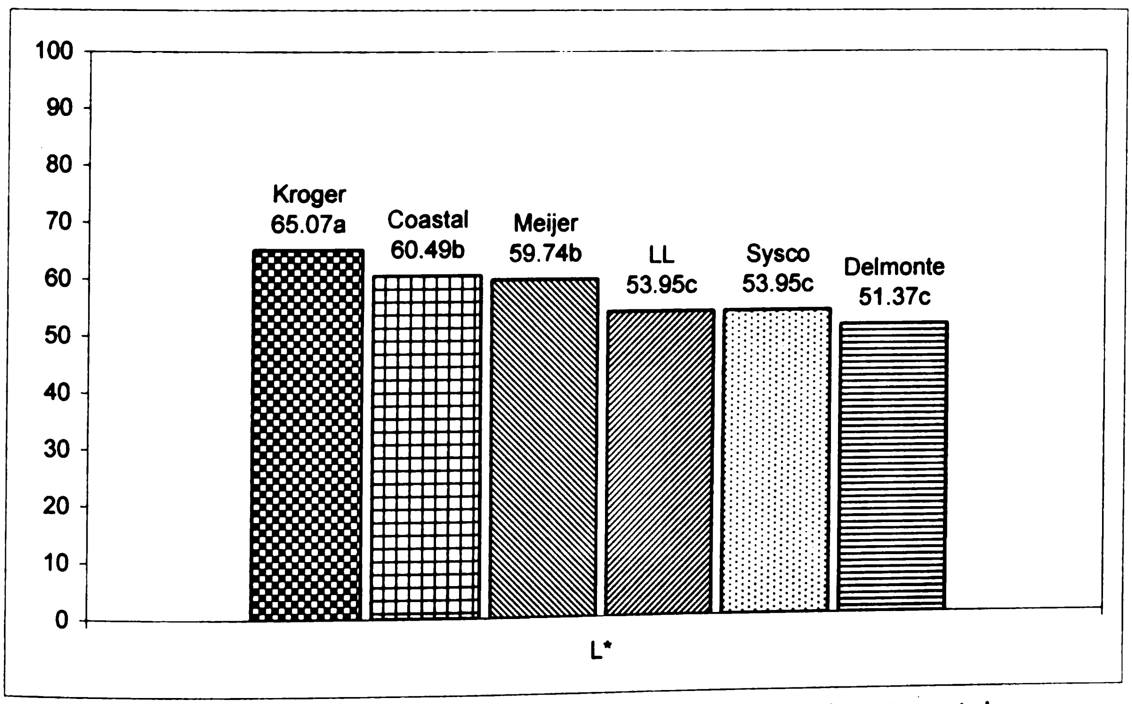


Figure 22. Average L* value for commercially available fresh-cut cantaloupe
*Mean value with different letters are significantly different ($p<0.05$)

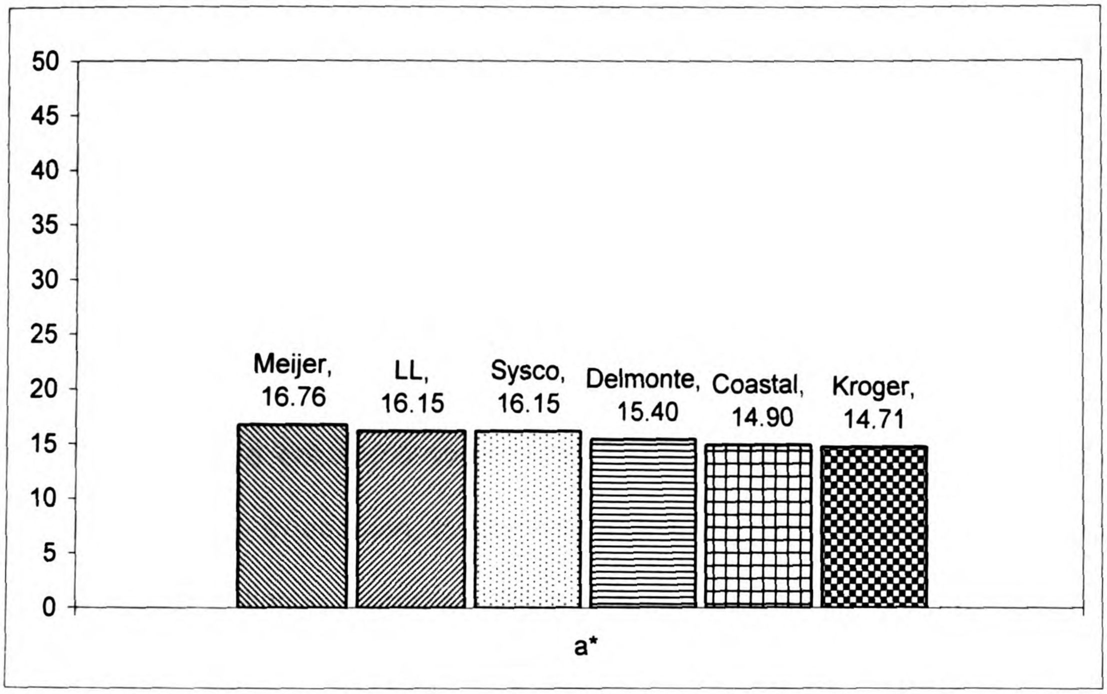


Figure 23. Average a* value for commercially available fresh-cut cantaloupe
*Mean value with different letters are significantly different (p<0.05)

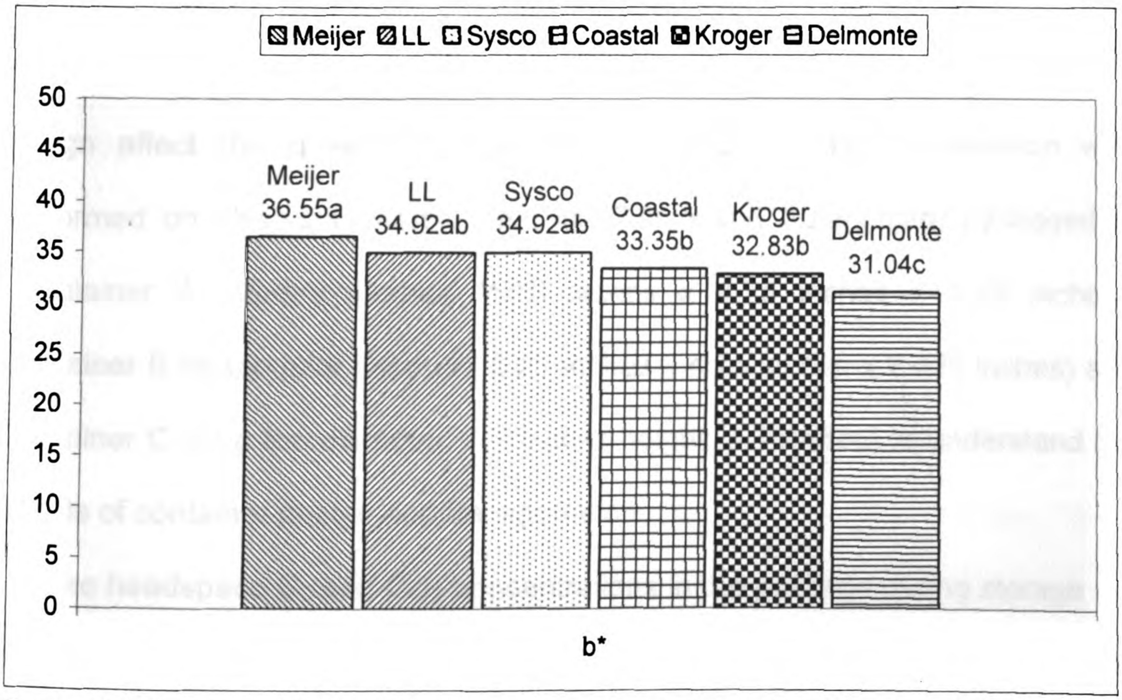


Figure 24. Average b* value for commercially available fresh-cut cantaloupe
*Mean value with different letters are significantly different (p<0.05)

4.2.2 Effect of Container Design

A consumer's decision to buy fresh-cut fruit is dependent on its quality. Quality is dependent on sensory characteristics of the product at the time of purchase. Sensory quality of these products is a cumulative effect of aroma, appearance (color), flavor (sweetness) and texture, and the overall quality of the product is assessed by the consumer. The two most important quality indicators for cantaloupe are color and sweetness (Fisher and Bennett, 1991 and Gross and Sams, 1984). In addition, cutting operations and transportation can result in broken cells and tissue damage leading to fruit decay. Therefore, the texture of cut fruit has a significant effect on the fresh-cut cantaloupe (FCC) quality. Quality is maintained during storage through a combination of various post harvest treatments, post-cutting treatments, modified atmosphere packaging and storage temperature. A key factor which remains to be understood is can packaging design affect the quality of fresh-cut cantaloupe. Sensory evaluation was performed on fresh-cut cantaloupe (Size-2.5cm and Size-1.5cm) packaged in '.Container A' square shaped (4.75 inches x 4.75 inches x 1.75 inches), Container B rectangular shaped (5.25 inches x 4.75 inches x 2.625 inches) and Container C (Cup top diameter: 4.7 inches height: 3.1 inches) to understand the effects of container design and transportation.

The headspace O_2 and CO_2 concentrations in the package during storage are shown in Tables 9-10. The lower limit for O_2 below which fruit injury such as discoloration or other disorder can occur for fresh-cut cantaloupe is approximately 3% at 4°C (Beaudry, 2000). The oxygen concentration in all the containers ranged between 17-18% during 10 days of storage. Therefore the risk of fruit decay due to low O_2 concentration was minimal. Similarly, Qi et al, 1999 found that a modified atmosphere package of 2% O_2 + 10% CO_2 in the package headspace was beneficial in maintaining quality and retarding increased metabolism and microbiological growth. The CO_2 concentration in all 3 container package headspace ranged from 2-4% during the storage period. This was within the tolerance level of CO_2 (10%) for fresh-cut cantaloupe (Tables 11-12). Beyond this level fresh-cut cantaloupe can be susceptible to fruit decay caused by undesirable levels of oxygen and carbon dioxide.

The trend for the aroma intensity of fresh-cut cantaloupe showed an increasing intensity for all 3 container designs during storage (Figure 25 and 34). This trend was observed for both fruit sizes (2.5cm and 1.5cm) subjected to a transport vibration time 60 mins (500 miles) (Figure 25 and 34). The Aroma intensities of the FCC packaged in 'Container B' and 'Container C' were rated higher than 'Control' and 'Container A' FCC samples. This was expected as Container B and Container C are taller and have more void spaces than 'Container A'. This can lead to more frictional damage of the cut fruits during vibration causing further tissue damage and release of sweet aromatic volatiles. It was observed that FCC (Size-1.5cm) had higher aroma intensity when packaged in Container C at days 1, 4 and 7 compared to Container A and Container B.

The color intensity of FCC increased during storage during storage for both fruit sizes and subjected to a transport vibration time 60 mins (500 miles) for all types of containers (Figures 26 and 35). FCC samples packaged in 'Container B' and 'Container C' were rated to have the higher color intensity compared to control and 'Container A' FCC samples. Color ratings were higher for FCC samples which underwent transport vibration to simulate a 1000 mile trip compared to FCC samples which were simulated to travel a 500 mile trip (Figure 26 & appendix G). The CIE L* values for FCC samples showed a gradual decreasing trend during storage (Figures 30 and 39). Lower L* color values indicate a darker surface. Container C FCC samples had the lowest L* values by day 10 indicating a darker surface color than FCC sample packed in Container A and B (Figures 30 and 39). This suggests that there was accelerated fruit degradation due to enzymatic browning as result of tissue damage in Container C compared to Container A and B FCC samples. A similar trend was observed for a* values (Figures 31 and 40) and b* values (Figures 32 and 41). The CIE color value a* indicates redness and b* indicates yellowness on the cut surface. It was observed that during storage a* and b* values decreased for all the FCC samples. 'Container A' FCC samples had highest a* and b* values indicating yellowish-reddish color compared to Container B and C FCC samples. As discovered from the study mentioned in the previous section, consumers liked the more yellowish-reddish color. Therefore, on the basis of color analysis, Container A maintained the best color quality of the fresh-cut cantaloupe followed by Container B and Container C.

The sweetness of the FCC sample increased during storage for both fruit sizes and transport distances for all types of container (Figures 27 and 36). FCC samples exposed to transport vibration conditions were more sweet than control samples during storage (Figures 27,36 and appendix G). Container B had the highest sweetness rating at the end of the storage study as seen in Figure 27 for Size-2.5cm. Whereas Container B and C had higher sweetness rating than Container A and control samples at day 10 for Size-1.5cm (Figure 36). This is supported by the total soluble solids content where it was observed that fresh-cut cantaloupe packaged in 'Container B and 'Container C' had higher %TSS than 'Container A' at Day 10 (Table 7-8), for both fruit sizes at the end of the storage stage. This effect was more evident for FCC samples which were simulated to travel a 1000 mile trip (Appendix G).

Firmness of FCC samples decreased during storage for both fruit sizes and transport distances for all types of container (Appendix G). Control samples (un-vibrated samples) were rated to more firm than FCC samples subjected to transport vibration (Figures 28 and 37). Container C FCC samples were found to have the lowest firmness at the end of the storage study as seen in Figures 28 and 37. This was more evident for FCC Size B (1.5cm) samples which were simulated to travel a 1000 mile trip (Appendix G). Texture analysis to measure firmness of fresh-cut cantaloupe cubes was performed during the storage period. It was found that flesh firmness decreased for all the FCC samples during storage (Figures 33 and 42). The firmness values of FCC samples packaged in Container C were significantly lower by Day 10 compared to FCC samples stored in Container A and B (Figures 33 and 42). This indicates that there is more frictional damage of surface tissue of FCC samples in Container C, caused by vibration during transportation. It was also observed that FCC samples exposed to a 1000 mile trip had lower firmness values than FCC samples exposed to a 500 mile trip in Container C (Appendix G). The firmness values for FCC samples in Container A and B were not affected as much by the simulated shipping distances.

Overall quality of fresh-cut cantaloupe packaged in 'Container B' had the highest firmness for both fruit sizes and shipping distances during storage (Figures 33-34, 51-52). Container B FCC samples had higher overall quality during Day 4 and 7 as seen in Figures 33-34, 51-52.

Sensory analysis, color analysis (CIE L*,a* and b*) and texture analysis of fresh-cut cantaloupe samples suggests that Container B is capable of maintaining better sensory quality attributes compared to Container A and C. Fresh-cut cantaloupe packaged in Container B a medium height container with sloping side walls had better sensory characteristics than Container A (shallow height and straight wall) and Container C (Tall height and sloping side wall). It was found that shallow height container will preserve better texture properties during transportation. However, the trained panel rated fruit dices packaged in Container B higher for overall quality as they were firm and juicier than FCC packaged in Container A. Similarly, FCC sample packaged in Container C with a taller height and sloping side walls showed poorer sensory characteristics and firmness measurements compared to FCC samples packaged in Container B rigid containers.

Table 7. Change in percent total soluble solid concentration of fresh-cut cantaloupe (2.5cm) in Container A, B & C during storage

Container	1	4	7	10
A	8.0±0.1	8.3±0.2	8.4±0.2	8.2±0.1
B	8.2±0.1	8.6±0.1	8.5±0.2	8.5±0.2
C	8.1±0.2	8.4±0.2	8.3±0.2	8.5±0.1

Table 8. Change in percent total soluble solid concentration of fresh-cut cantaloupe (1.5cm) in Container A, B & C during storage

Container	1	4	7	10
A	7.9±0.1	8.1±0.2	8.2±0.3	8.2±0.1
B	8.1±0.2	8.3±0.1	8.3±0.2	8.5±0.2
C	8.0±0.1	8.1±0.2	8.2±0.1	8.4±0.1

Table 9. Percent O_2 concentration of fresh-cut cantaloupe (2.5cm) in Container A, B & C during storage

	Days Stored			
Container	1	4	7	10
A	18.4±2.1	17.5±3.1	19.1±2.1	18.8±3.1
B	18.5±2.3	17.9±2.4	17.9±2.5	17.5±3.2
C	18.2±2.1	17.1±3.1	17.8±3.1	17.6±2.1

Table 10. Percent O_2 concentration of fresh-cut cantaloupe (1.5cm) in Container A, B & C during storage

	Days Stored			
Container	1	4	7	10
A	18.2±2.1	17.4±2.4	19.3±2.5	18.3±2.1
B	18.8±2.4	17.7±2.5	17.9±2.1	17.7±2.3
C	18.4±2.5	18.7±2.9	17.1±2.5	17.5±2.6

Table 11. Percent CO_2 concentration of fresh-cut cantaloupe (2.5cm) in Container A, B & C during storage

	Days Stored			
Container	1	4	7	10
A	3.5±0.8	5.1±1.3	2.9±0.9	2.9±1.9
B	3.5±1.1	3.9±1.6	4.8±1.3	2.5±2.1
C	3.8±0.5	4.2±1.8	4.8±1.6	2.7±2.2

Table 12. Percent CO_2 concentration of fresh-cut cantaloupe (2.5cm) in Container A, B & C during storage

	Days Stored			
Container	1	4	7	10
A	3.3±0.7	5.7±1.3	3.3±0.7	2.9±0.8
B	3.7±0.5	3.9±1.2	4.9±0.9	2.5±0.9
C	3.9±0.7	4.3±1.3	4.8±1.2	2.5±1.1

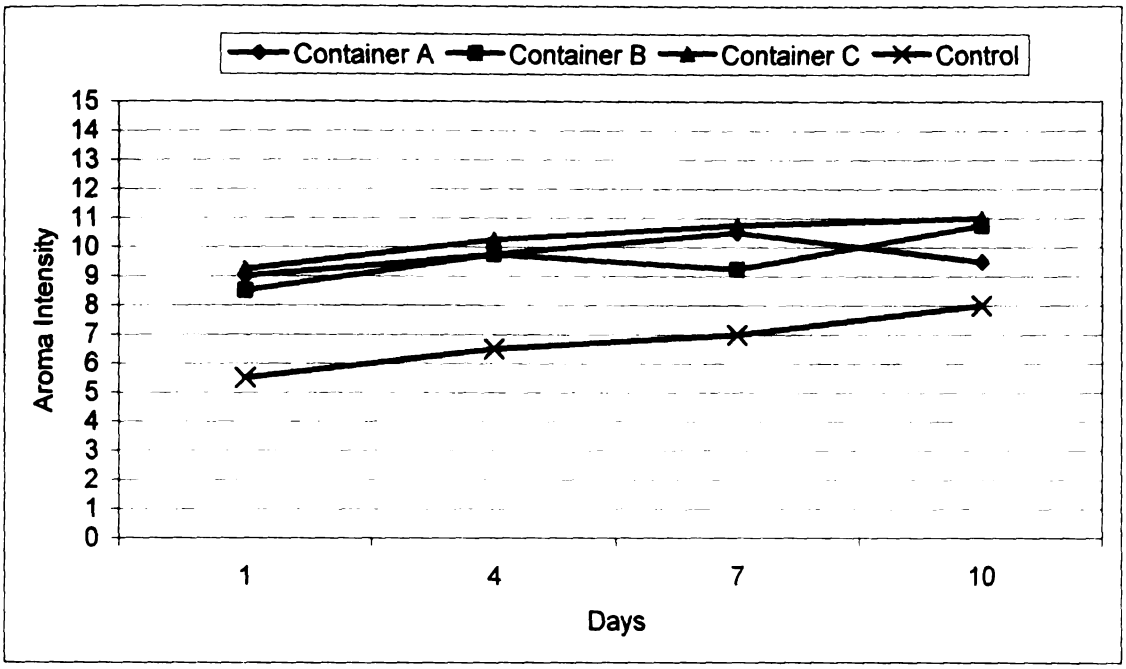


Figure 25. Trained panel (n=6) mean aroma scores of fresh-cut cantaloupe (Size -2.5cm) as an affect of container design; 500 mile trip

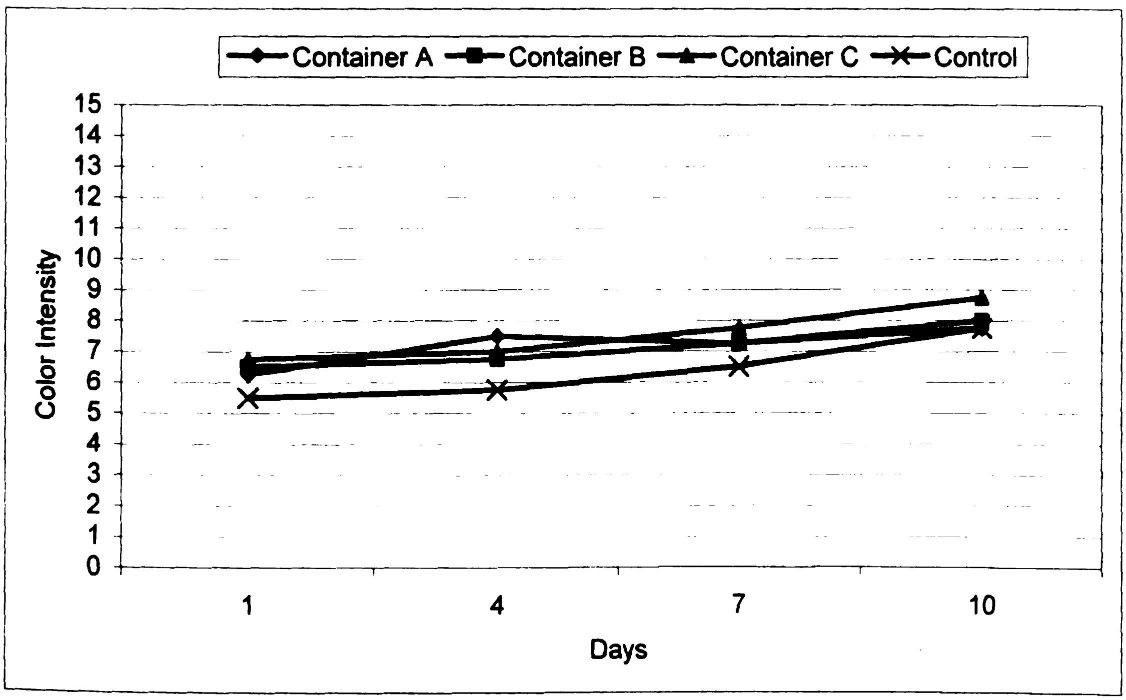


Figure 26. Trained panel (n=6) mean color scores of fresh-cut cantaloupe (Size - 2.5cm) as an effect of container design; 500 mile trip

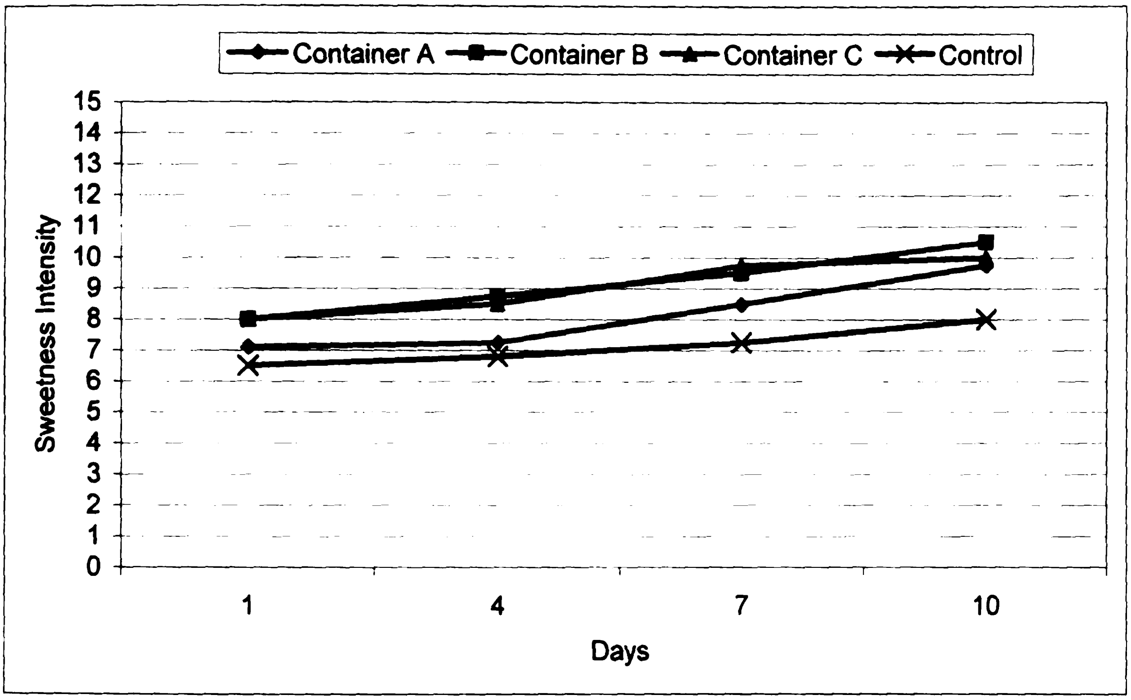


Figure 27. Trained panel (n=6) mean sweetness scores of fresh-cut cantaloupe (Size -2.5cm) as an effect of container design; 500 mile trip

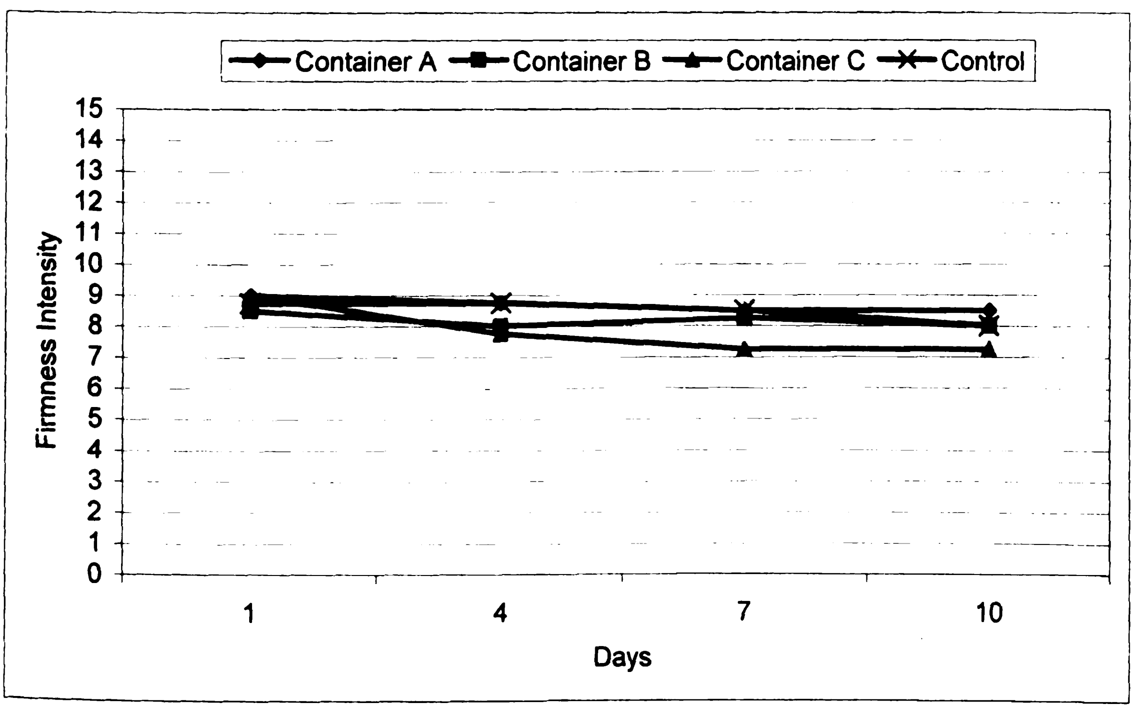


Figure 28. Trained panel (n=6) mean firmness scores of fresh-cut cantaloupe (Size-2.5cm) as an effect of container design; 500 mile trip

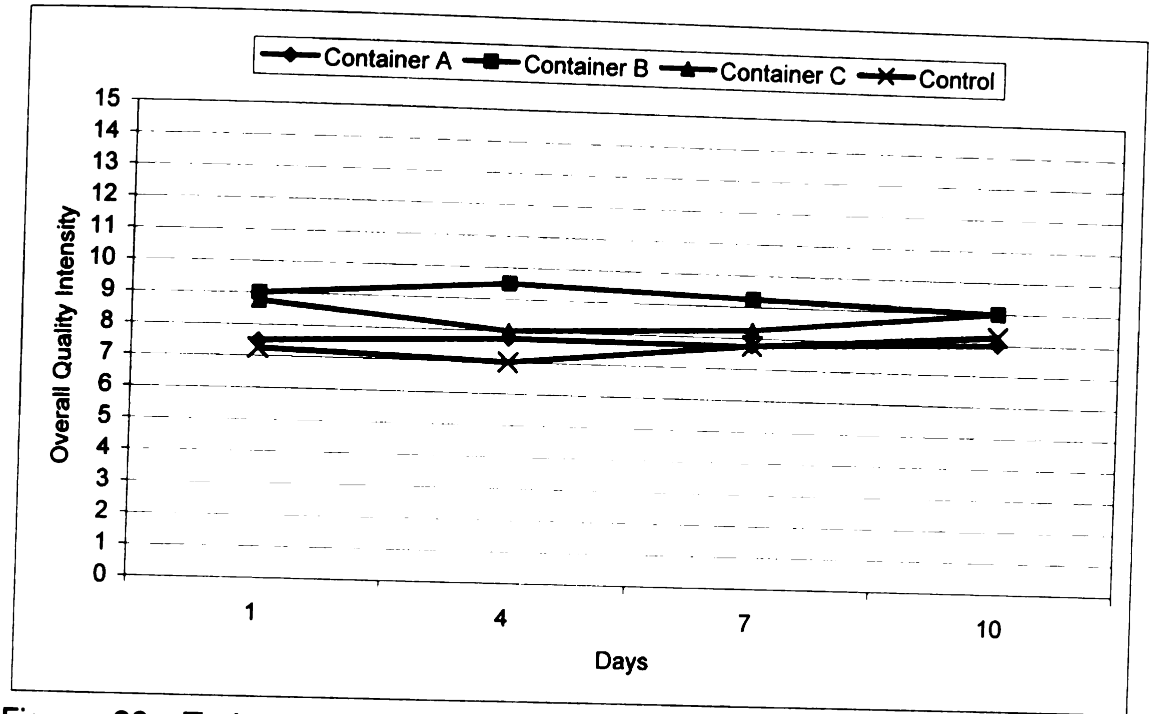


Figure 29. Trained panel (n=6) mean overall quality scores of fresh-cut cantaloupe (Size -2.5cm) as an effect of container design; 500 mile trip

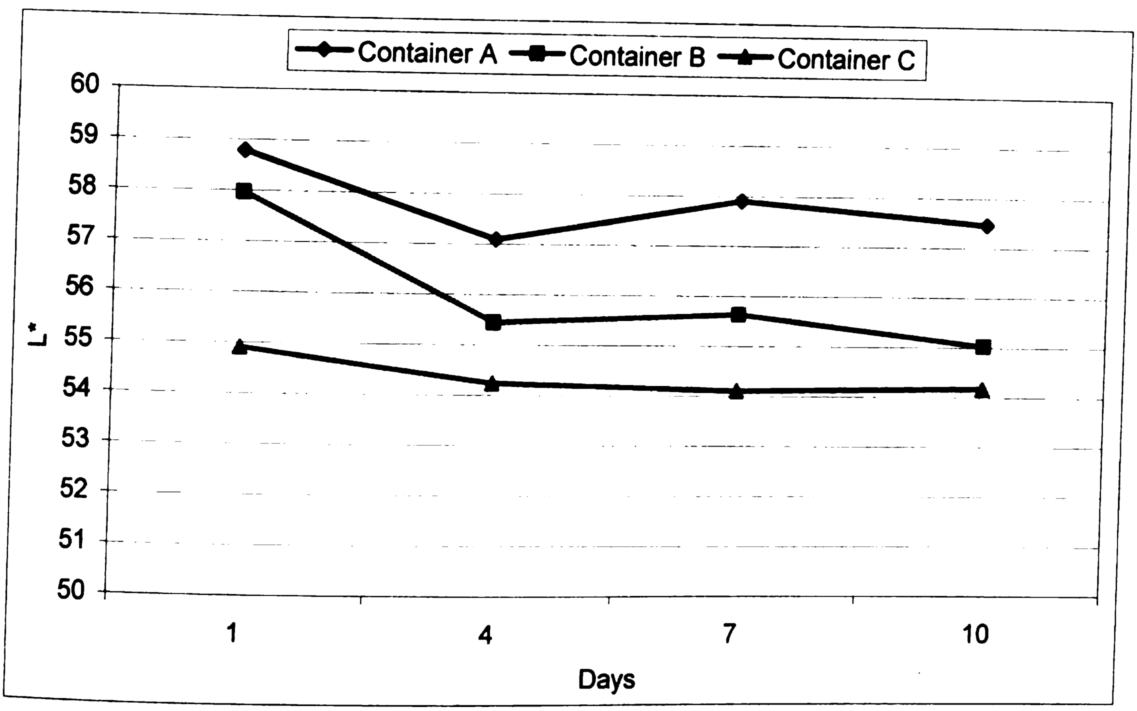


Figure 30. Effect of container design L* values of fresh-cut cantaloupe (Size - 2.5cm); 500 mile trip

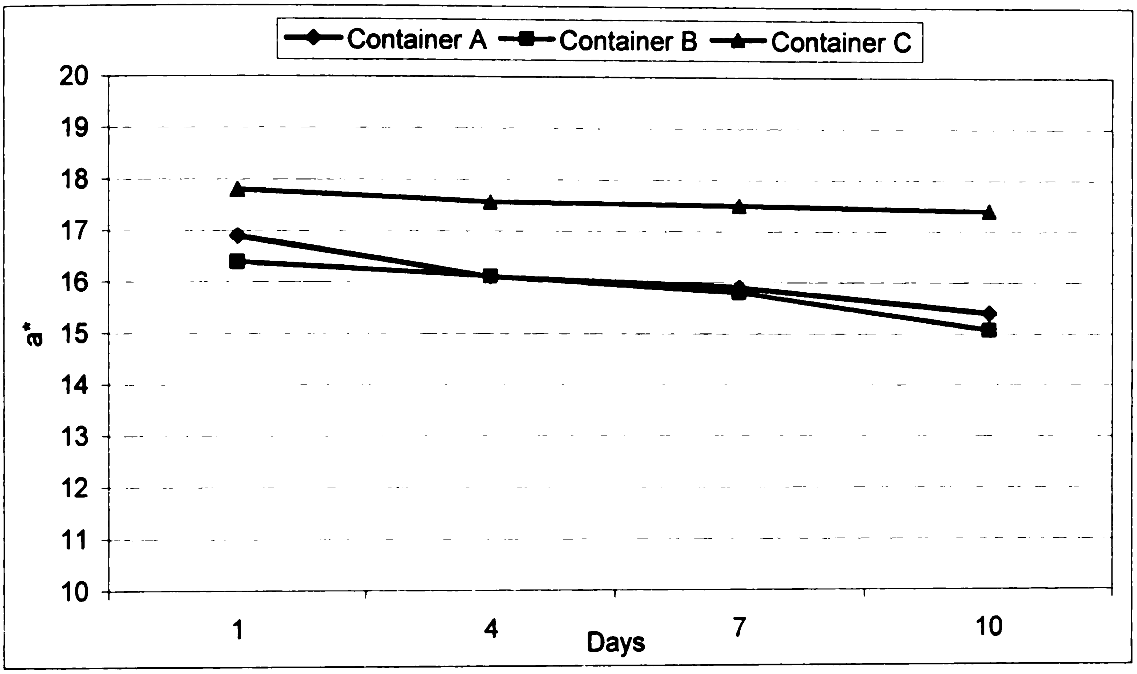


Figure 31. Effect of container design a* values of fresh-cut cantaloupe (Size-2.5cm); 500 mile trip

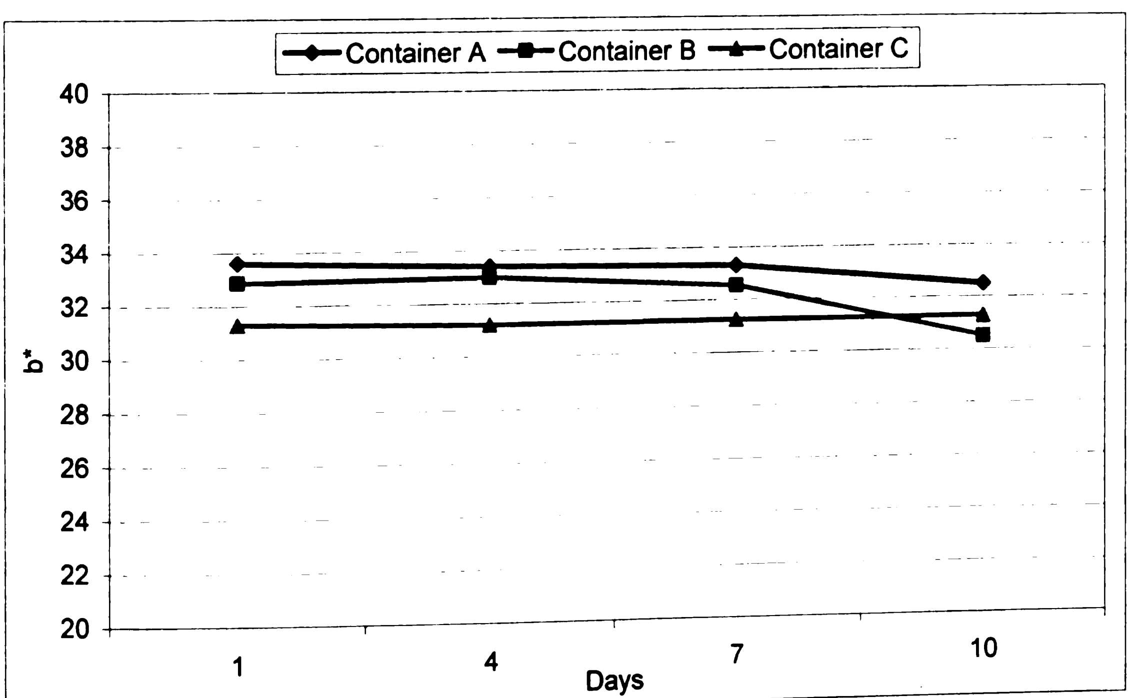


Figure 32. Effect of container design b* values of fresh-cut cantaloupe (Size-2.5cm); 500 mile trip

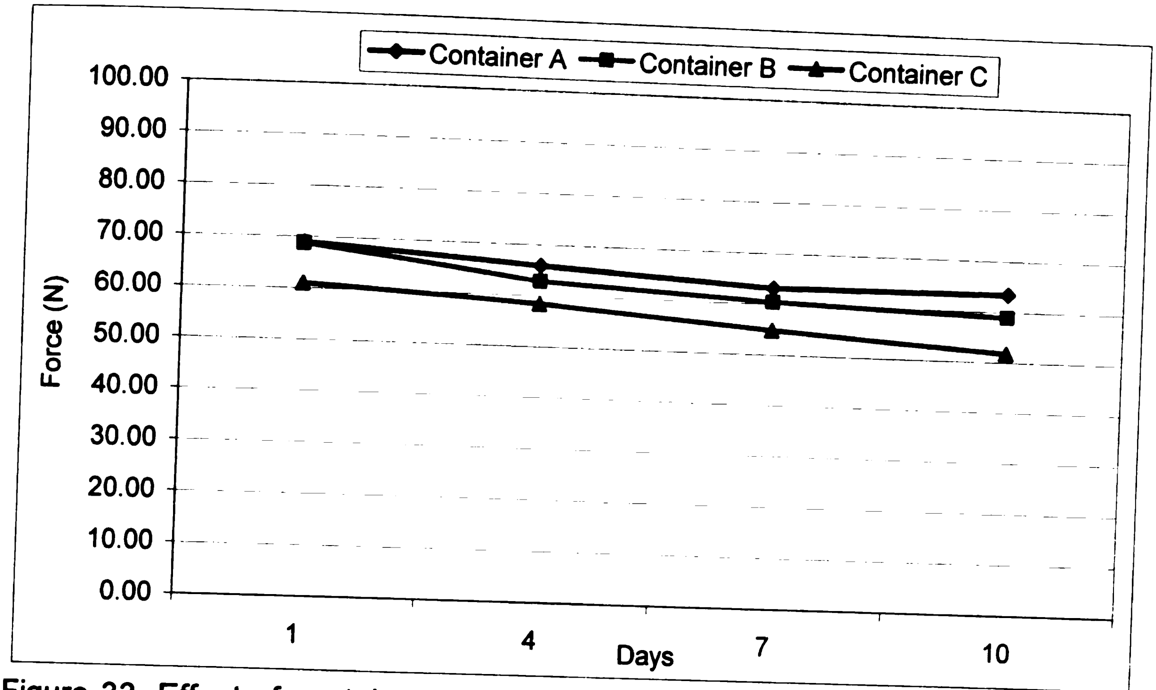


Figure 33. Effect of container design on firmness values of fresh-cut cantaloupe (Size -2.5cm); 500 mile trip

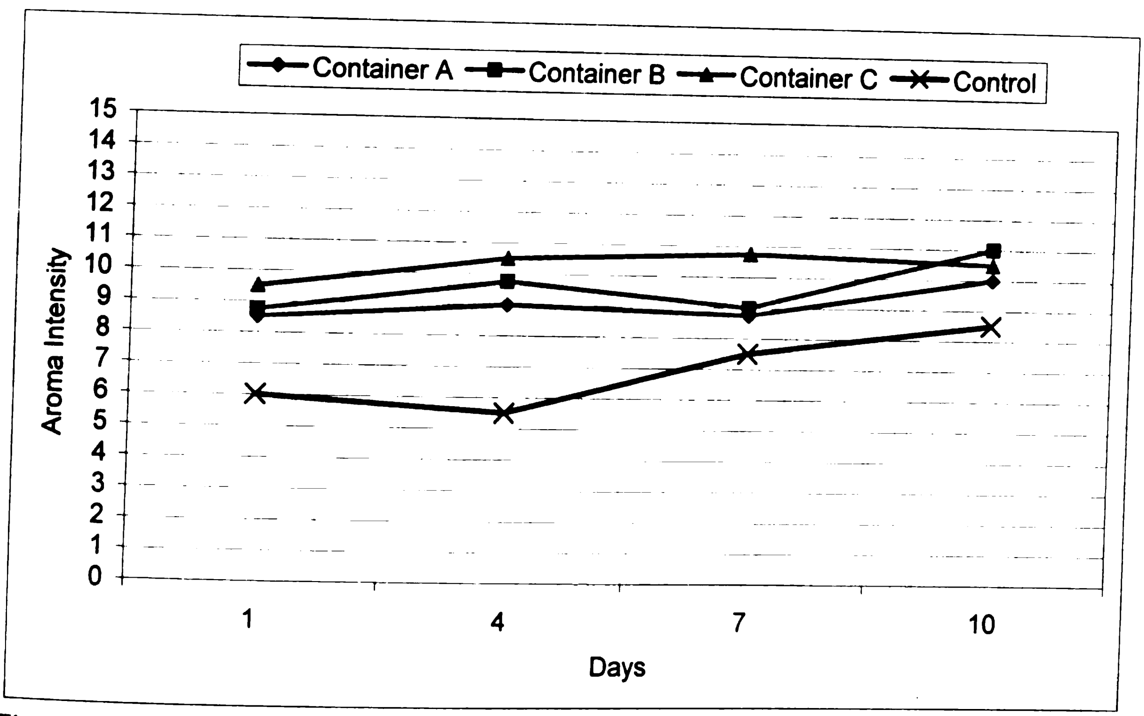


Figure 34. Mean aroma scores of fresh-cut cantaloupe (Size -1.5cm) as an effect of container design; 500 mile trip

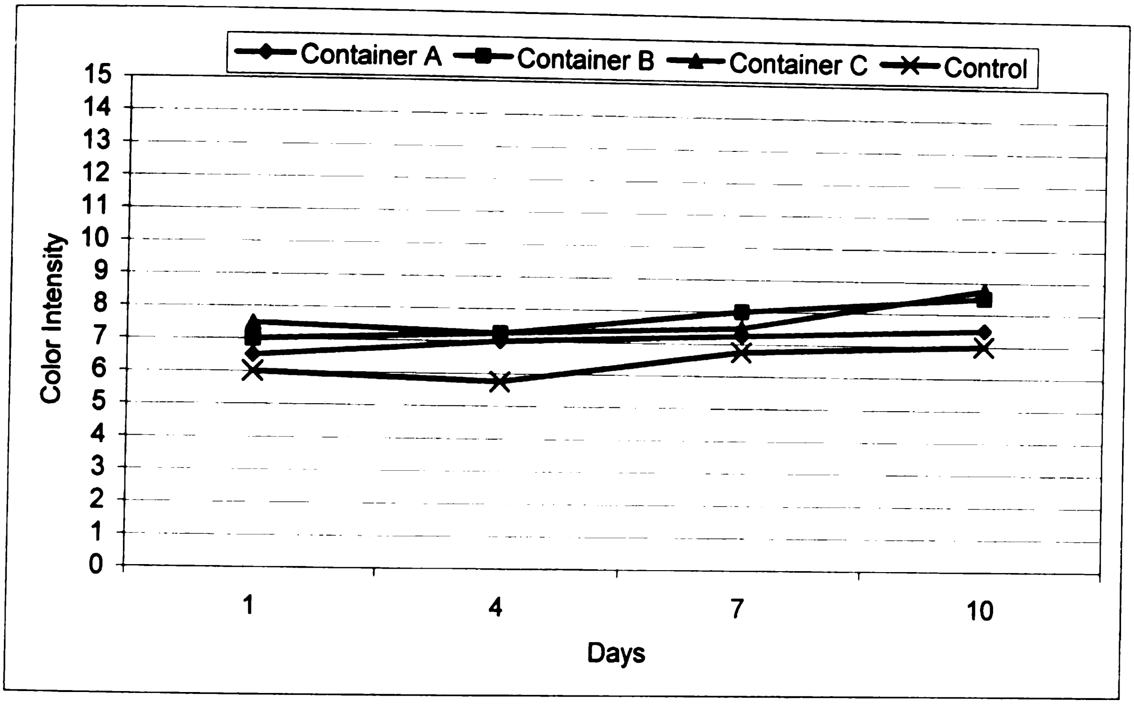


Figure 35. Trained panel (n=6) mean color scores of fresh-cut cantaloupe (Size-1.5cm) as an effect of container design; 500 mile trip

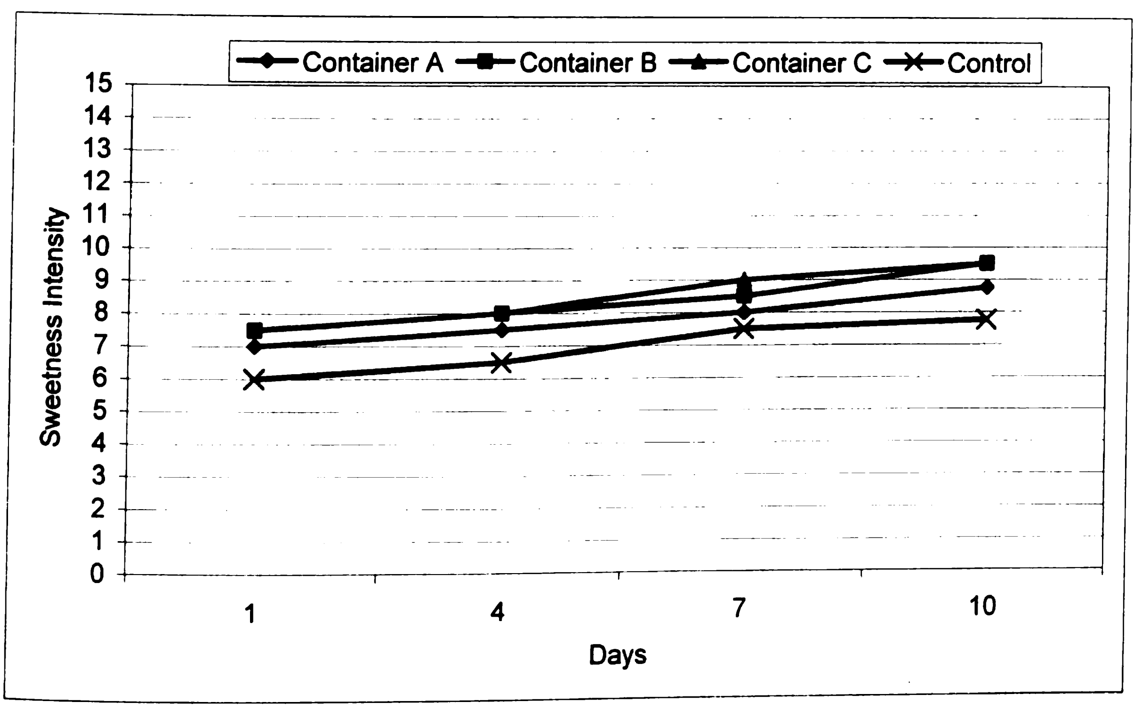


Figure 36. Trained panel (n=6) mean sweetness scores of fresh-cut cantaloupe (Size-1.5cm) as an effect of container design; 500 mile trip

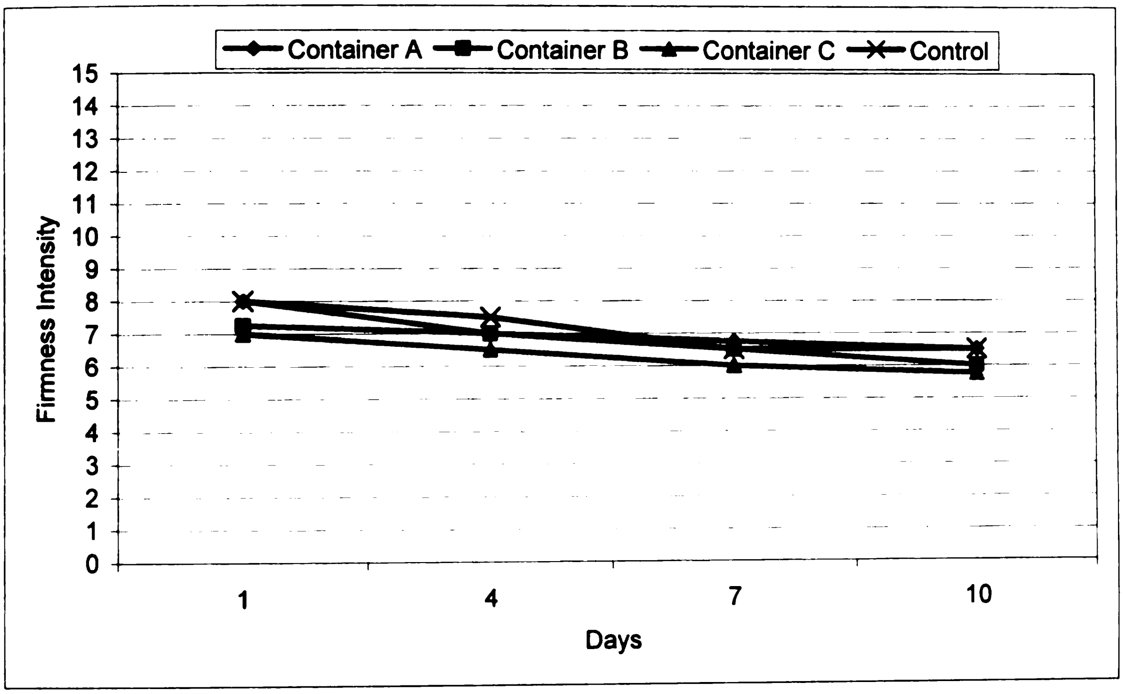


Figure 37. Trained panel (n=6) mean firmness scores of fresh-cut cantaloupe (Size-1.5cm) as an effect of container design; 500 mile trip

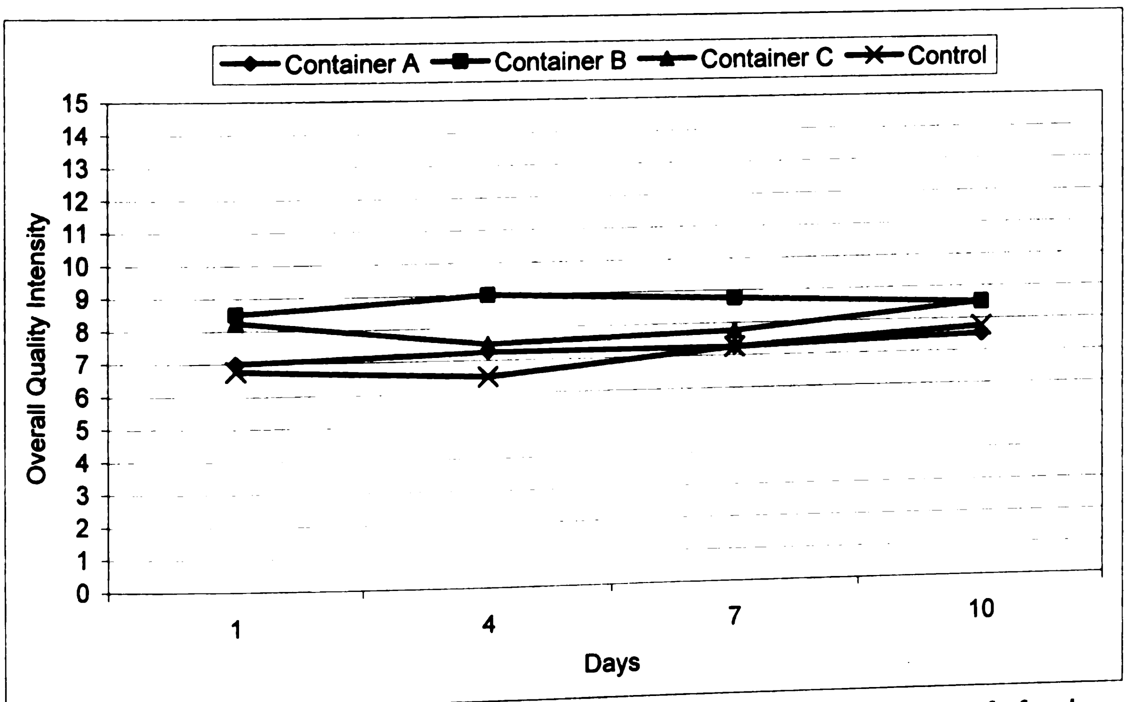


Figure 38. Trained panel (n=6) mean overall quality scores of fresh-cut cantaloupe (Size-1.5cm) as an effect of container design; 500 mile trip

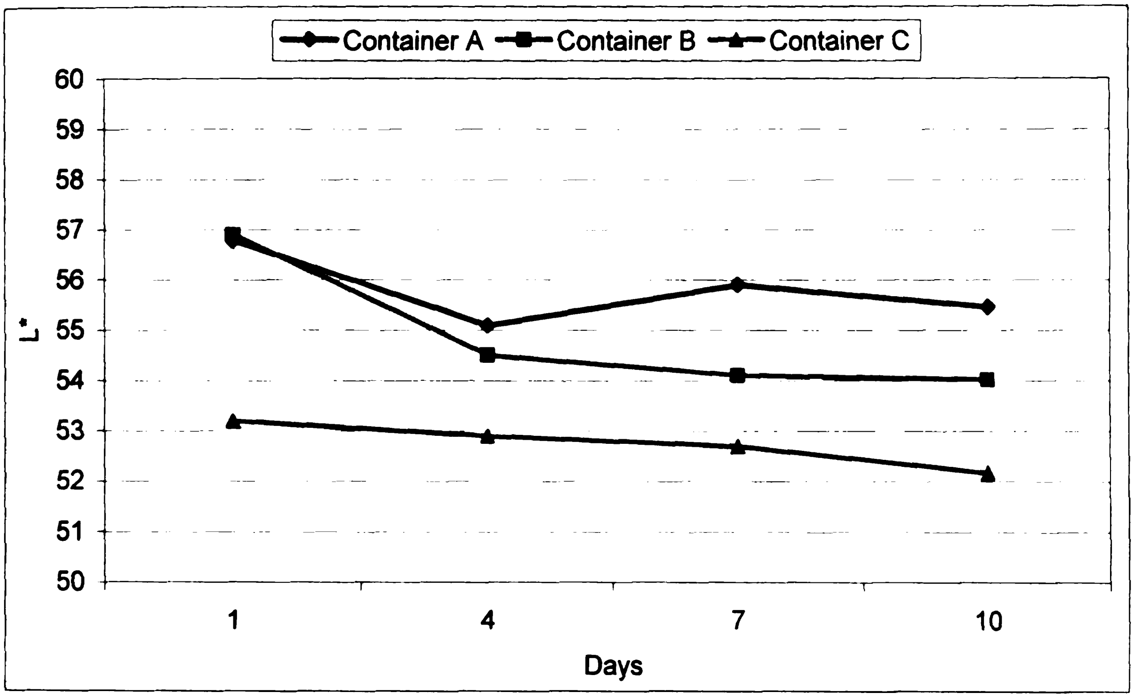


Figure 39. Effect of container design L* values of fresh-cut cantaloupe (Size-1.5cm); 500 mile trip

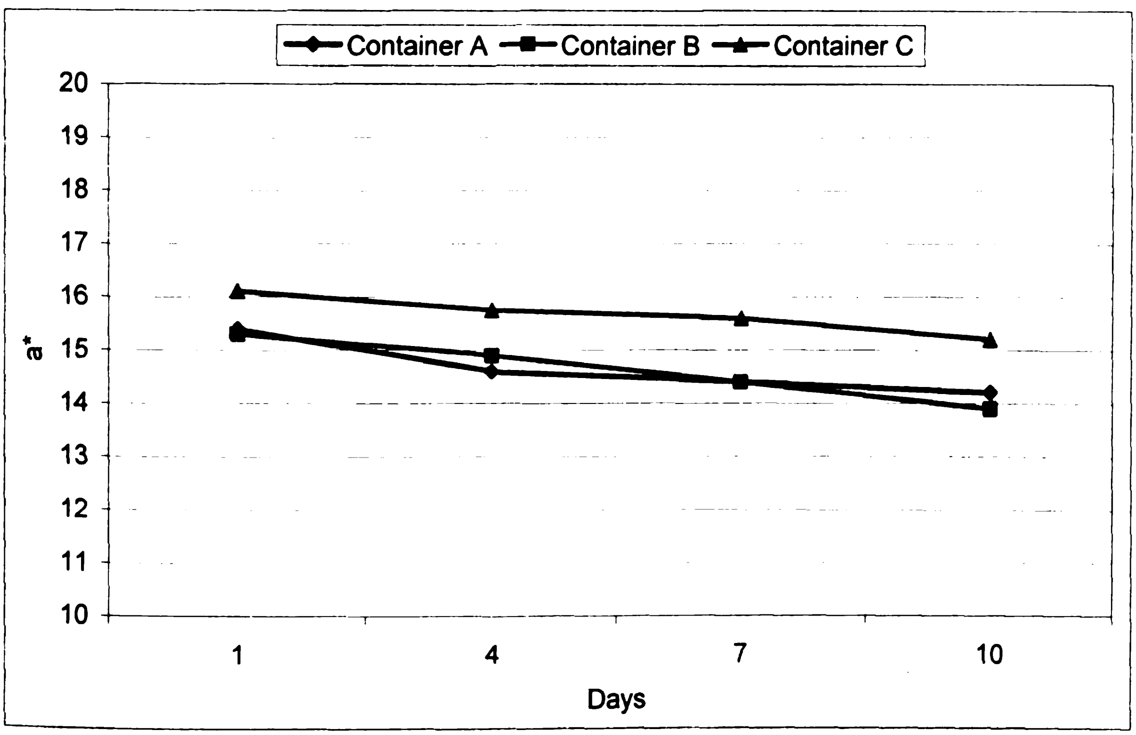


Figure 40. Effect of container design a* values of fresh-cut cantaloupe (Size-1.5cm); 500 mile trip

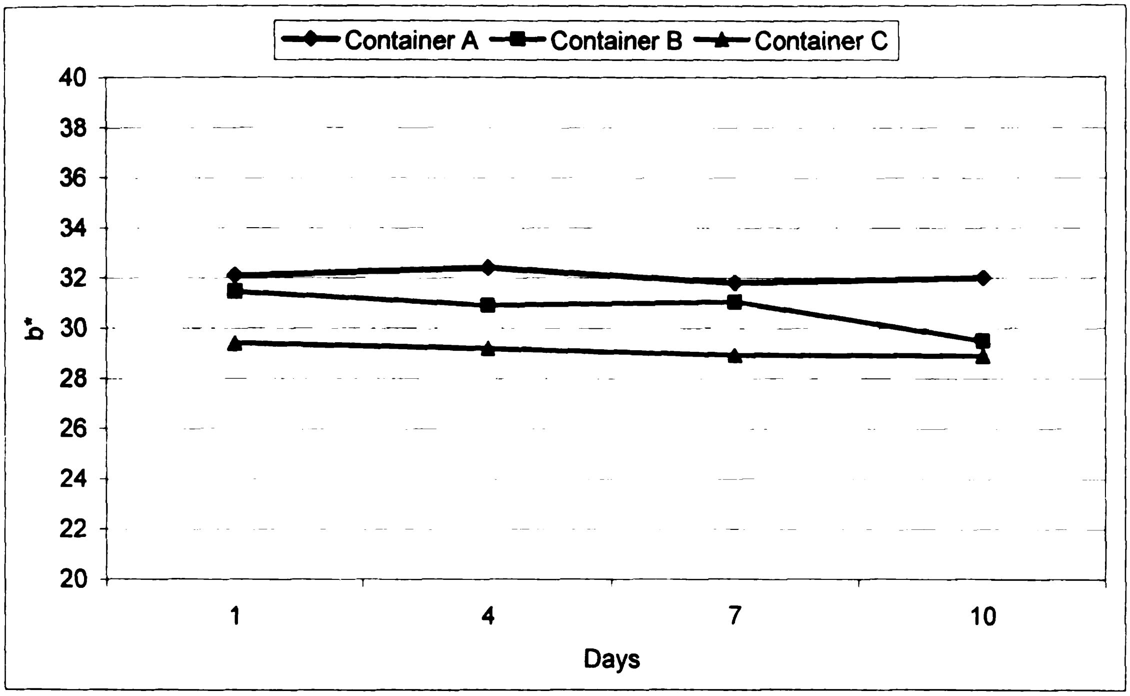


Figure 41. Effect of container design b* values of fresh-cut cantaloupe (Size-1.5cm); 500 mile trip

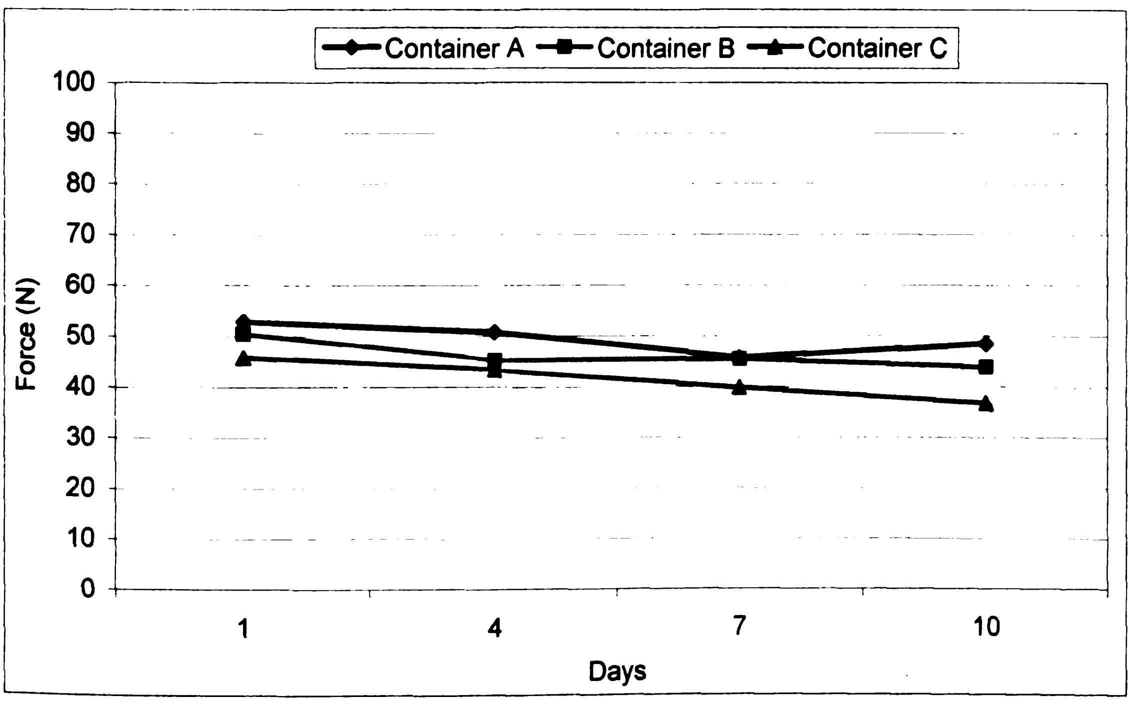


Figure 42. Effect of container design on firmness values of fresh-cut cantaloupe (Size-1.5cm); 500 mile trip

4.2.3 Effect of Dice Size

Quality of fresh-cut fruit can be affected by the type of cut or cutting shape (Lopez et al., 2005 and Aguayo et al., 2004). This study was performed to explore the effects of transportation on cube sizes (fresh-cut cantaloupe) and package design (3 types of containers) on the sensory properties such as color and texture quality components of fresh-cut cantaloupe.

The aroma intensity for both cube sizes (2.5cm and 1.5cm) increased during storage (Figures 43, 48 and 53). Unexpectedly, fresh-cut cantaloupe cube sizes did not affect the aroma intensity in the package headspace. However, the FCC samples subjected to vibration during transportation showed significantly higher aroma intensity than the control samples during storage. This behavior was consistent with both types of cube sizes packaged in all 3 types of containers s (Figures 43, 48 and 53).

Fresh-cut cantaloupe color increased during storage for both cube sizes in all 3 types of containers (Figures 44, 49 and 54). The color intensity of cubes was distinctly different from control (non-vibrated) samples at Day 4 and 7 for all 3 container treatment. The smaller cube size-1.5cm showed higher color rating for FCC samples packaged in Container A and B at days 1,4 7 and 10 (Figure 44 and 49). Whereas in Container C FCC samples size-2.5cm and size-1.5cm had the same color rating by day 10 (Figure 54). Similarly, transportation simulation affected color of cube cut surfaces significantly compared to control samples (Figures 58, 61 and 64). The CIE L*,a* and b* values decreased for both cube Size-2.5cm and 1.5cm in all 3 packaging containers during storage (Figures 58-

66). FCC Size 1.5cm was significantly darker than Size 2.5 (Figures 58,61 and 64). This indicates that Size-1.5cm was more susceptible to tissue damage and fruit decay caused by vibration during transportation, than Size-2.5cm samples. Similarly, a* and b* values indicate the red and yellow color of the flesh respectively. It was observed that fresh-cut cantaloupe samples for cube Size 2.5cm had a higher degree of yellowish-red color (orangish) compared to Size 1.5cm (Figures 59,62 and 65). As discussed earlier (Quality of Commercial Fresh-cut Cantaloupe) consumer rated melons with a brighter yellowish-red color higher than darker yellowish-red color. Therefore, the color analysis results suggest that fresh-cut cantaloupe prepared to a cube size of 2.5cm is better suited to withstand vibrational damage during transportation, thus maintaining the desirable yellowish-red color during storage.

The sweetness intensity for both cube sizes (2.5cm and 1.5cm) increased during storage (Figures 45, 50 and 55). The control samples had lower sweetness ratings than FCC samples subjected to transportation abuse during storage. Fresh-cut cantaloupe cube Size-2.5 cm had significantly more sweetness than Size-1.5cm for samples packaged in Container B and Container C (Figures 50 and 55). The FCC Size-1.5cm cubes were susceptible to more frictional damage than Size-2.5cm FCC samples, as a result of vibration during transportation. This can result in increased respiration rate and enzymatic degradation due to tissue wounding and cell damage resulting in decreased sweet aromatic compounds (Lamikanra and Watson 2000, Lamikanra and Watson, 2001 and Lamikanra and Watson, 2004).

Fresh-cut cantaloupe (FCC) sample firmness decreased during storage for both cube sizes, this was consistent with all 3 containers (Figures 46, 51 and 56). As illustrated in Figures 46, 51 and 56, control and Size-2.5cm FCC samples had significantly higher firmness ratings than Size-1.5cm at days 7 and 10, for all 3 containers. This indicates that a cube size of 1.5 cm is more susceptible to textural damage during transportation compared to a cube size of 2.5cm. Quantitative descriptive analysis of FCC firmness was supported by instrument texture analysis results as shown in Figures 67, 68 and 69. Texture analysis of fresh-cut cantaloupe indicates that cube Size-2.5cm required significantly higher compression force compared to cube Size-1.5cm (Figure 67, 68 and 69). In addition, the textural properties of cube Size-1.5cm was adversely affected when packaged in Container C. This indicates that a cube size of 1.5 cm is susceptible to extensive surface tissue damage during transportation when packaged in a deeper container (Container C-3.1 inches) compared to a shallow container (Container A-1.75 inches and Container B-2.625 inches).

The overall quality of fresh-cut cantaloupe deteriorated for both Size-2.5cm and Size-1.5 cm samples packaged in 'Container B' and 'Container C' but had a higher overall quality than control samples (Figures 52 and 57). Whereas FCC samples in 'Container A' did not show much difference in overall quality during storage (Figures 47). This indicates that aroma, sweetness and texture of FCC samples packaged in Container A did not appeal to the panelists compared to the FCC samples packaged in Container B and C. Panelists were trained to look for sweet aromatic flavor compounds and reddish-yellow color. FCC samples were less susceptible to physical abuse during transport vibration in Container A. This could be explained since Container A was shallower and the dices were arranged in one layer compared to multiple layers in Container B and randomly oriented dices in Container C suffered more surface tissue damage. Therefore, dices in Container A had less sweet aromatic compound released during transport vibration and a lighter flesh color resulted during storage. It was observed that sample Size-2.5cm had relatively higher overall quality than Size-1.5cm in Container B and Container C. This indicates that a cube size of 2.5cm is less susceptible to tissue damage and fruit decay during storage and transportation.

Sensory analysis, color analysis (CIE L*,a* and b*) and texture analysis of fresh-cut cantaloupe samples suggested that a fruit size of 2.5cm is capable of maintaining better sensory quality attributes compared to fruit size 1.5cm during transportation and storage. Fresh-cut cantaloupe Size-2.5 cm had better sensory characteristics than Size-1.5cm packaged Container A, B and C. It was found that Size-2.5cm preserved better texture properties than 1.5cm during transportation. A smaller size fresh-cut cantaloupe cube was found to be more susceptible to surface tissue damage during transportation as determined by texture analyzer. Similarly, color properties were better maintained for Size-2.5cm during transportation than Size-1.5cm packaged in Container A, B and C rigid containers. This suggested that the overall quality of fresh-cut cantaloupe will be best maintained during transportation when cubes are diced to a size of 2.5 cm.

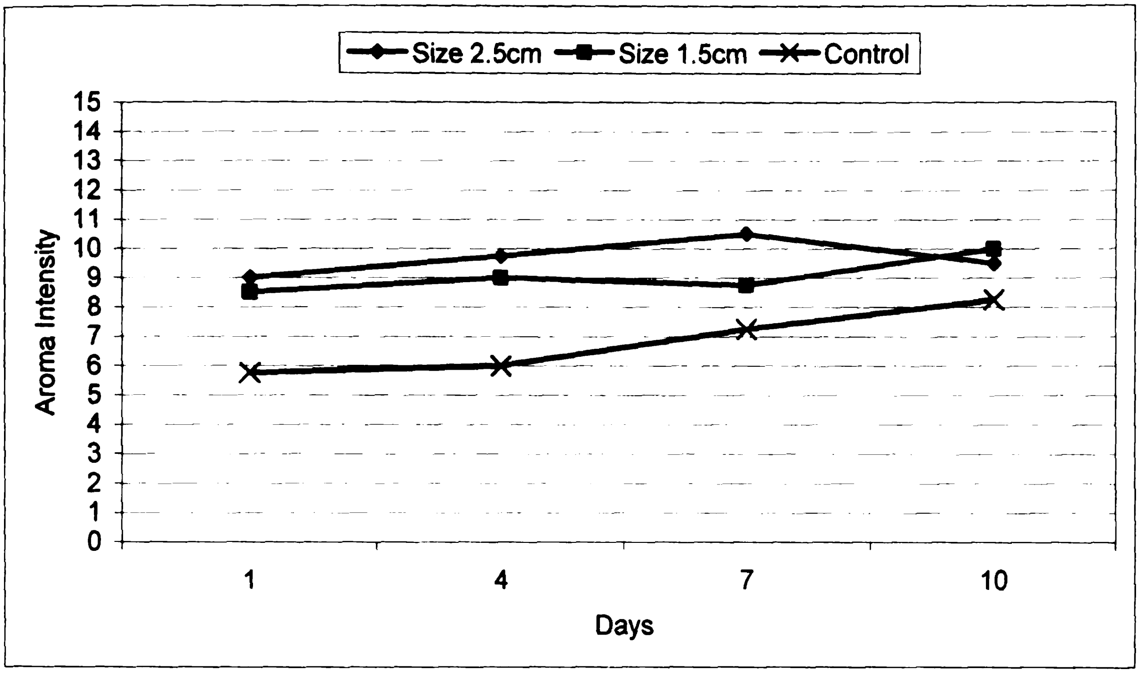


Figure 43. Trained panel (n=6) mean aroma scores of fresh-cut cantaloupe (Container A) as an effect of fruit dice size; 500 mile trip

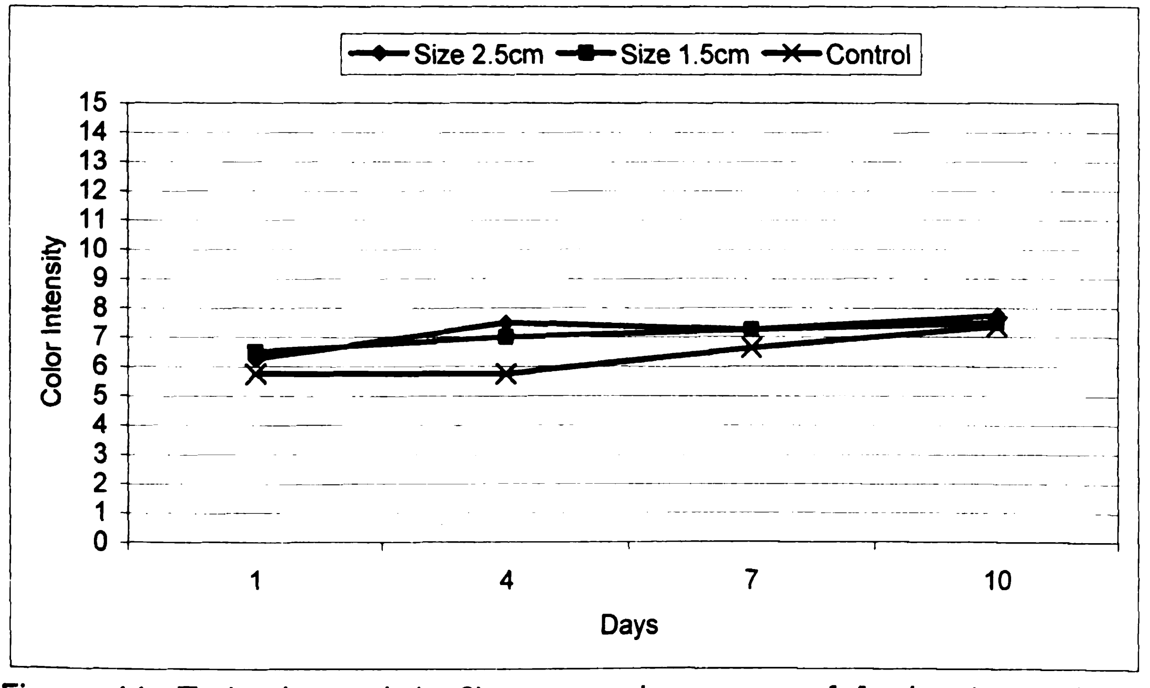


Figure 44. Trained panel (n=6) mean color scores of fresh-cut cantaloupe (Container A) as an effect of fruit dice size; 500 mile trip

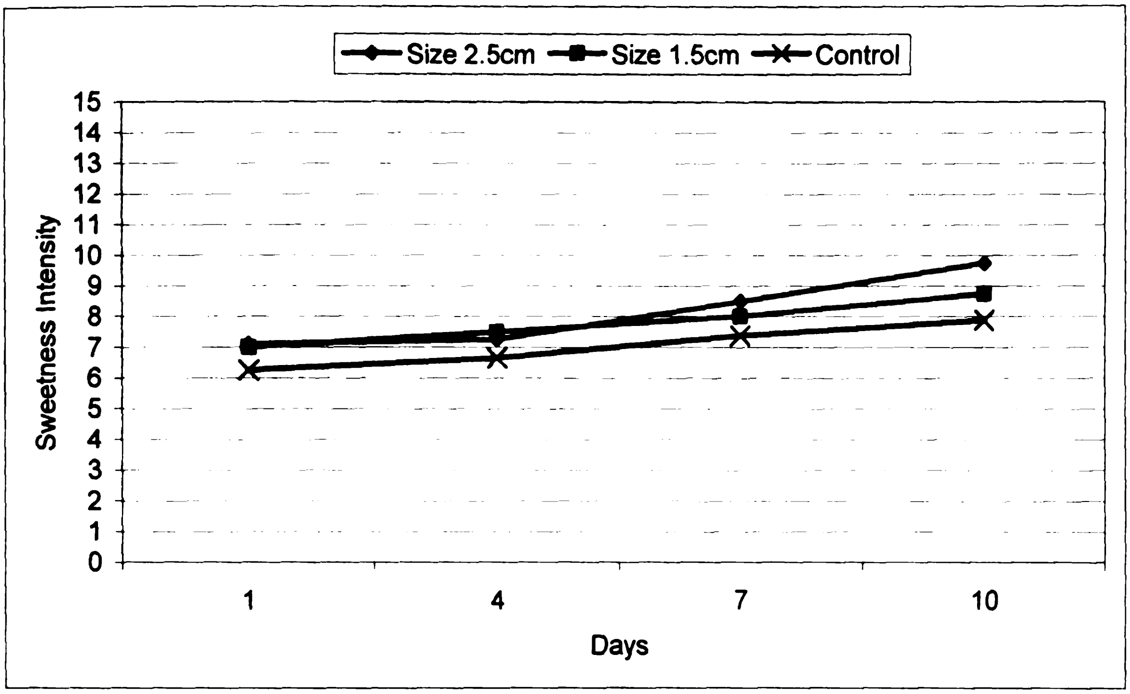


Figure 45. Trained panel (n=6) mean sweetness scores of fresh-cut cantaloupe (Container A) as an effect of fruit dice size; 500 mile trip

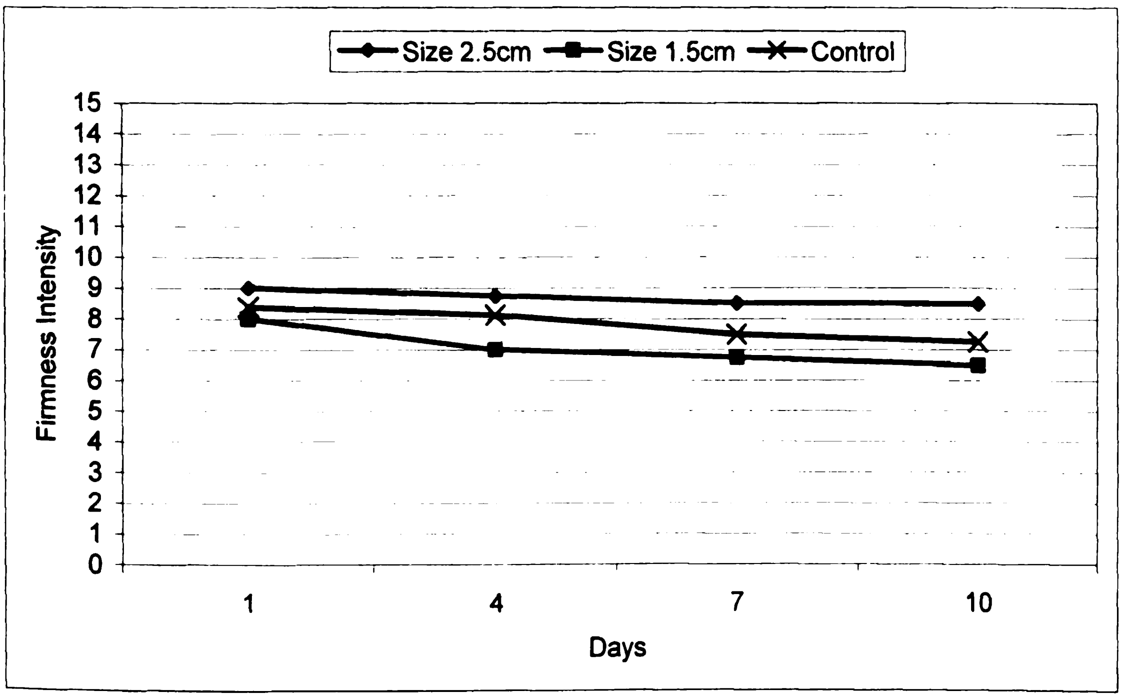


Figure 46. Trained panel (n=6) mean firmness scores of fresh-cut cantaloupe (Container A) as an effect of fruit dice size; 500 mile trip

Overall Quality

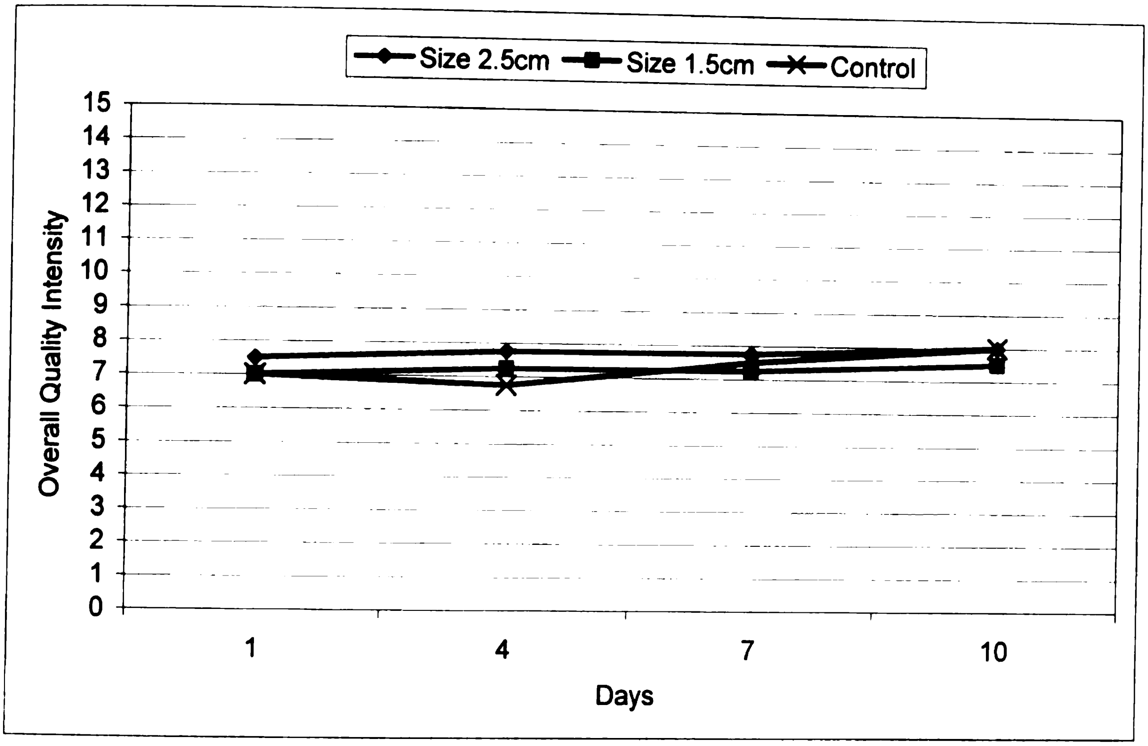


Figure 47. Trained panel (n=6) mean overall quality scores of fresh-cut cantaloupe (Container A) as an effect of fruit dice size; 500 mile trip

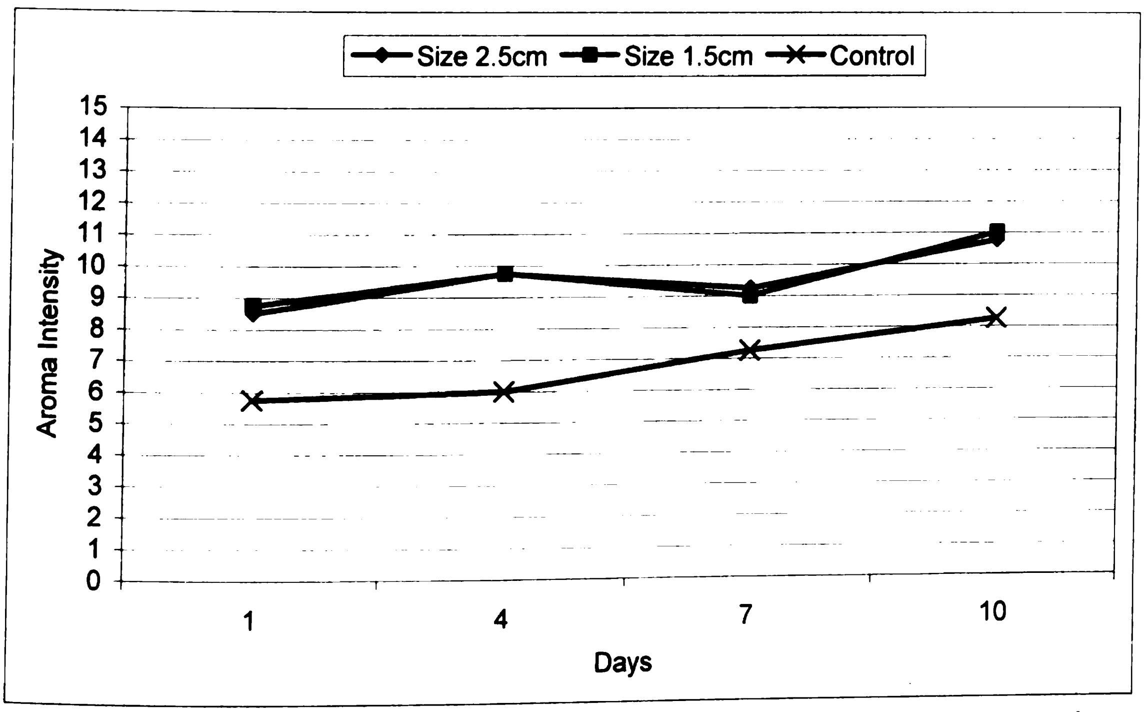


Figure 48. Trained panel (n=6) mean aroma scores of fresh-cut cantaloupe (Container B) as an effect of fruit dice size; 500 mile trip

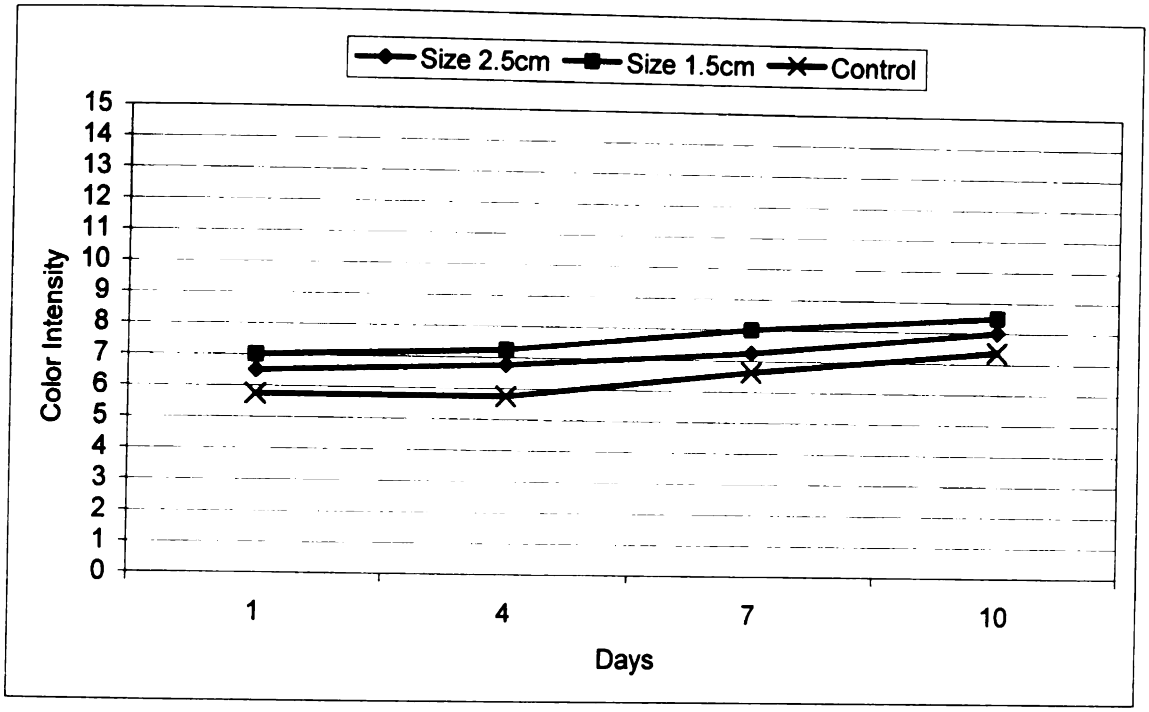


Figure 49. Trained panel (n=6) mean color scores of fresh-cut cantaloupe (Container B) as an effect of fruit dice size; 500 mile trip

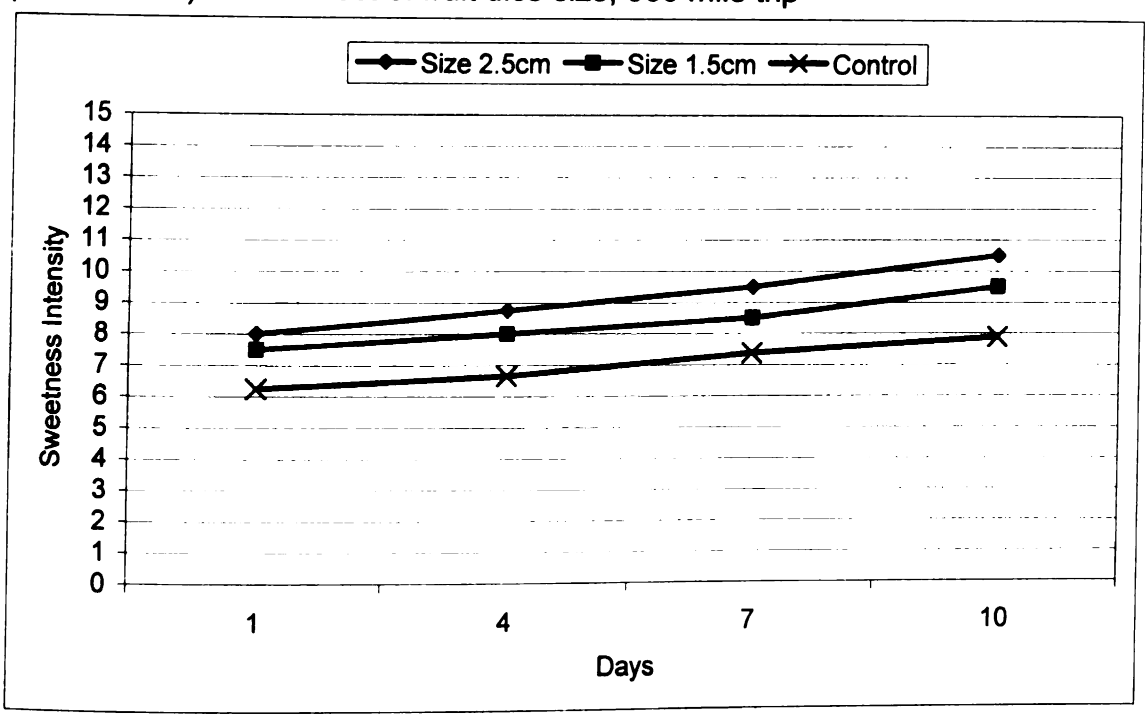


Figure 50. Trained panel (n=6) mean sweetness scores of fresh-cut cantaloupe (Container B) as an effect of fruit dice size; 500 mile trip

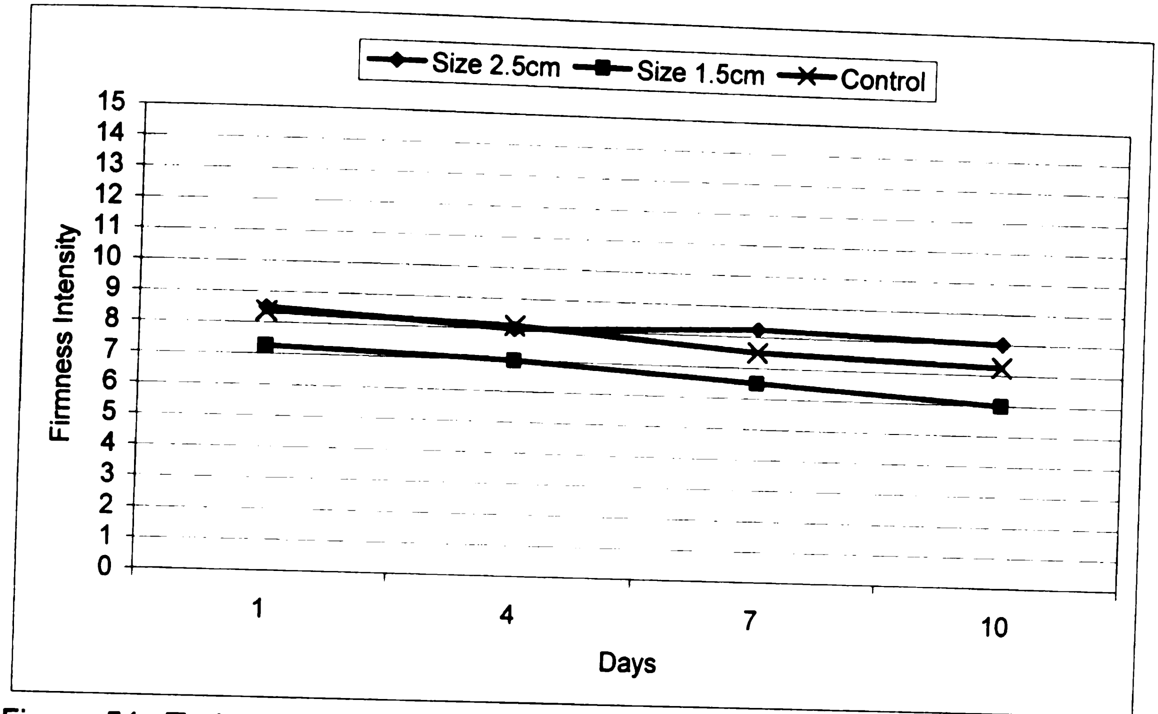


Figure 51. Trained panel (n=6) mean firmness scores of fresh-cut cantaloupe (Container B) as an effect of fruit dice size; 500 mile trip

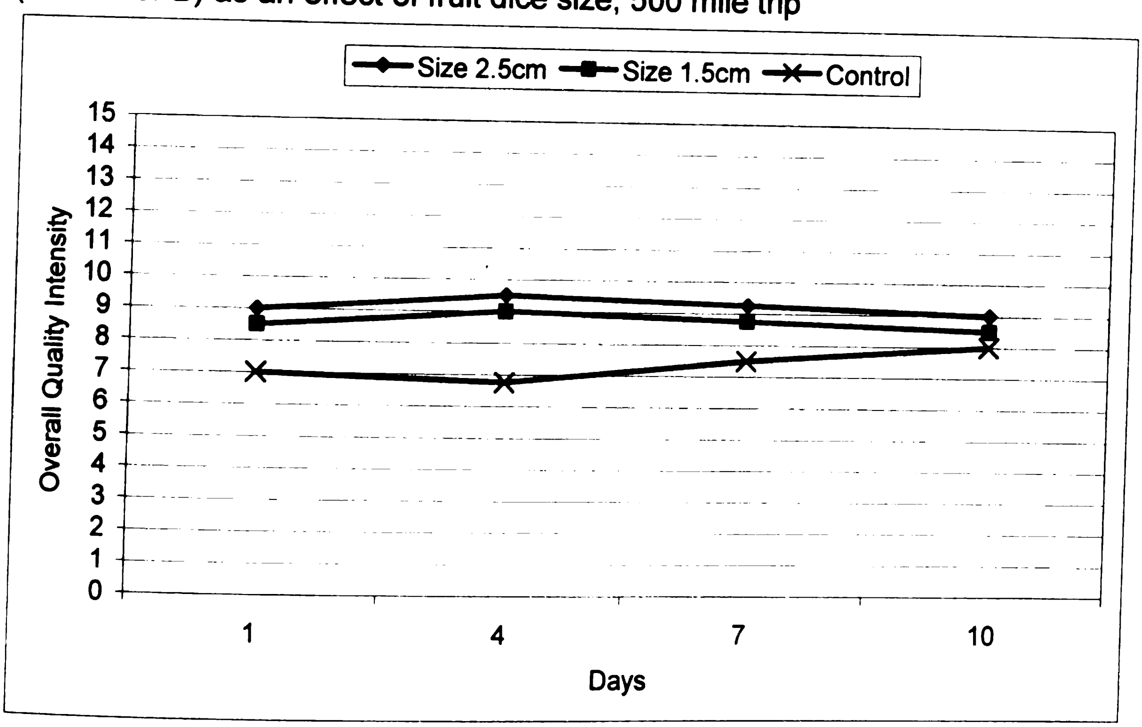


Figure 52. Trained panel (n=6) mean overall quality scores of fresh-cut cantaloupe (Container B) as an effect of fruit dice size; 500 mile trip

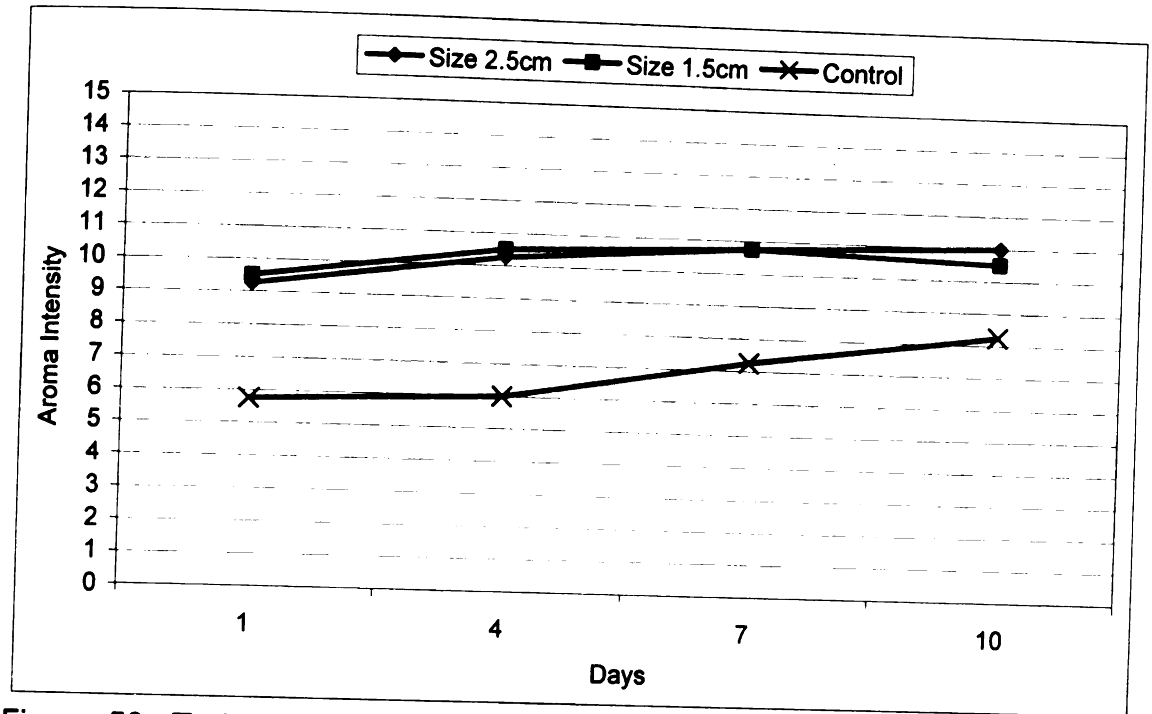


Figure 53. Trained panel (n=6) mean aroma scores of fresh-cut cantaloupe (Container C) as an effect of cut fruit dice size; 500 mile trip

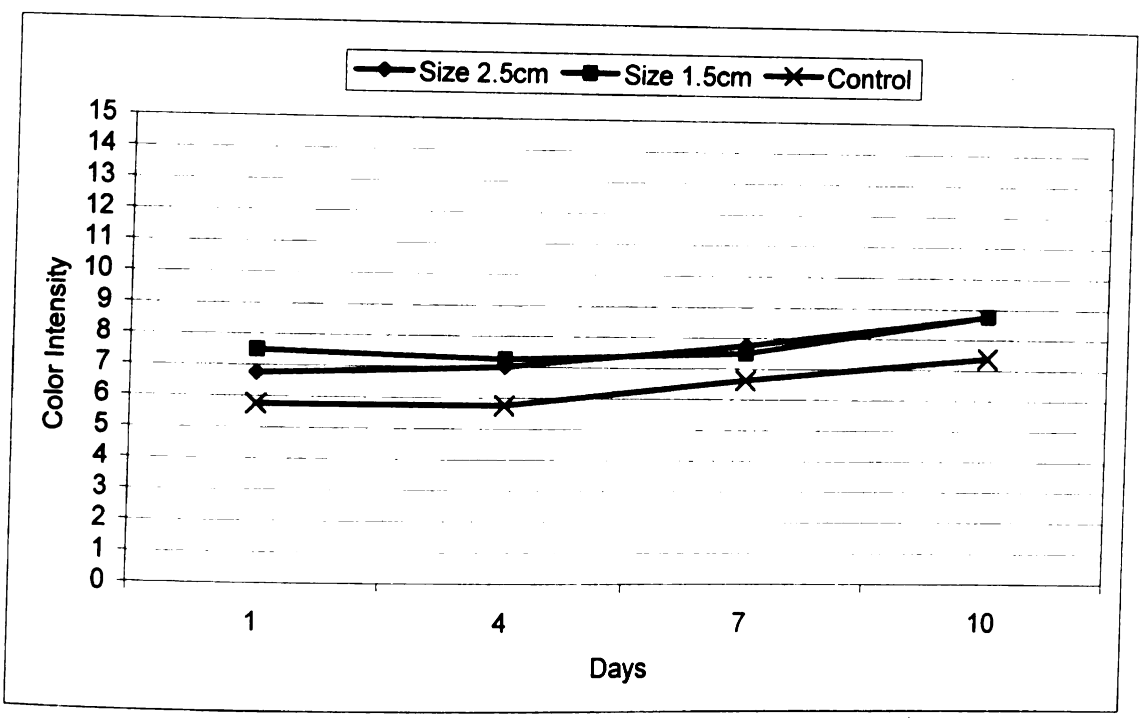


Figure 54. Trained panel (n=6) mean color scores of fresh-cut cantaloupe (Container C) as an effect of fruit dice size; 500 mile trip

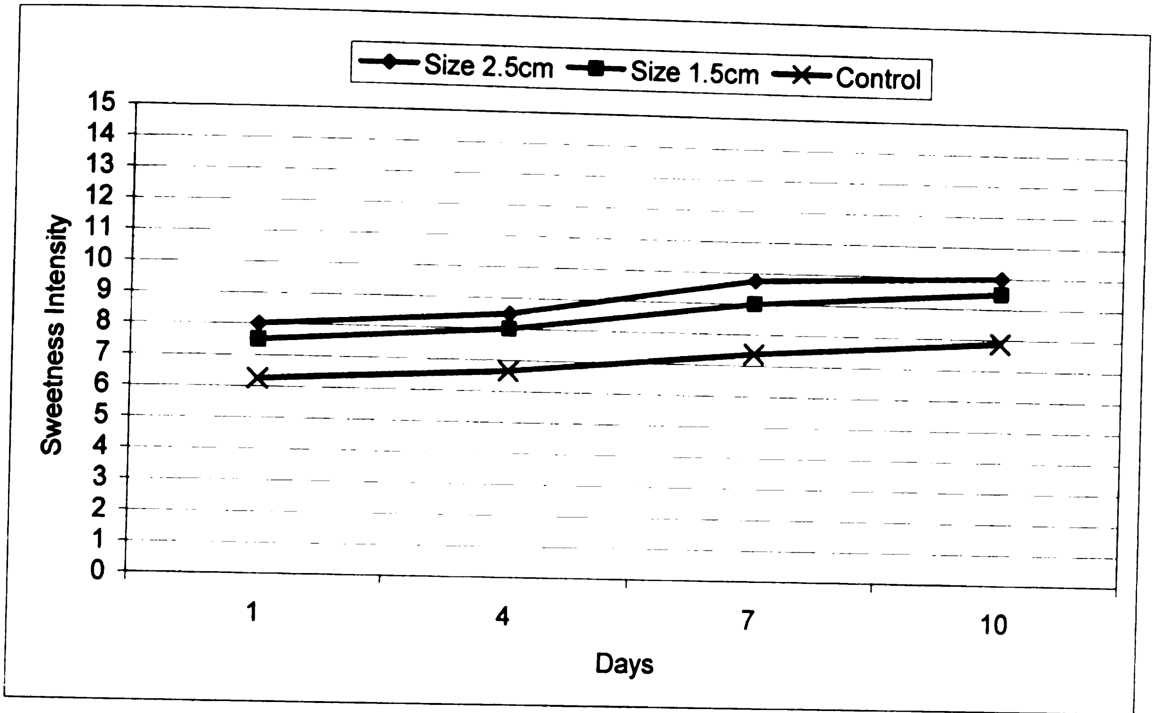


Figure 55. Trained panel (n=6) mean sweetness scores of fresh-cut cantaloupe (Container C) as an effect of fruit dice size; 500 mile trip

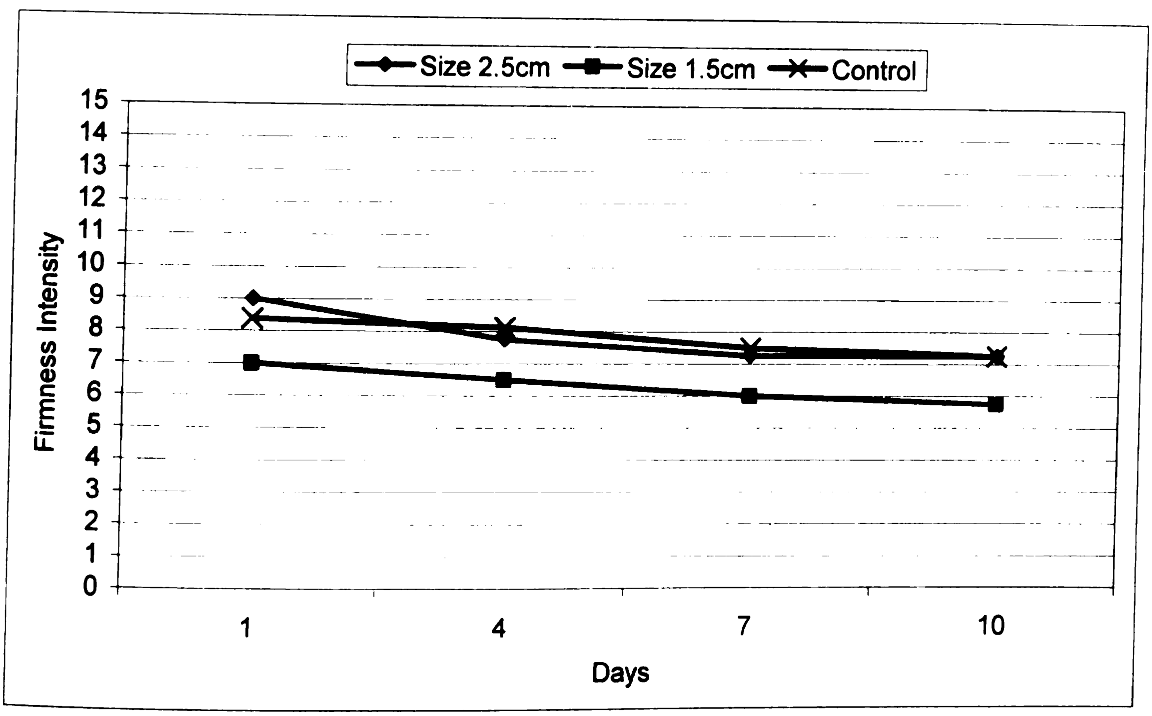


Figure 56. Trained panel (n=6) mean firmness scores of fresh-cut cantaloupe (Container C) as an effect of fruit dice size; 500 mile trip

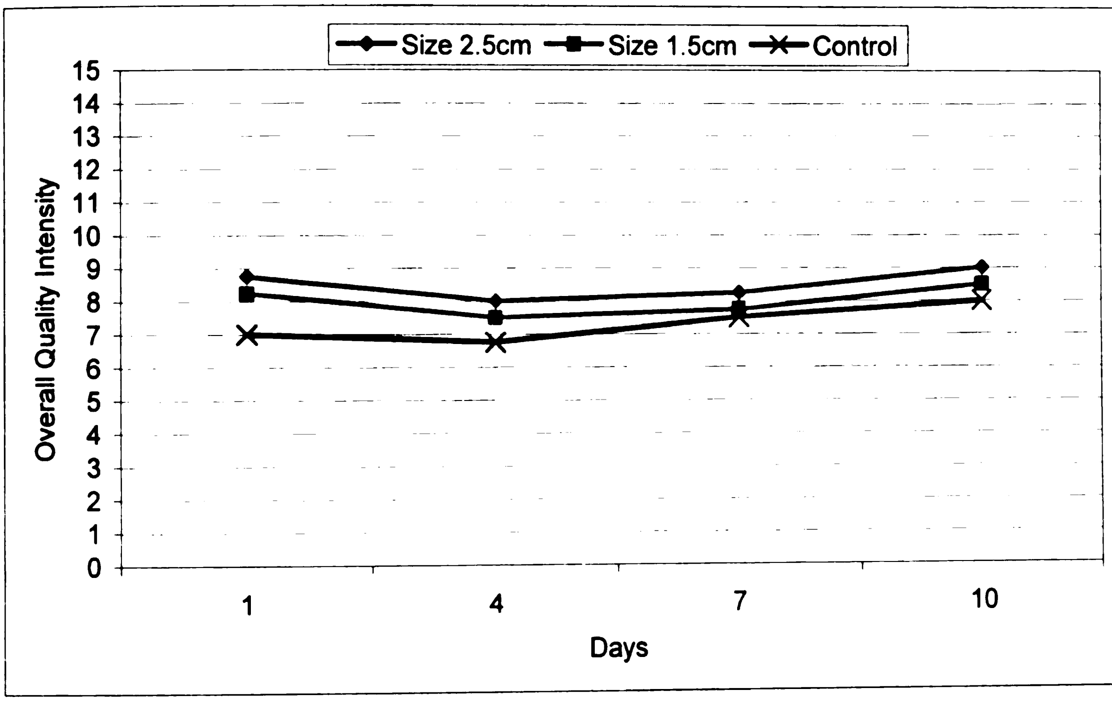


Figure 57. Trained panel (n=6) mean overall quality scores of fresh-cut cantaloupe (Container C) as an effect of fruit dice size; 500 mile trip

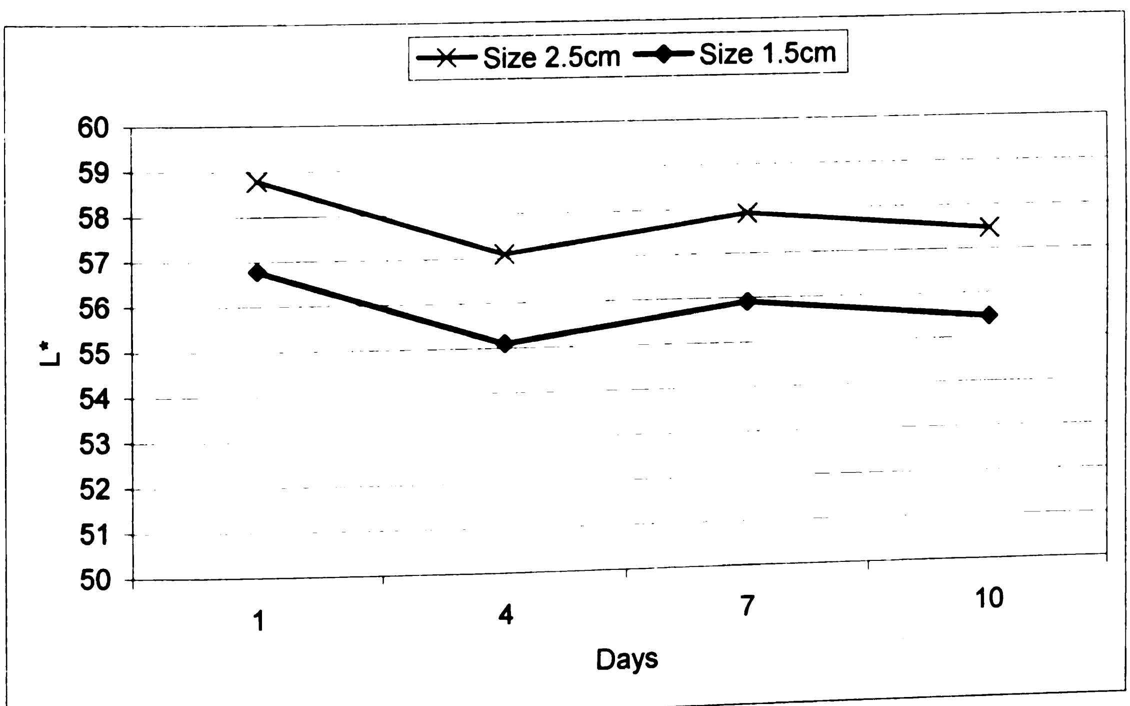


Figure 58. Effect of fruit dice size on L* values of fresh-cut cantaloupe (Container A); 500 mile trip

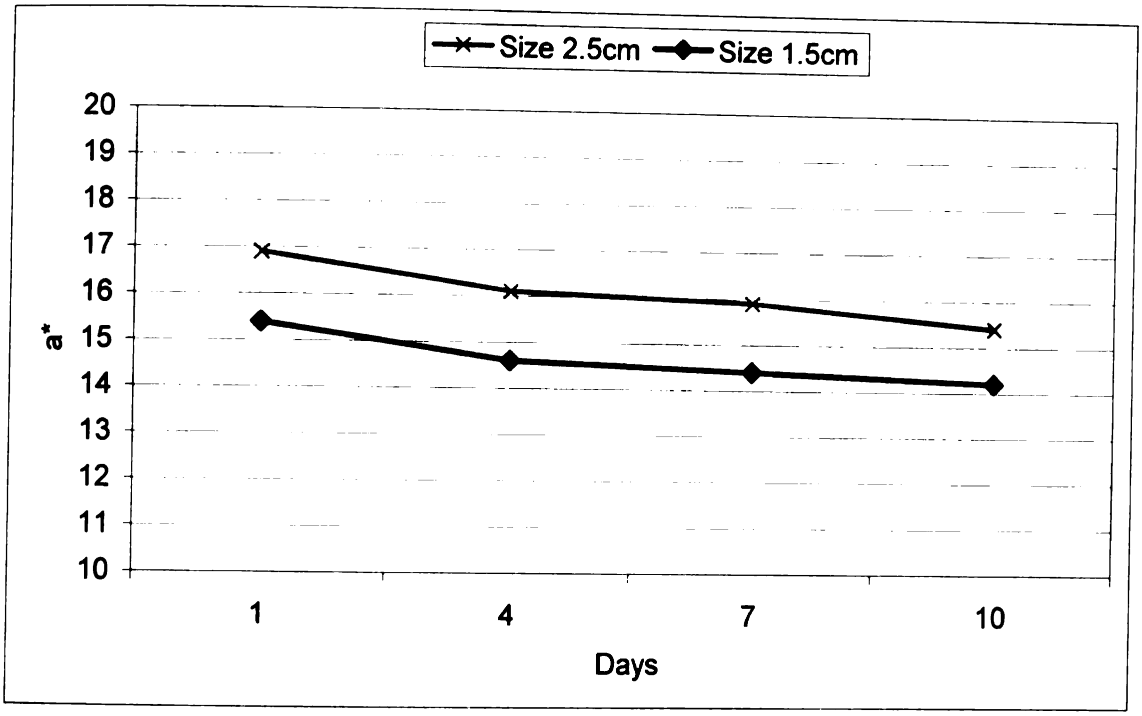


Figure 59. Effect of fruit dice size on a* values of fresh-cut cantaloupe (Container A); 500 mile trip

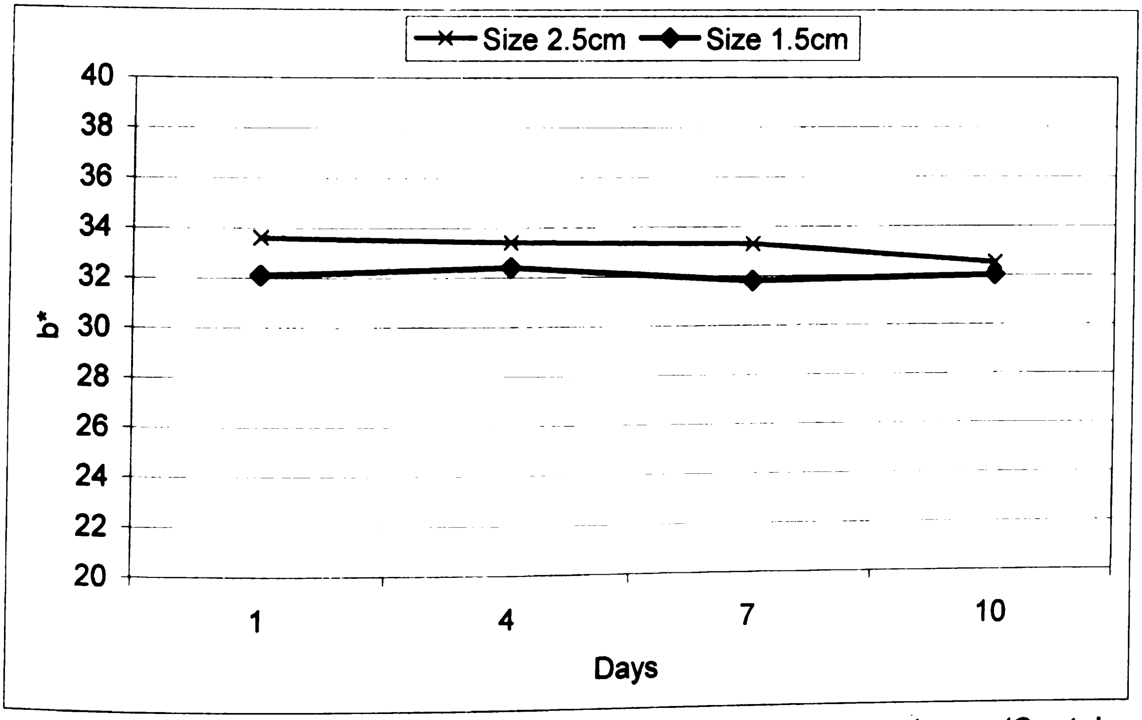


Figure 60. Effect of fruit dice size on b* values of fresh-cut cantaloupe (Container A); 500 mile trip

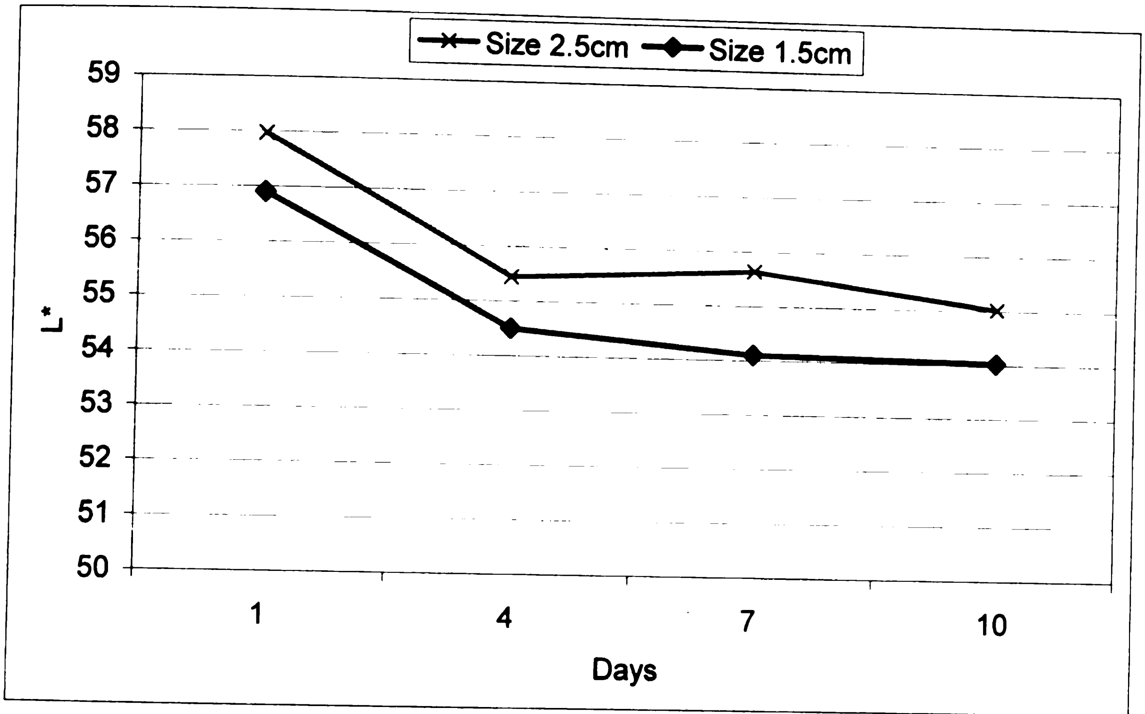


Figure 61. Effect of fruit dice size on L* values of fresh-cut cantaloupe (Container B); 500 mile trip

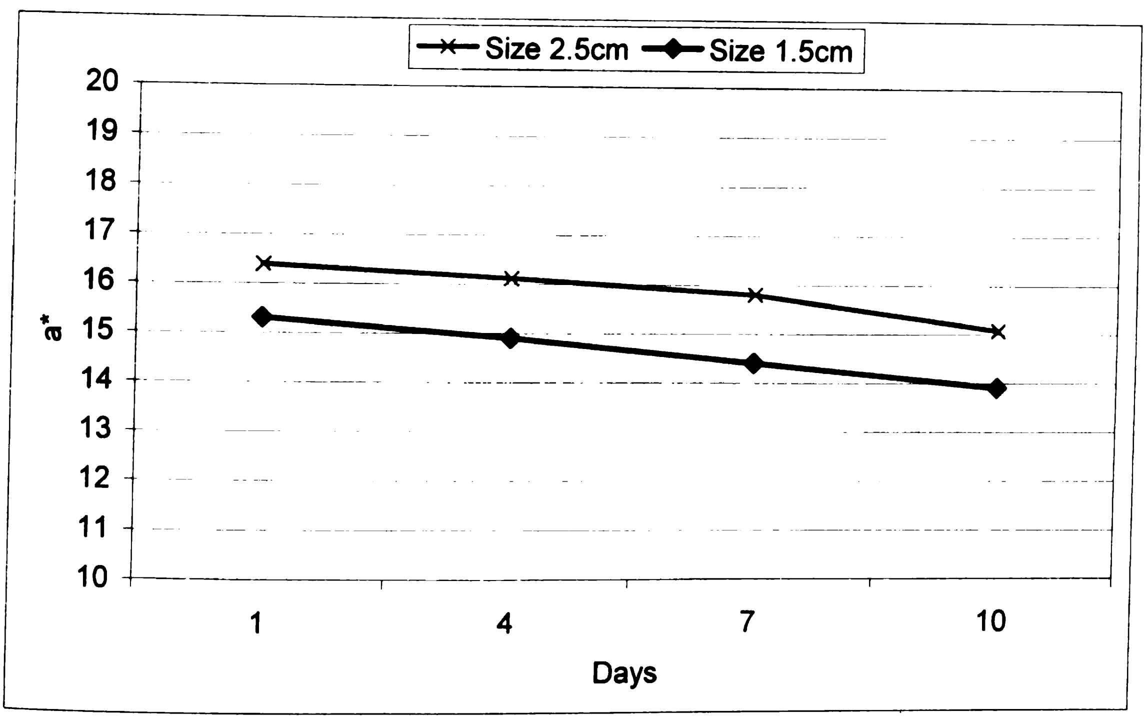


Figure 62. Effect of fruit dice size on a* values of fresh-cut cantaloupe (Container B); 500 mile trip

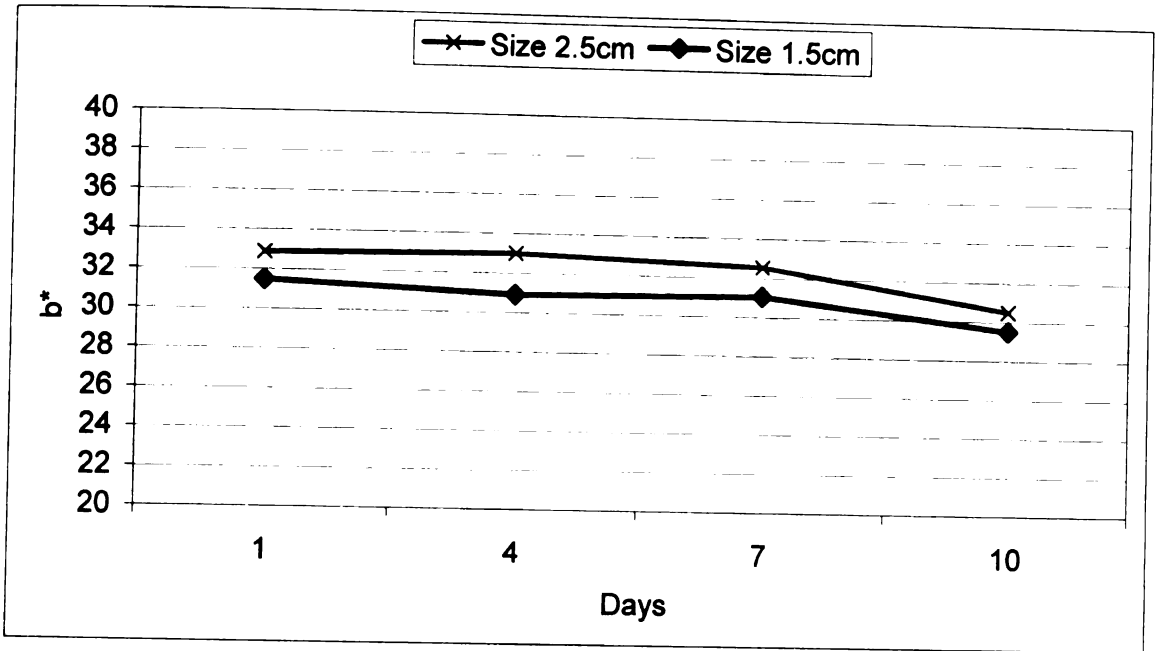


Figure 63. Effect of fruit dice size on b* values of fresh-cut cantaloupe (Container B); 500 mile trip

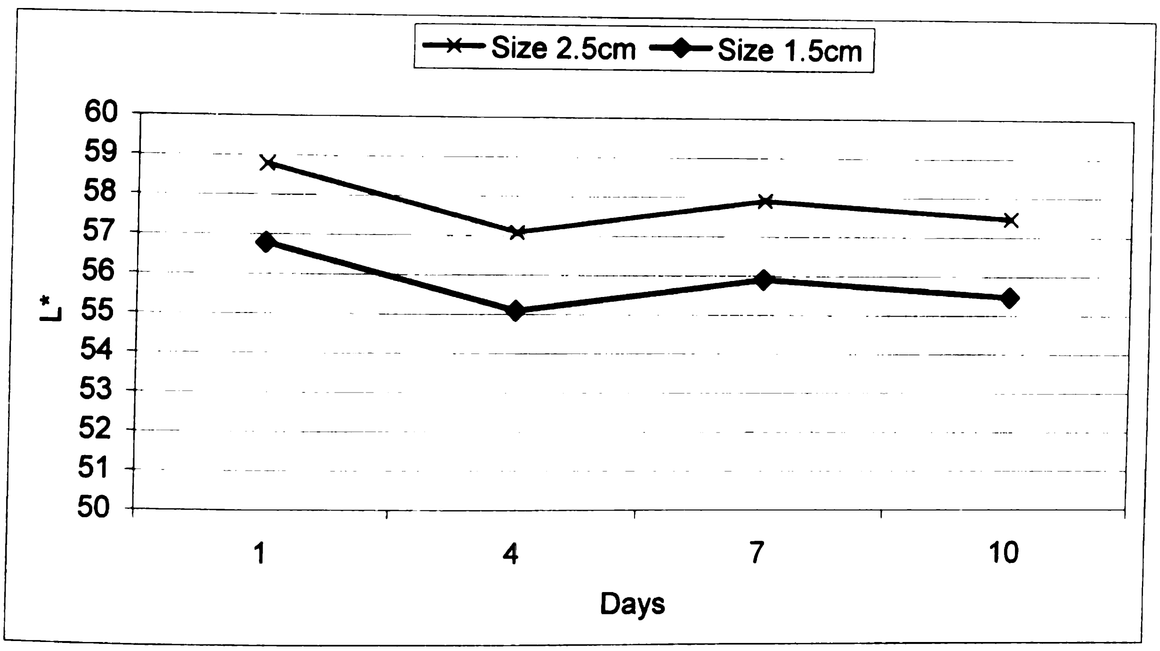


Figure 64. Effect of fruit dice size on L* values of fresh-cut cantaloupe (Container C); 500 mile trip

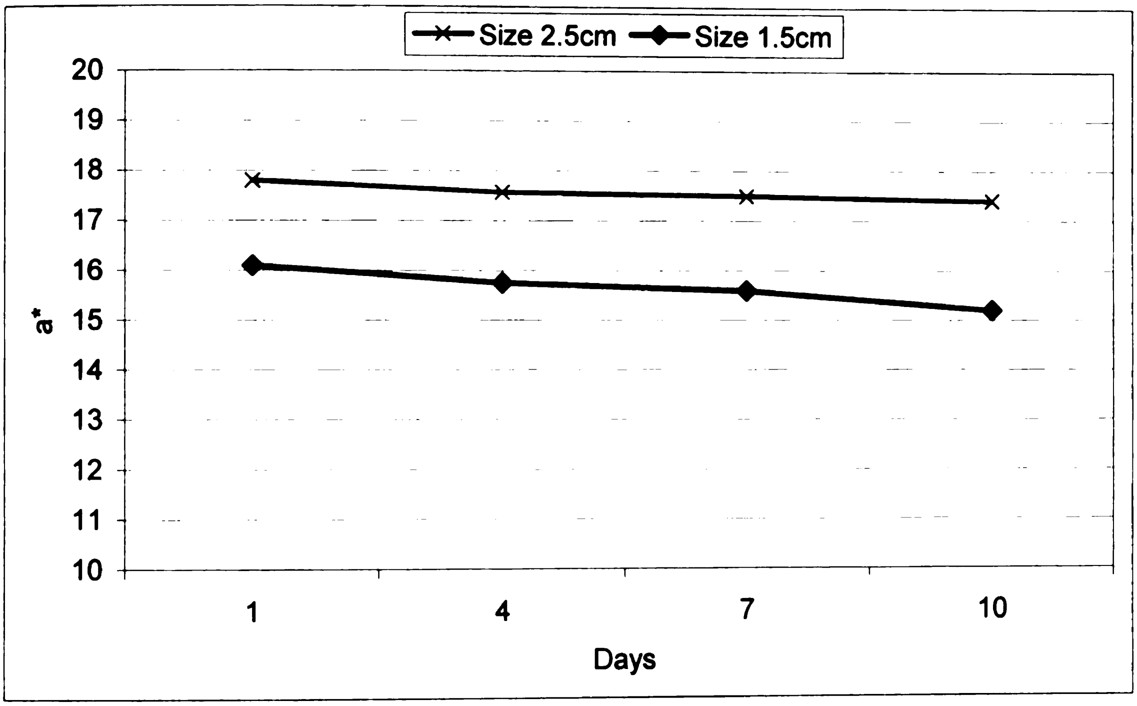


Figure 65. Effect of fruit dice size on a* values of fresh-cut cantaloupe (Container c); 500 mile trip

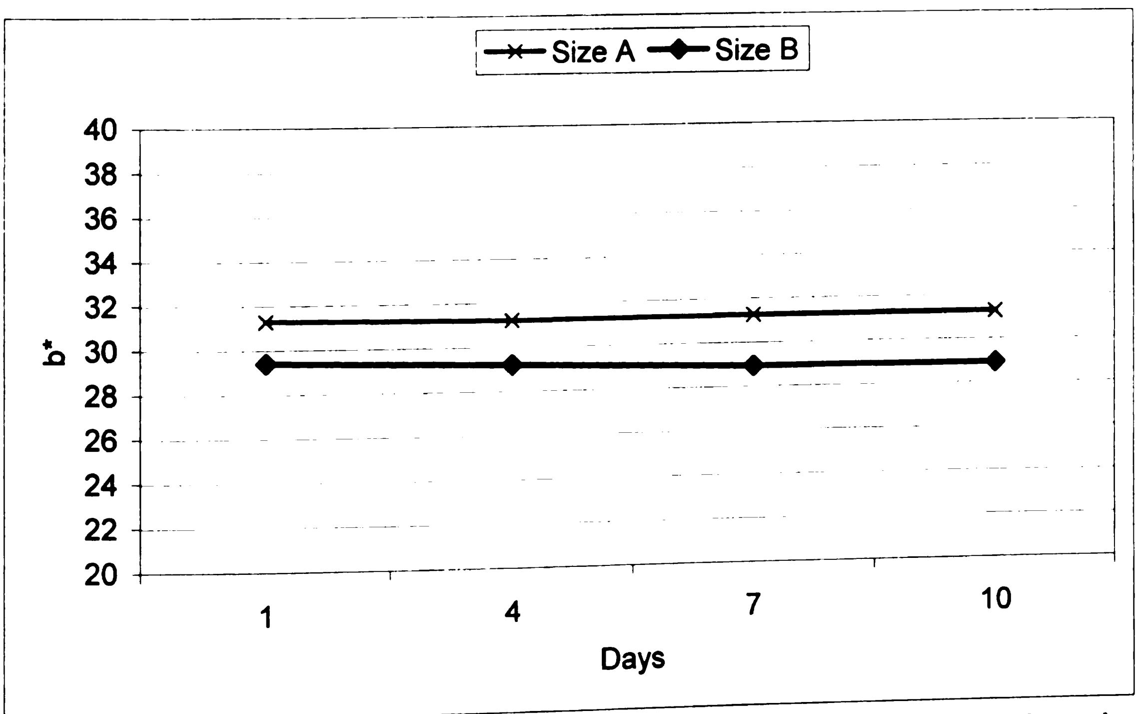


Figure 66. Effect of fruit dice size on b* values of fresh-cut cantaloupe (Container C); 500 mile trip

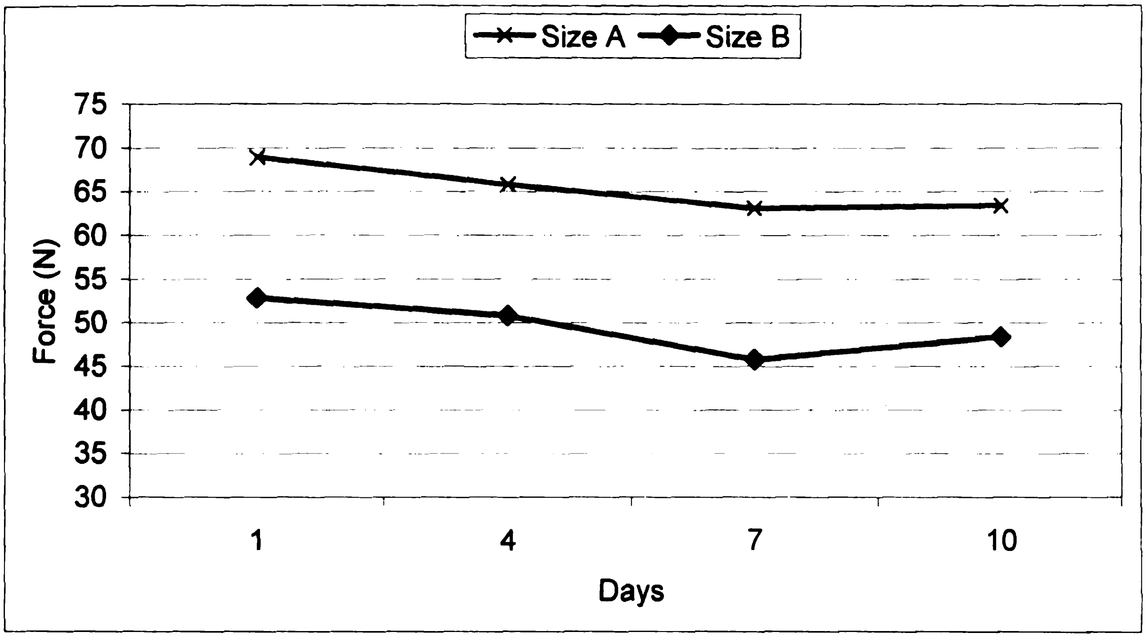


Figure 67. Effect of fruit dice size on firmness values of fresh-cut cantaloupe (Container A); 500 mile trip

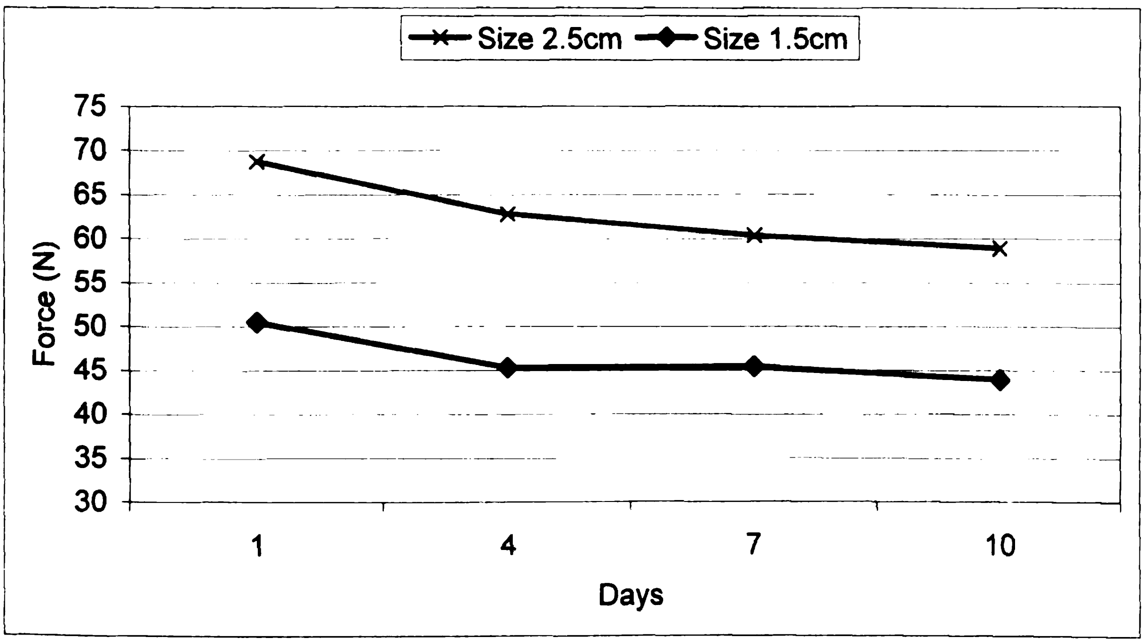


Figure 68. Effect of fruit dice size on firmness values of fresh-cut cantaloupe (Container B); 500 mile trip

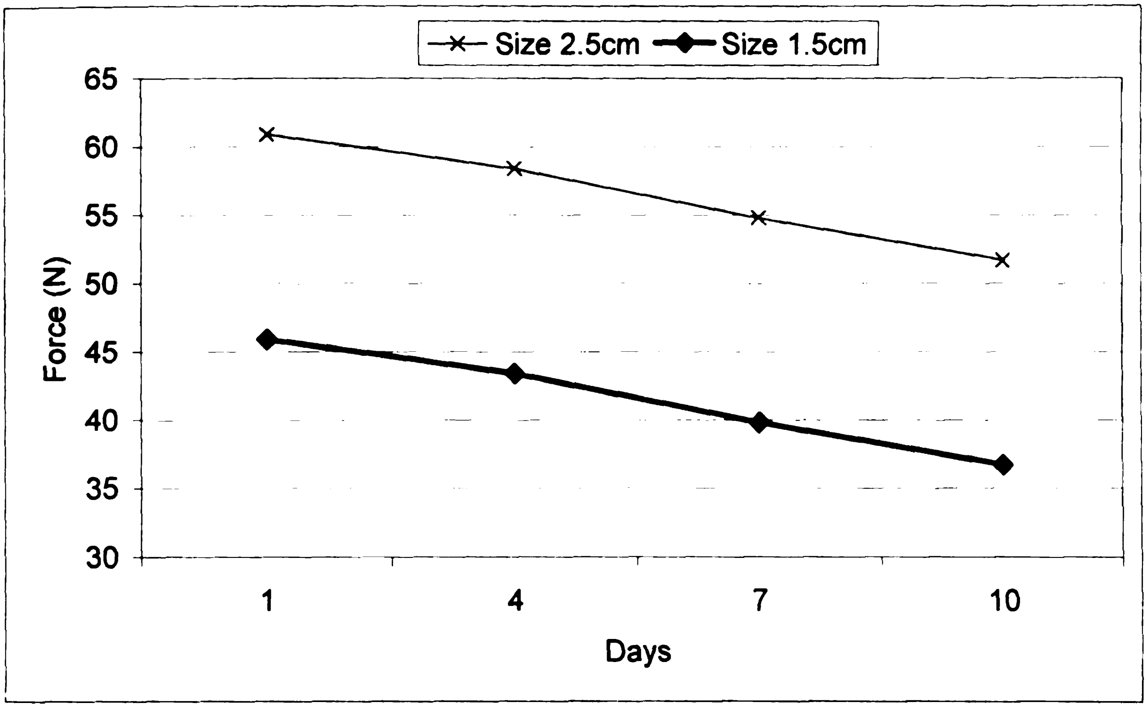


Figure 69. Effect of fruit dice size on firmness values of fresh-cut cantaloupe (Container C) 500 mile trip

4.2.4 Correlation of E-Nose and Sensory Results

Multivariate statistical techniques were used to analyze olfactory response data from E-Nose. The degree of discrimination between fresh-cut cantaloupe were studied using principle component analysis (PCA). The correlation between E-Nose and sensory results were determined using partial least square technique.

Principal component analysis was used to ascertain the similarity or dissimilarity between fresh-cut cantaloupes, as an effect of different treatments and to understand the relationship between E-Nose sensor responses. Principal component analysis involves recognizing patterns of association in multivariate data sets. When PCA is applied to a data set, the E-Nose sensor responses are mathematically converted to a new set of variables called components. Each component is expressed as linear combination of the original E-Nose sensor response. The principal component (PC1) explains the maximum amount of variation possible in one direction for given data set. Thus, PC1 contains the maximum amount of information. The second principle component (PC2) is orthogonal to PC1 and explains the maximum amount remaining variation (Alpha MOS Fox 3000 Manual). The degree of discrimination indicated how well the sensor responses are able to distinguish between the different treatments of fresh-cut cantaloupe, based on their olfactory profile. A high degree of discrimination would imply that the E-Nose is capable and efficient in discriminating the fresh-cut cantaloupe subjected to different treatments (storage days and transportation distance). Such a procedure can be used to determine aroma volatile difference in fresh-cut cantaloupe (FCC) prepared from whole fruits of different maturity and ripeness (Beaulieu et al, 2004 and Oliu and Fortuny, 2007).

The partial least squares (PLS) method was used to correlate the E-Nose sensor responses of the different FCC procured from various commercial vendors and FCC subjected to different experimental treatments, to the sensory analysis results. PLS is based on a linear regression technique, which is used to extract the quantitative information. The data collected from E-Nose sensors were used to build a model than can predict the sensory panel aroma score for a fresh-cut cantaloupe product. Quantitative measurements (sensory panel score) are contained in matrix Y, where as Y' is the predictive values and X is the matrix built with E-Nose detector measurements. The PLS generates a 'matrix that minimizes the distance between Y and Y' giving Y'=XB. The 'B' matrix is used to predict quantitative information (sensory aroma score) for a fresh-cut cantaloupe sample. The measurement matrix is multiplied by B to obtain the prediction (Alpha MOS Fox 3000 Manual).

The primary aim was to ascertain if there was a difference in the olfactory responses from E-Nose sensors for fresh-cut cantaloupe samples obtained from six different vendors and effects of experimental treatment on fresh-cut cantaloupe. Principal component analysis was performed on the olfactory response of the E-Nose sensors, to understand its capability to differentiate between FCC samples, based on a degree of discrimination. A set of twelve sensor responses was generated for each sample. PCA reduces the factor of variability between various sensor response by a linear combination of the responses. The location of a FCC sample in two dimensional PCA plot gives an idea of their similarity or dissimilarity in between FCC samples.

4.2.4.1 E-Nose Analysis of Commercial Fresh-cut Cantaloupe

Three replicates of fresh-cut cantaloupe procured from six different commercial vendors were analyzed using E-Nose according to run conditions as shown in Table 5. E-Nose was found to be efficient in discriminating the commercial FCC samples (Figure 70). A high discrimination percentage (94%) in PCA profiles as seen Figure 70 indicates that E-Nose was successful in distinguishing between the constituent volatile components present in various FCC samples. This could be as result of different ripeness levels, harvest maturity or post cutting treatments while preparing the fresh-cut cantaloupe (Oms and Fortuny, 2007,Luna-Guzman and Barett, 2000, Lamikanra et al., 2003, Bealieu, 2004)

The olfactory data generated by the E-Nose for all the commercial FCC samples were correlated with the sensory panel results using partial least squares (PLS) linear regression model. The correlation between the expected (consumer panel response) and predicted values (E-Nose sensor response) are illustrated in Figure 71, for the commercial FCC sample olfactory response. It is evident from Figure 71 that a good correlation percentage (88%) exists between the predicted and expected values. If an unknown commercial FCC sample was analyzed using E-Nose, a predicted value can be obtained for it based on its sensor response. Based on the linear regression correlation model, an expected sensory score for aroma can be estimated, which could be a reliable indication of an actual sensory score based on sensory response. According to the sensory panel aroma ratings Sysco and Meijer FCC samples had significantly higher aroma scores from the remaining FCC samples (Figure 16) and consumers liked the aroma of these samples. If the estimated aroma score for an unknown FCC sample according to the linear regression model is close to the expected aroma scores of Sysco and Meijer FCC samples, then it can be expected with a certain level of confidence that a consumer panel will like the aroma of this unknown FCC samples during a real time sensory evaluation. However, the robustness of such a linear regression model is dependent on the number of different FCC samples utilized in its development.

4.2.4.2 E-Nose Analysis of Fresh-cut Cantaloupe Subjected to Random Vibration Spectrum

Fresh-cut cantaloupe (FCC) was prepared to a size of 2.5cm and packaged in 'Container B'. These containers were subjected to transport vibration for 60 minutes (simulating a distance of 500 miles) and 120 minutes (simulating a distance of 1000 miles). Three replicates of each treatment were analyzed using E-Nose according to run conditions as shown in Table 5 at Day 1, 4, 7 and 10. Principal component analysis of olfactory responses of the E-Nose sensors was found to have a high discrimination index between the FCC control and FCC samples subjected to 500 mile and 1000 mile transport vibration at days 1, 4, 7 and 10 (Figures 72-75). The discrimination index steadily increased from a 76% at day 1 to 96% by day 10. This suggested that aromatic volatiles released by FCC samples subjected to transport vibration were significantly more than non-vibrated control samples. From previous studies it was indicated that aroma volatile content changes due to harvest maturity, cutting and cultivars (Beaulieu et al., 2004 and Lamikanra et al., 2003). In this study, whole fruits used were from the same cultivar and similar harvest maturity. Therefore it can be asserted with some certainty that the change in aroma content in package headspace was primarily due to vibration damage.

Similarly, PCA was performed on olfactory responses of E-Nose sensors, to compare the similarity or dissimilarity between FCC samples affected by days stored and subjected to transport vibration (Figures 76-77). There is a high percentage of discrimination (93%) between olfactory responses obtained for FCC samples subjected to a random vibration for 500 mile transport vibration at day 1, 4, 7 and 10 (Figure 76). A similar, high discrimination index (93%) was found for FCC samples subjected to a random vibration for 1000 mile trip (Figure 77). This suggests that the content of aroma volatiles in the package headspace changes as an effect of days stored. Aroma volatiles content can change due change in package atmosphere as shown in a study by Lavilla et al (1999), where a relationship of volatile production was associated to sensory quality affected by different control atmosphere treatments. Similarly, a study performed Beaulieu and Grimm where it was that the sensory aroma score was significantly different between days stored under due to changing package atmosphere conditions. However, in this study the O_2 and CO_2 concentration in 'Container B' as seen in Tables 8-11 did not surpass the threshold limit for oxygen (>3%) and carbon dioxide (>10%) (Beaudry, 2000 and Qi et al., 1999). Therefore it can be suggested that vibration damage was effective in contributing towards aroma volatile change in package headspace. A principal component analysis of the olfactory responses for both FCC samples subjected to random vibration for 500 and 1000 mile trip showed that there is high percentage discrimination (93%) between all sample treatments as an effect of day stored and duration of random vibration (Figure 78). This shows that vibration damage during transportation can affect volatile aroma content in package headspace during storage.

The olfactory data generated by the E-Nose for FCC samples subjected to random vibration for a 500 and 1000 mile trip were correlated with the sensory panel results using partial least squares (PLS) linear regression model. The correlation between the expected (trained panel response) and predicted values (E-Nose sensor response) are illustrated in Figures 79-80. It is evident from Figures 79-80 that a good correlation percentage (96%) exists between the predicted and expected values for both FCC samples subjected to random vibration for 500 and 1000 mile trip. If an unknown FCC sample which is to be delivered to a location as far as 1000 mile, the olfactory response can be generated using E-Nose sensors. The olfactory response can be analyzed to provide a predicted value based on the linear regression correlation model and an expected sensory score for aroma can be estimated. This can provide essential information about the quality of fresh-cut cantaloupe packaged in a container to be delivered to a distant location prior to shipping a pallet load of fresh-cut fruits.

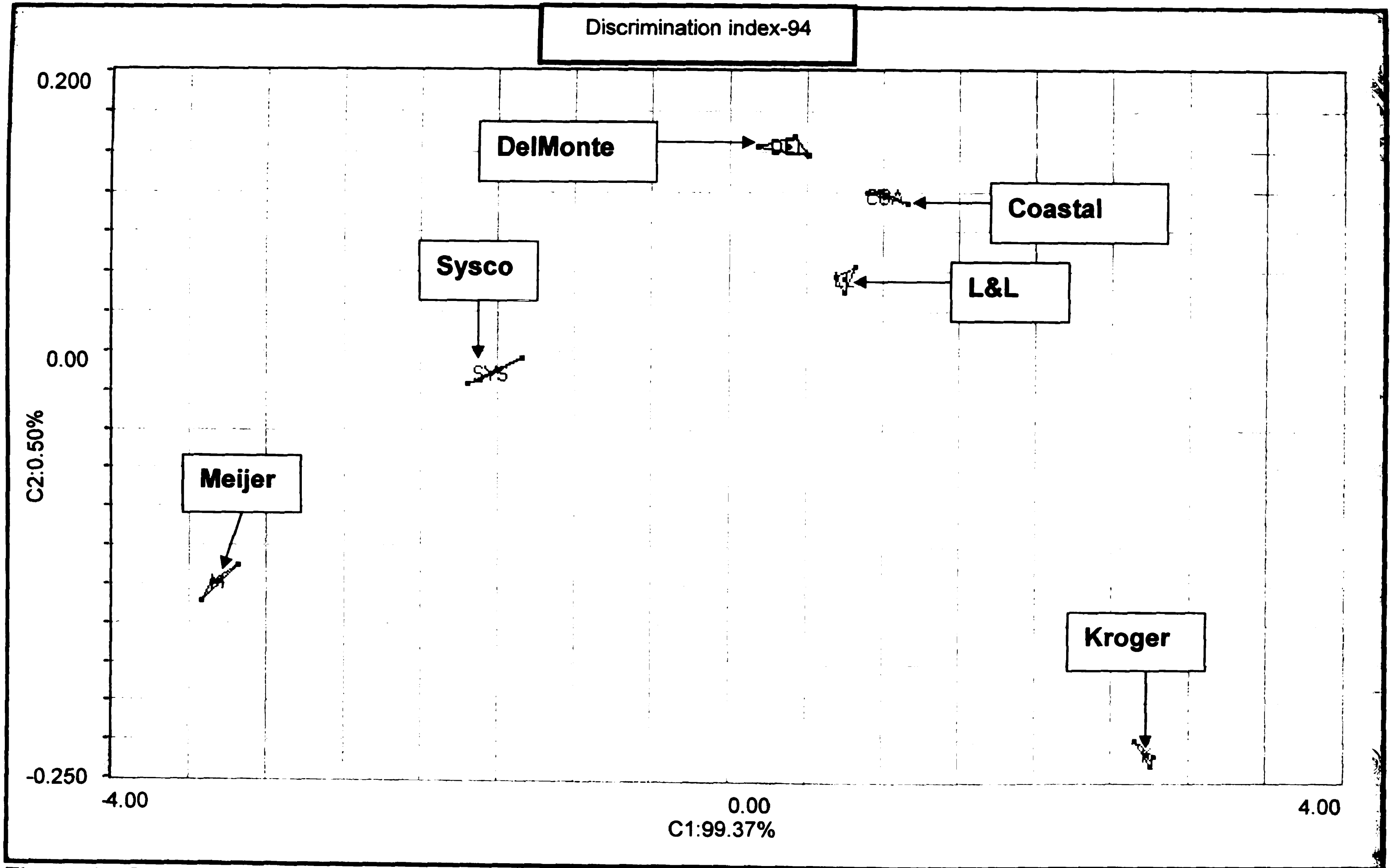


Figure 70. Principal component analysis of commercial fresh-cut cantaloupe from 6 different vendors

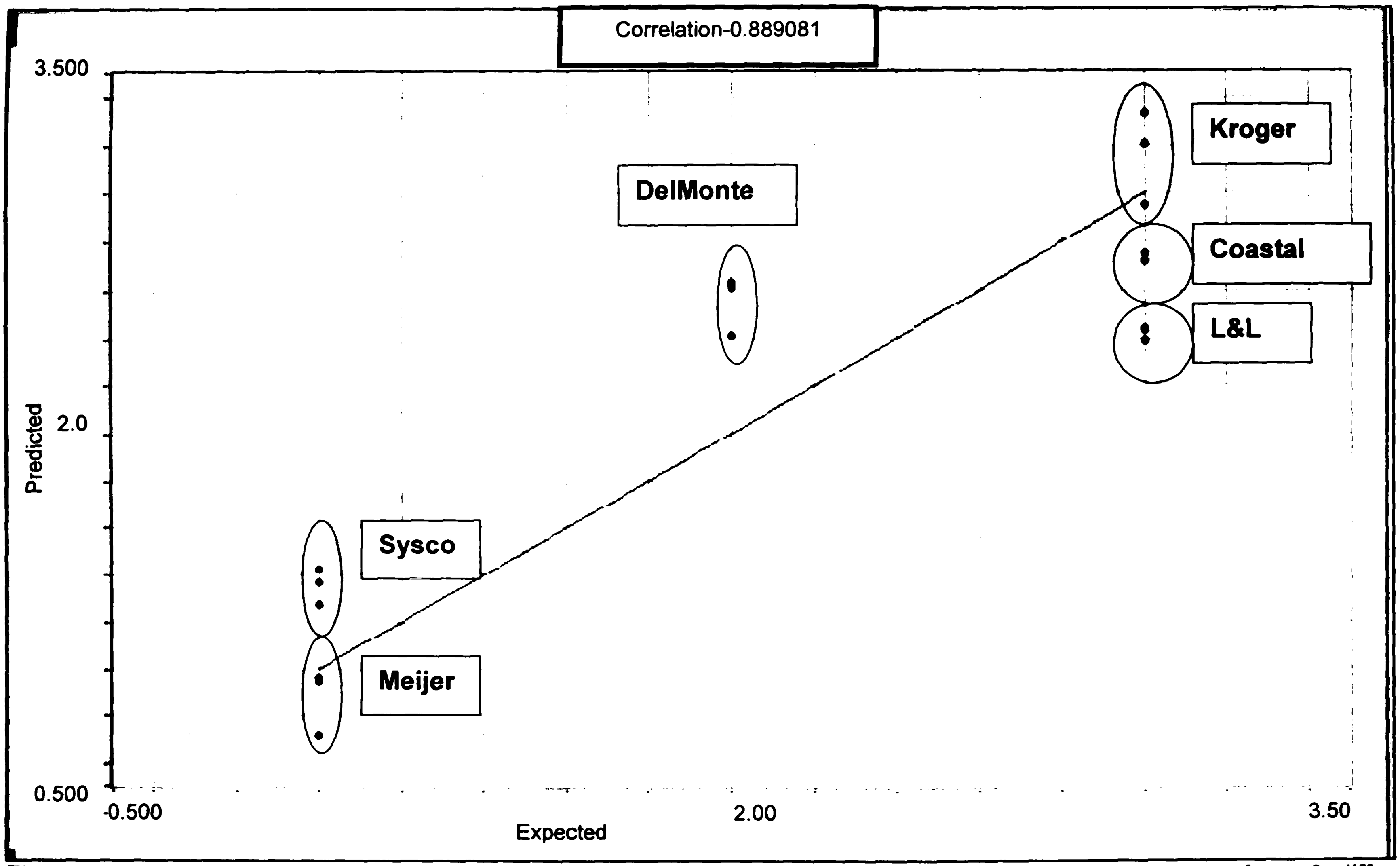


Figure 71. Correlation between expected and predicted values for commercial fresh-cut cantaloupe from 6 different vendors

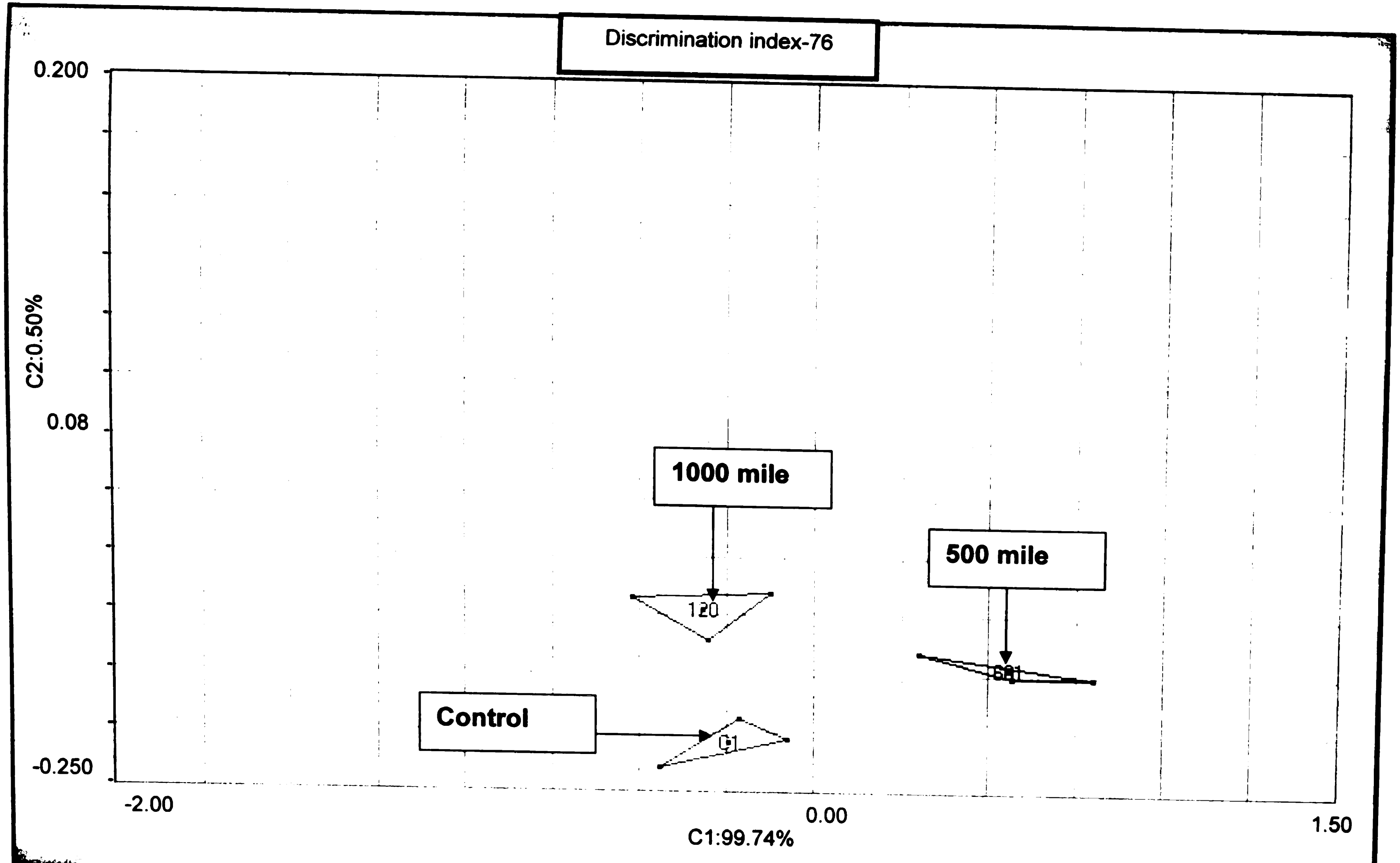


Figure 72. Principal component analysis of commercial fresh-cut cantaloupe packaged in 'Container B'; Fruit size-2.5cm Day 1

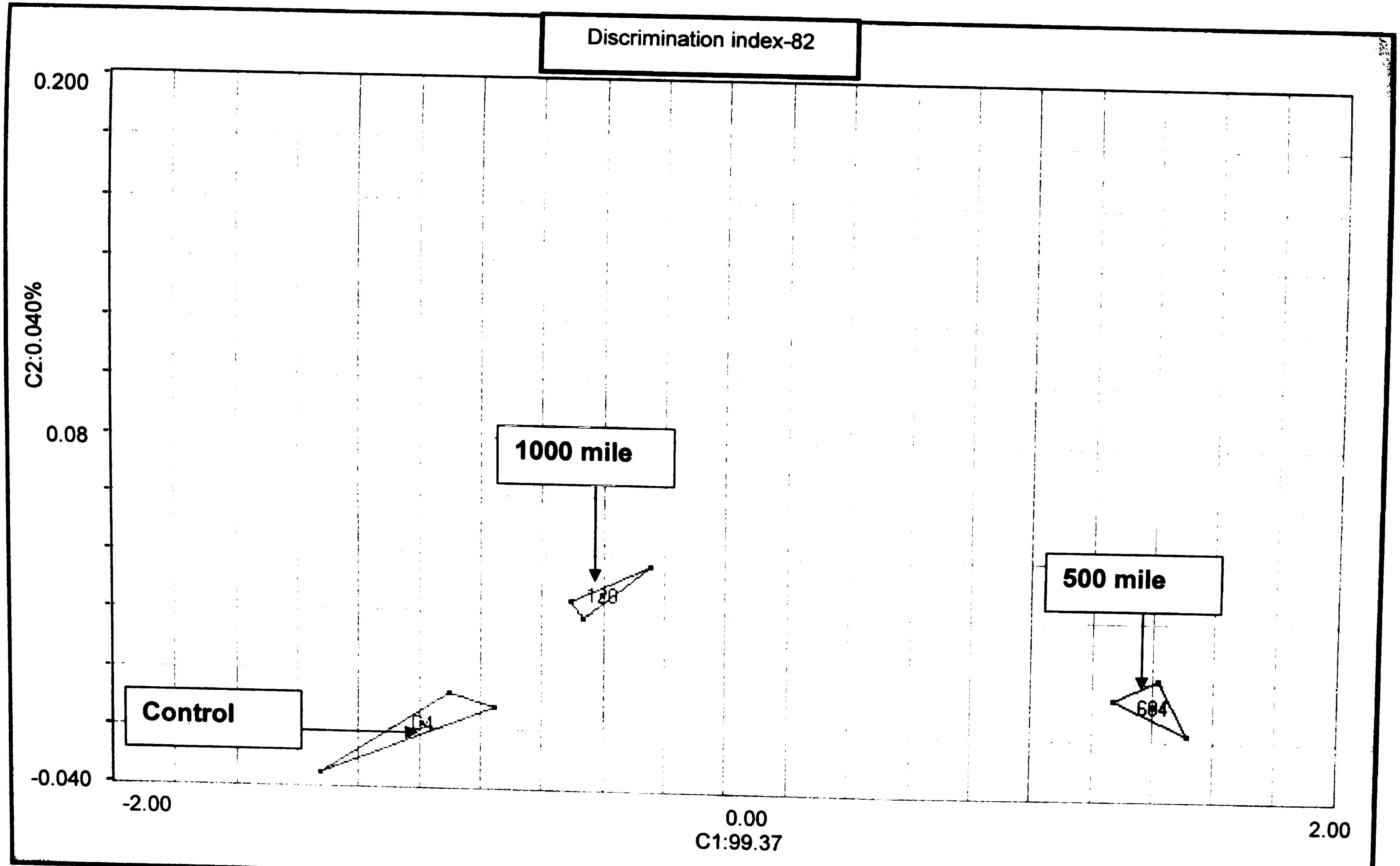


Figure 73. Principal component analysis of commercial fresh-cut cantaloupe packaged in 'Container B'; Fruit size-2.5cm Day 4

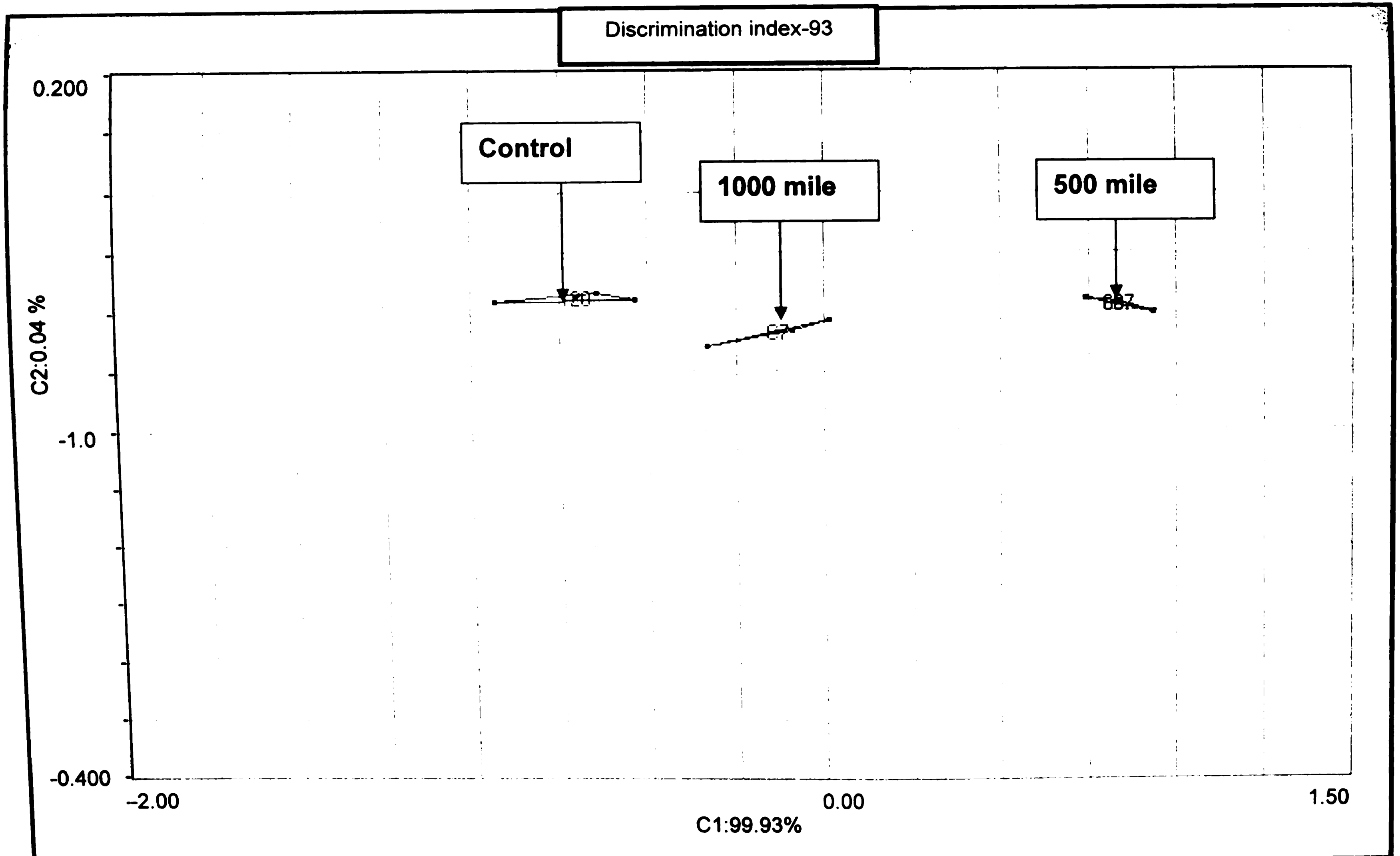


Figure 74. Principal component analysis of commercial fresh-cut cantaloupe packaged in 'Container B'; Fruit size-2.5cm Day 7

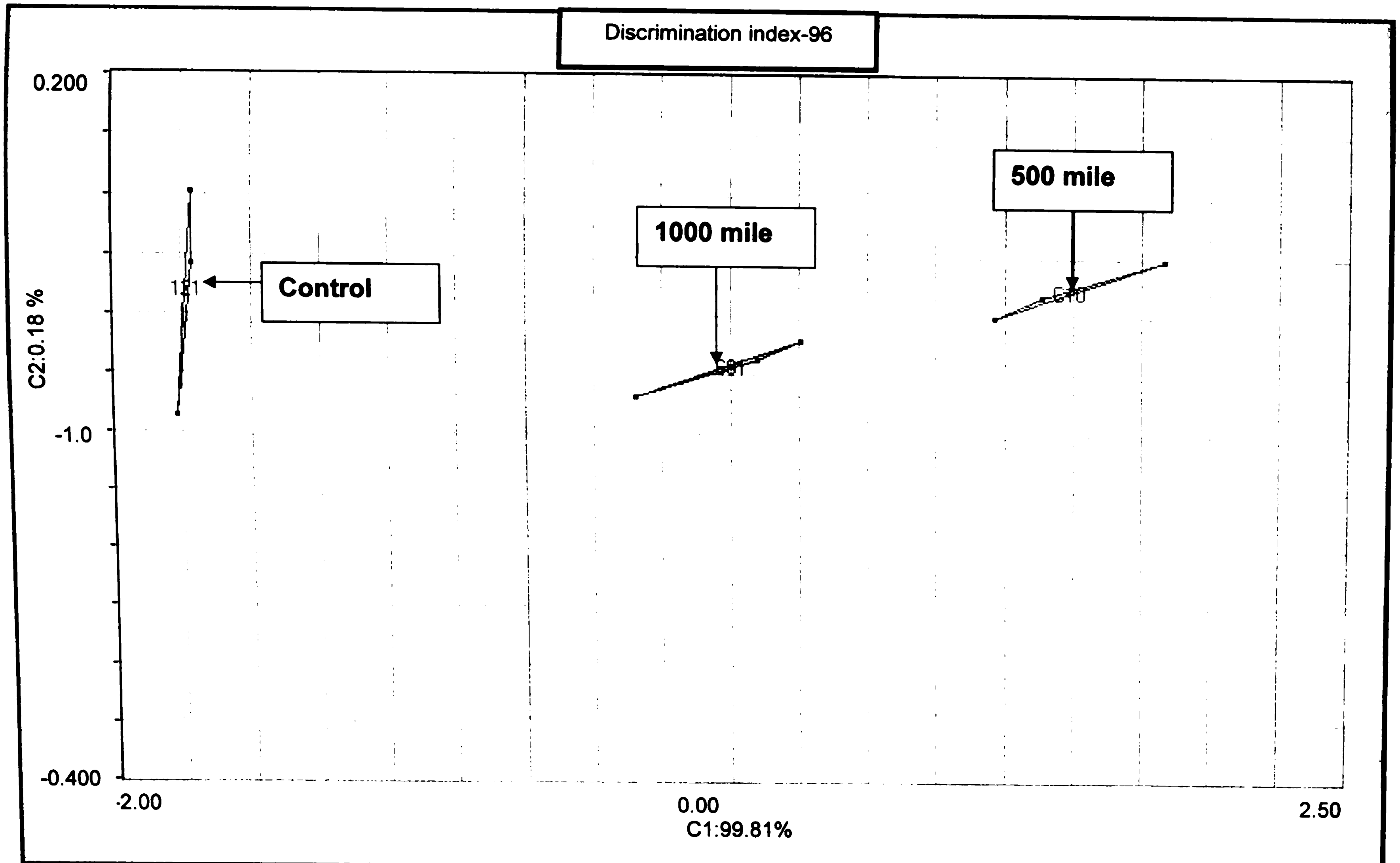


Figure 75. Principal component analysis of commercial fresh-cut cantaloupe packaged in 'Container B'; Fruit size-2.5cm Day 10

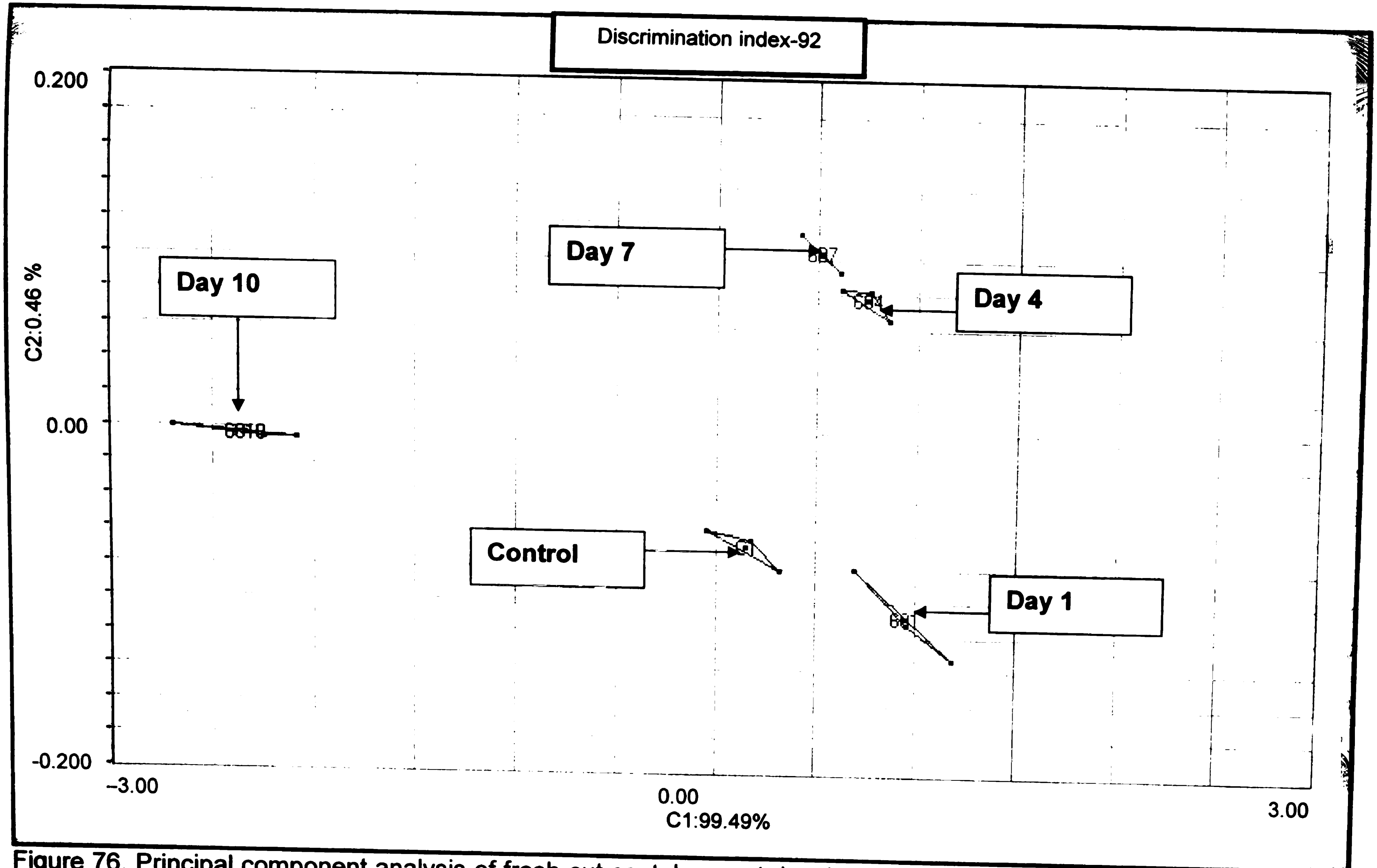


Figure 76. Principal component analysis of fresh-cut cantaloupe at day 1,4,7 and 10 day; packaged in 'Container B'; Fruit size-2.5cm; Subjected to random vibration for 60 minutes (500 mile) assurance level II

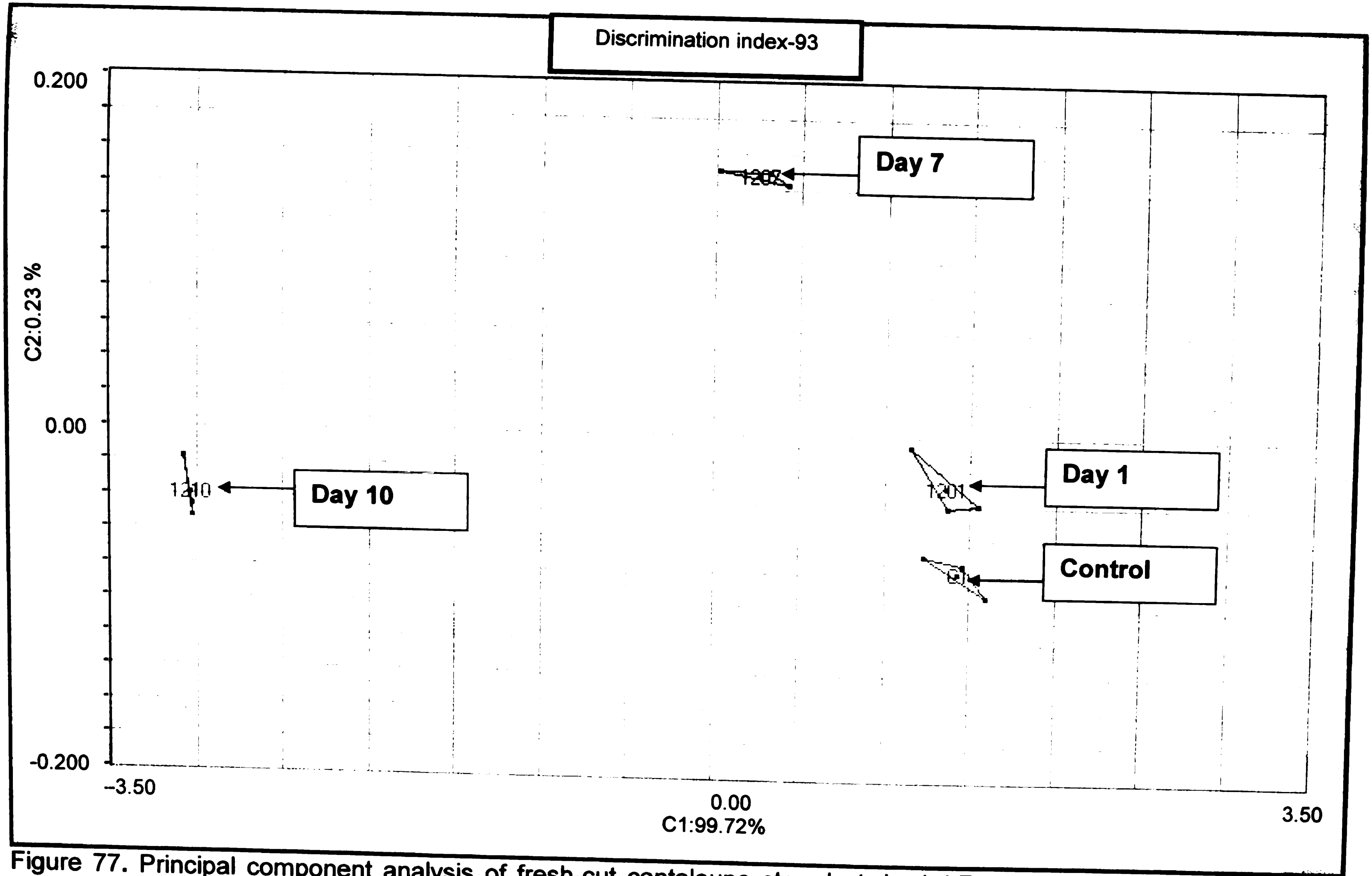


Figure 77. Principal component analysis of fresh-cut cantaloupe stored at day1,4,7 and10, packaged in 'Container B'; Fruit size-2.5cm; Subjected to random vibration for 120 minutes assurance level II

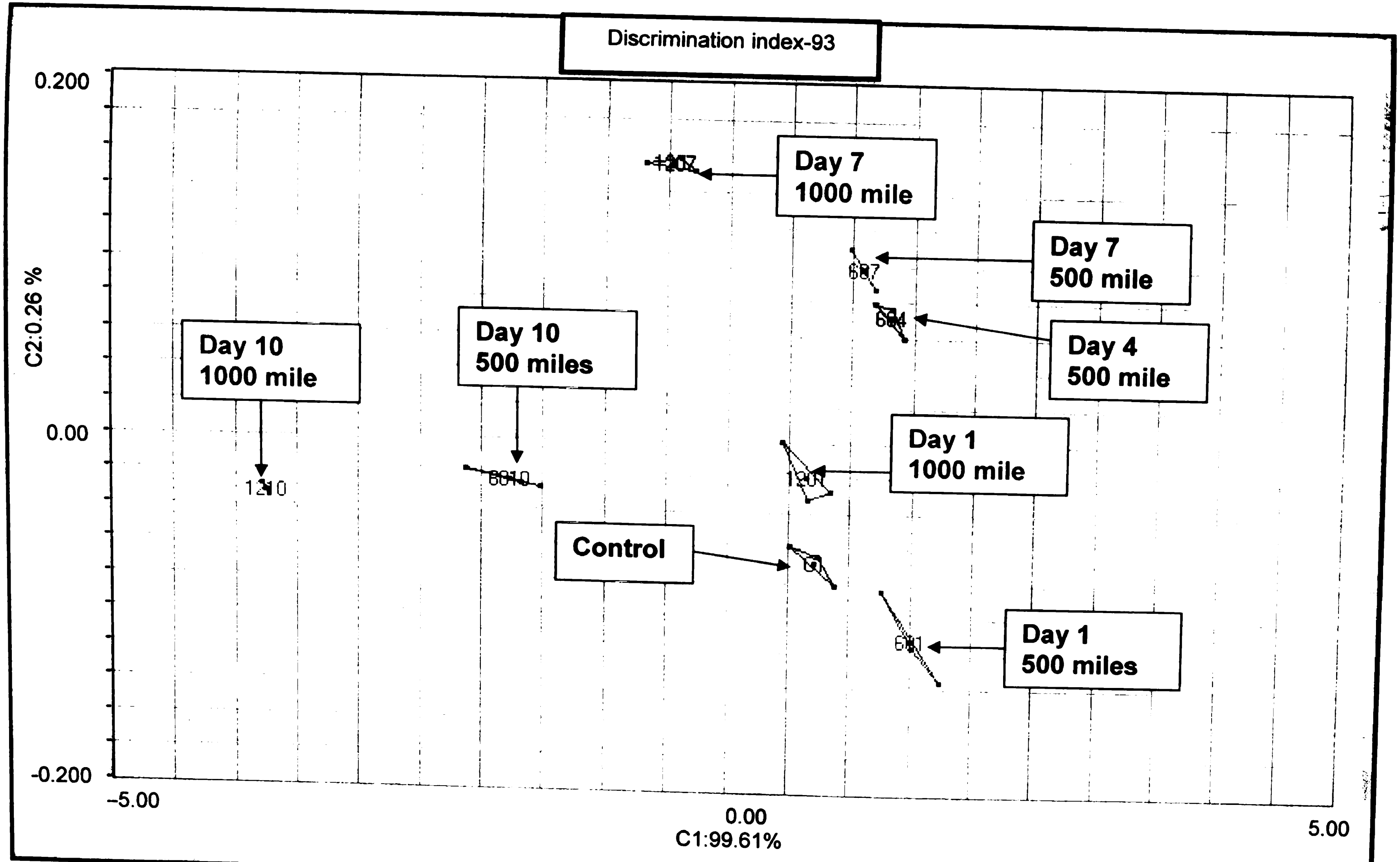


Figure 78. Principal component analysis of fresh-cut cantaloupe stored at day1,4,7 and10, packaged in ‘Container B’; Fruit size-2.5cm; Subjected to random vibration for 60 (500 mile) and 120 minutes (1000 mile) assurance level II

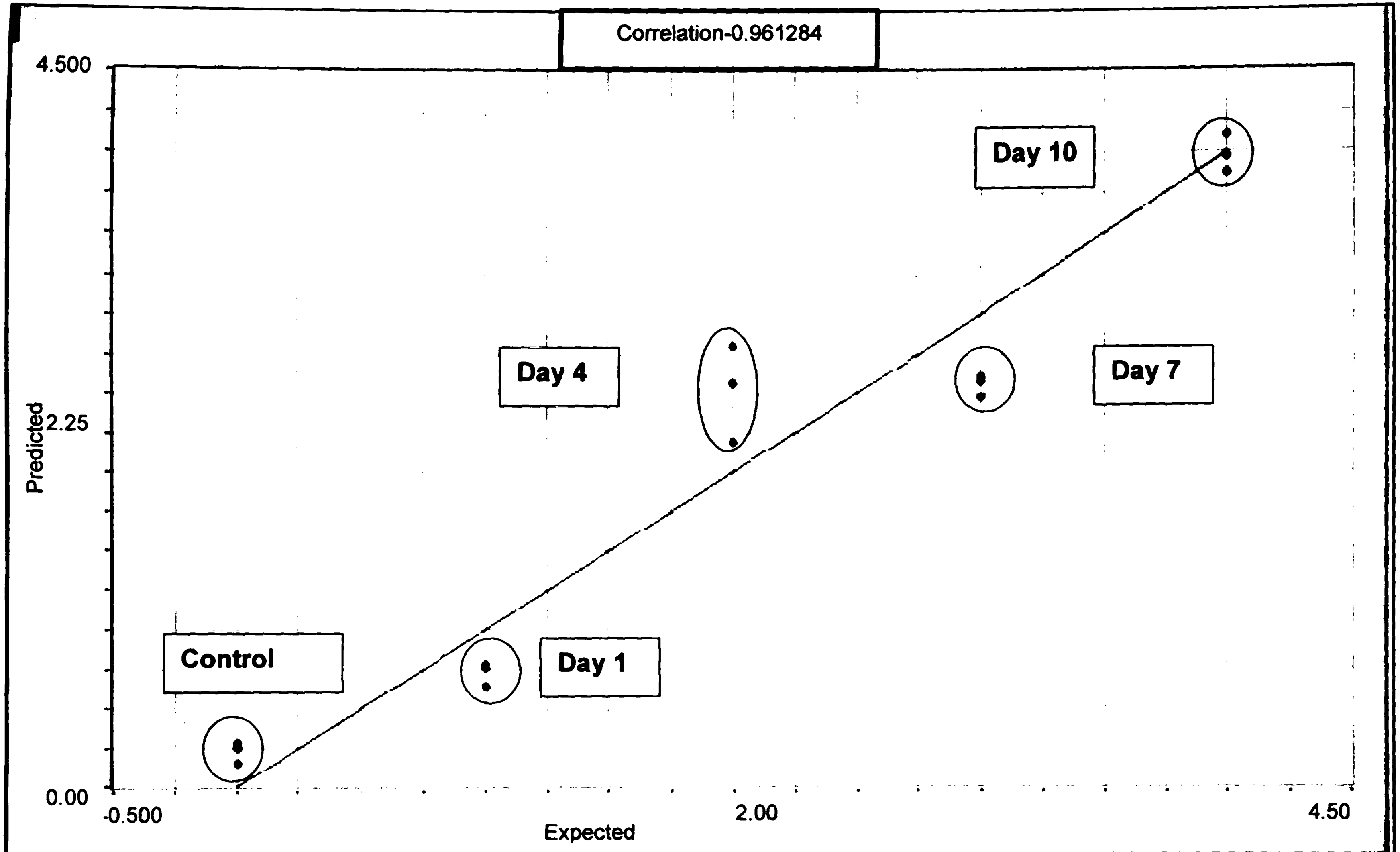


Figure 79. Correlation between expected and predicted values for fresh-cut cantaloupe at day 1,4,7 and 10 day; packaged in 'Container B'; Fruit size-2.5cm; Subjected to random vibration for 60 minutes (500 mile) assurance level II

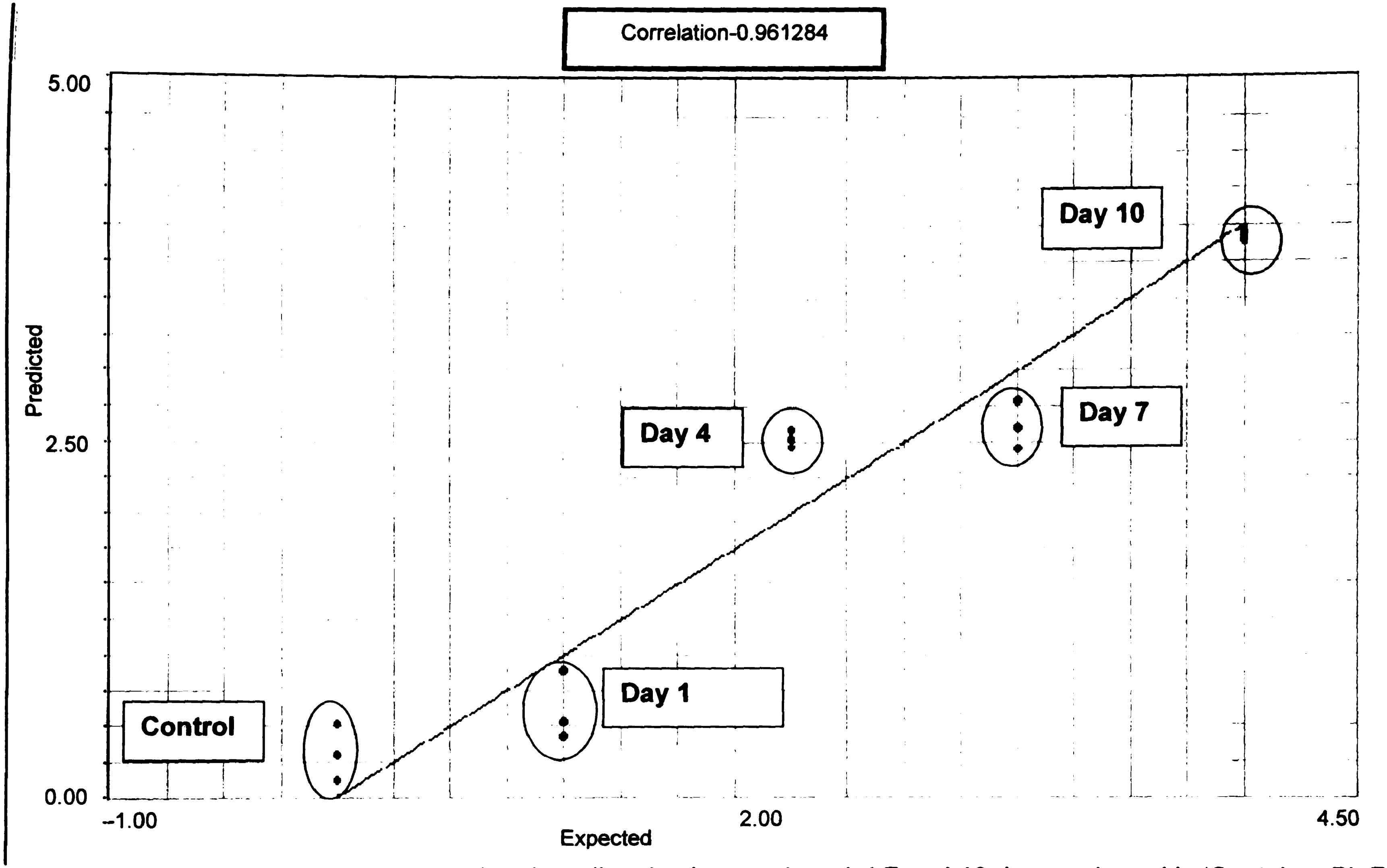


Figure 60. Correlation between expected and predicted values at days 1,4,7 and 10 day; packaged in 'Container B'; Fruit size-2.5cm; Subjected to random vibration for 120 minutes assurance level II

5. CONCLUSIONS

The results of this study have the following conclusions:

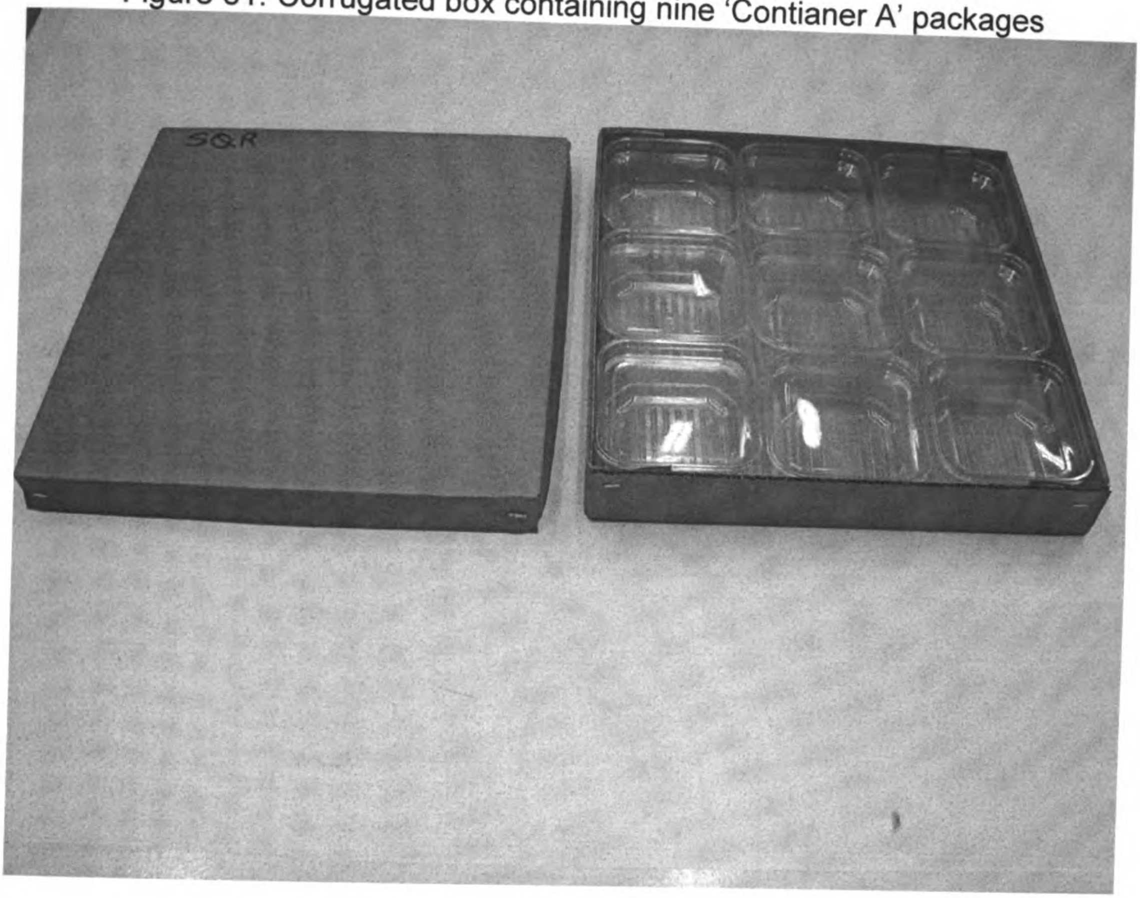
1. The change in the sensory properties of the cantaloupe can be attributed to the vibration movement observed by the fresh-cut fruit, package design and storage time.
2. Fruit dice size and shape will affect fruit quality. In general, a greater loss in the texture quality is likely of smaller sizes due to more total contact surface area.
3. Trained panelists and analytical measurements can both provide useful information, though the two may not be correlatable
4. Vibration test times (60 minutes and 120 minutes) representing shipping distances of 500 miles and 1000 miles caused high level release of aroma compounds in fresh cut fruit, that increased with storage time. Transportation in general has an effect on the quality of fresh-cut cantaloupe
5. Due to physical contact among moving fruit pieces (In-shipment) change in product quality can be affected. The size and shape of the container can impact fruit movement. The best sensory fruit quality was maintained in 'Container B'.
6. The methodology developed to assess the quality of fresh-cut cantaloupe affected by fruit dice size, container design and transportation remains to be verified for fruits with lower water content than melons. The findings of

this study may not necessarily be the same for fresh-cut fruits with lower percentage of water content, which is a potential area of research in the future. Similarly, a different fruit dice size may have a better result in a different container shape these remain to be verified following the methodology developed to assess quality of fresh-cut fruits in this research study.

APPENDICES

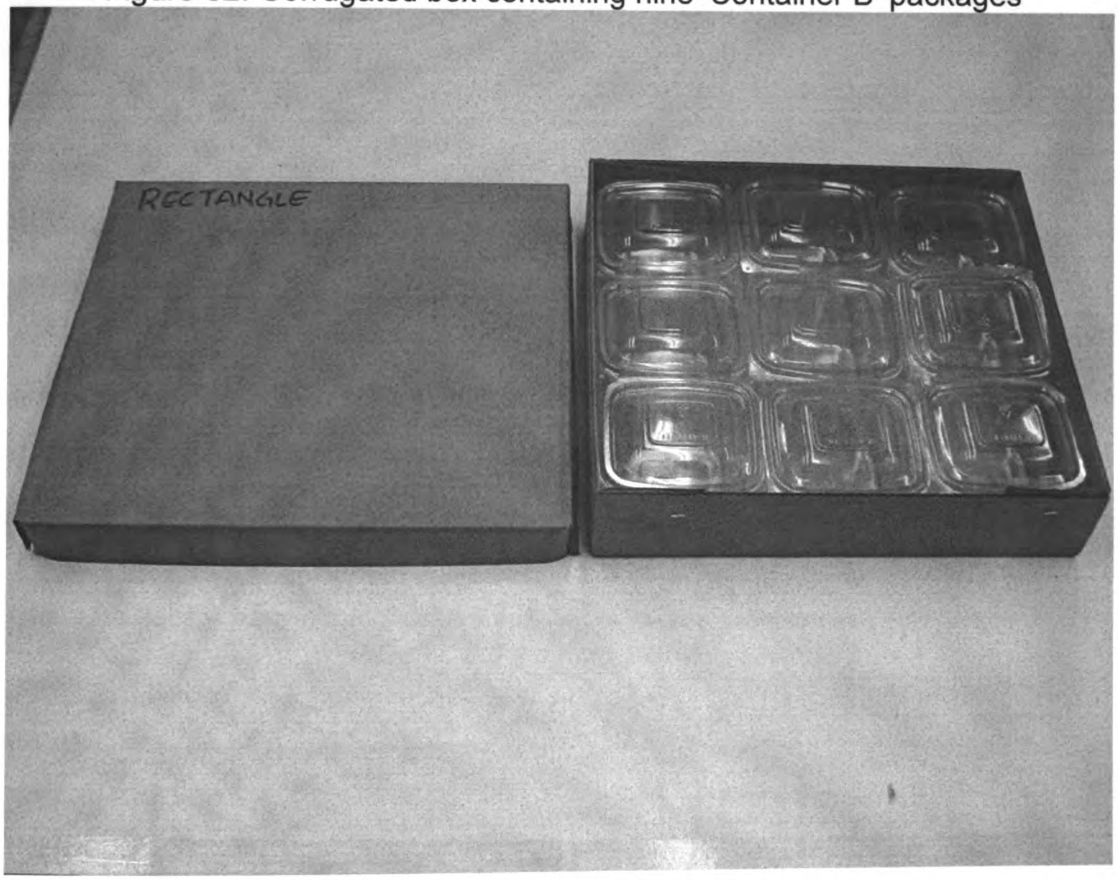
APPENDIX A

Figure 81. Corrugated box containing nine ‘Contianer A’ packages



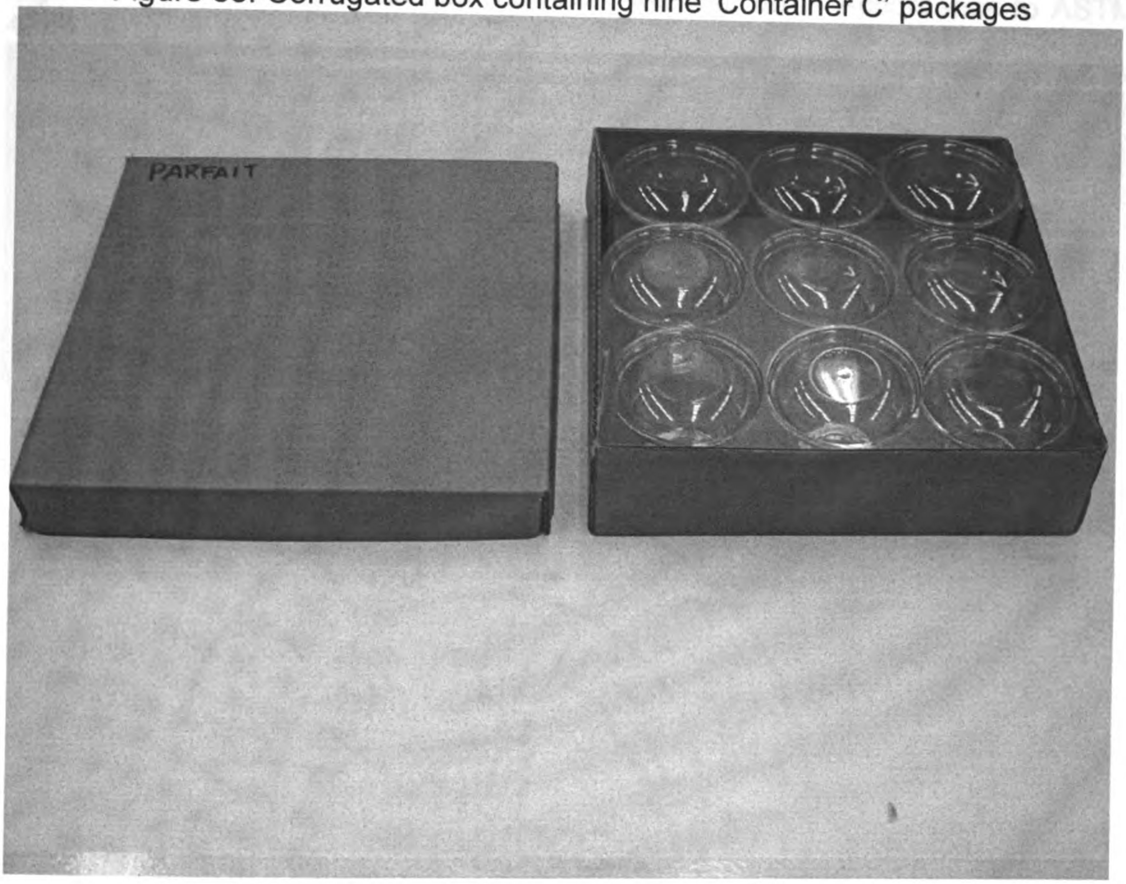
APPENDIX B

Figure 82. Corrugated box containing nine 'Container B' packages



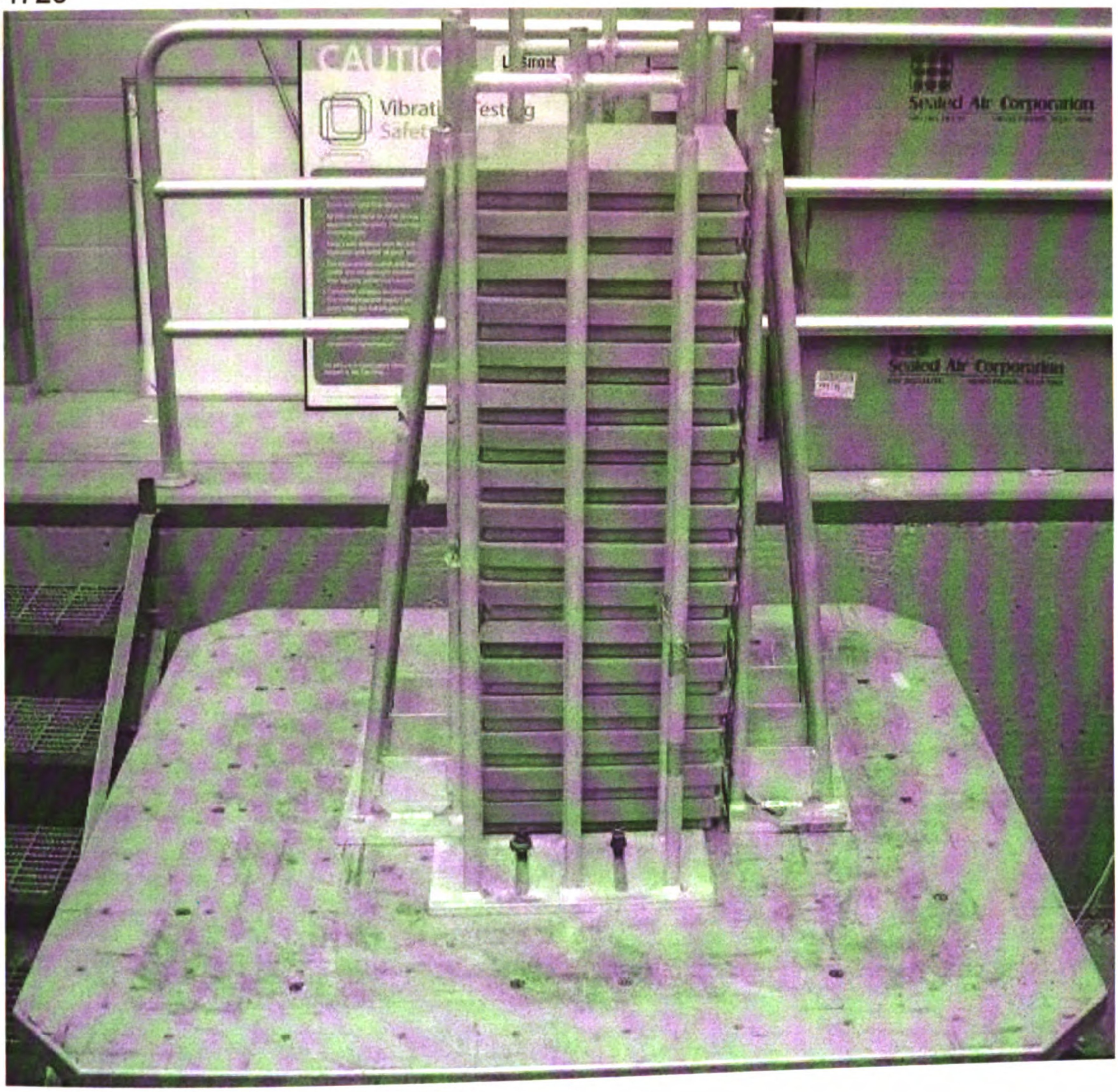
APPENDIX C

Figure 83. Corrugated box containing nine 'Container C' packages



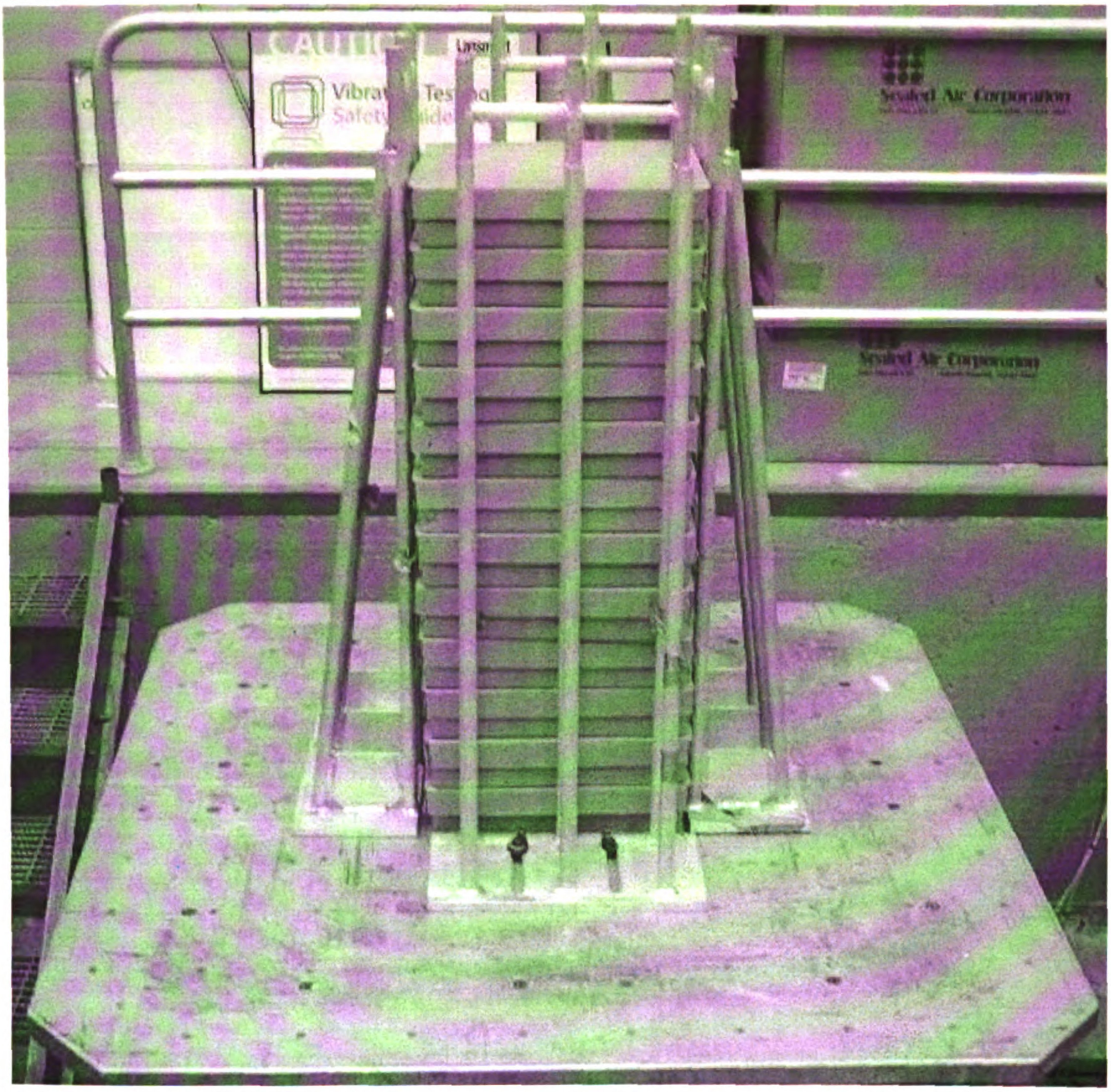
APPENDIX D

Figure 84. Container A Random Vibration Test Set up in Accordance to ASTM 4728



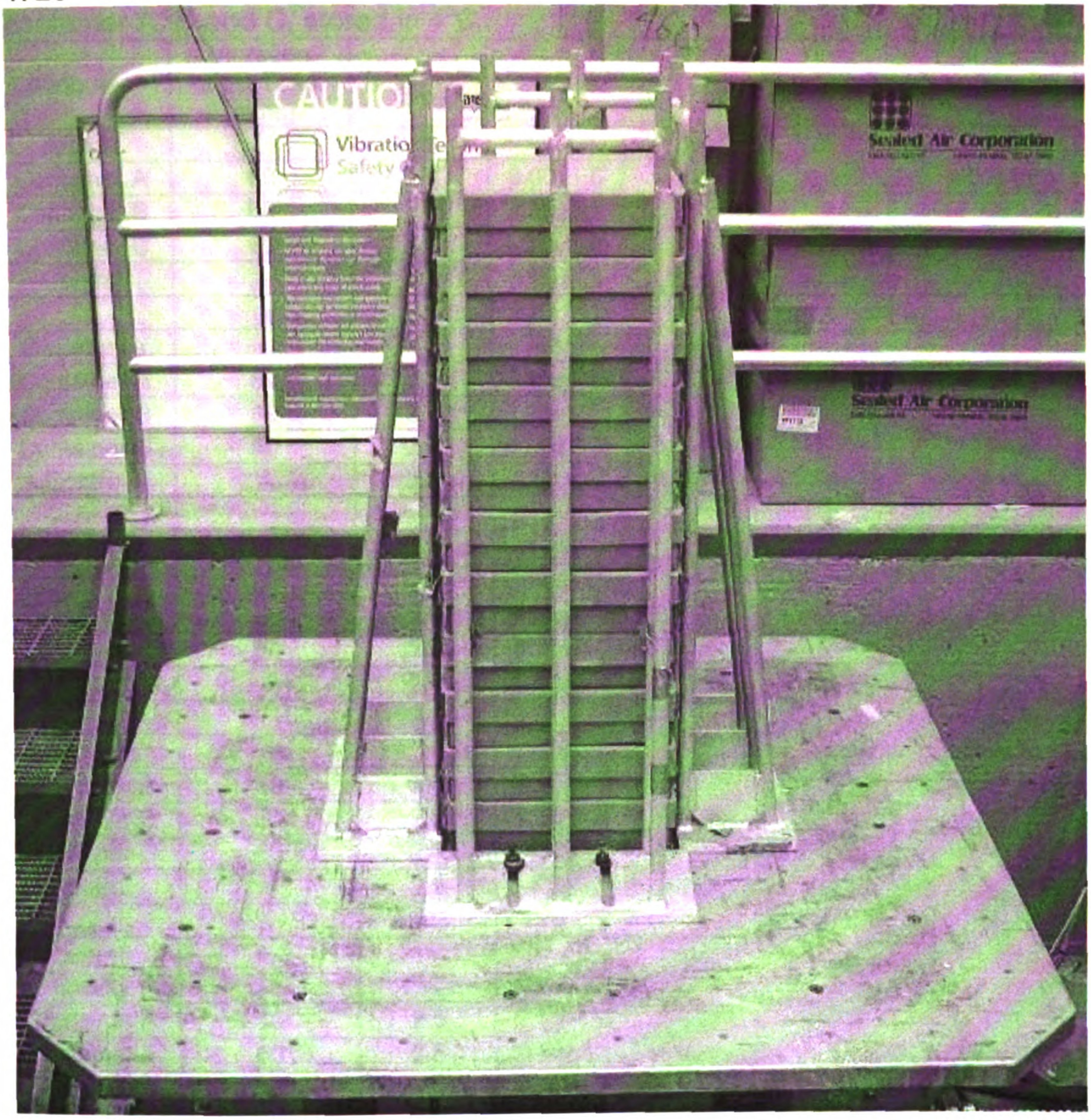
APPENDIX E

Figure 85. Container B Random Vibration Test Set up in Accordance to ASTM 4728



APPENDIX F

Figure 86. Container C Random Vibration Test Set up in Accordance to ASTM 4728



APPENDIX G

Table 13.Trained panel response (n=6) on effect of container design and transport vibration on sensory characteristics of fresh-cut cantaloupe packaged in container A, B and C, stored in 4°C

Attributes	Vibration Test Time (mins)	Dice Size (cm)	Days			
Aroma			1	4	7	10
Container A	60	2.5	9.00±1.5	9.75±1.7	10.50±1.3	9.50±1.65
Container B	60	2.5	8.50±1.8	9.75±1.7	9.25±1.3	10.75±1.25
Container C	60	2.5	9.25±1.75	10.25±1.25	10.75±1.5	11.00±1.75
Control	--	2.5	5.50±1.5	6.50±1.25	7.00±1.5	8.00±1.5
Sweetness			1	4	7	10
Container A	60	2.5	7.10±1.25	7.25±1.75	8.50±1.5	9.75±1.25
Container B	60	2.5	8.00±1.25	8.75±1.75	9.50±1.5	10.50±1.5
Container C	60	2.5	8.00±1.75	8.50±1.5	9.75±1.	10.00±1.
Control	--	2.5	6.50±1.5	6.80±0.5	7.25±1.25	8.00±1.75
Color			1	4	7	10
Container A	60	2.5	6.25±1.25	7.50±1.5	7.25±1.25	7.75±1.5
Container B	60	2.5	6.50±1.25	6.75±1.5	7.25±1.25	8.00±1.0
Container C	60	2.5	6.75±1.5	7.00±1.0	7.75±1.25	8.75±1.5
Control	--	2.5	5.50±1.5	5.75±1.25	6.50±1.25	7.75±1.5
Firmness			1	4	7	10
Container A	60	2.5	9.00±1.0	8.75±1.5	8.50±1.25	8.50±1.5
Container B	60	2.5	8.50±1.5	8.00±1.0	8.25±1.25	8.00±1.0
Container C	60	2.5	9.00±1.0	7.75±1.25	7.25±1.5	7.25±1.5
Control	--	2.5	8.75±1.25	8.75±1.5	8.50±1.75	8.00±1.0
Overall Quality			1	4	7	10
Container A	60	2.5	7.50±1.5	7.75±1.75	7.75±1.5	8.00±1.25
Container B	60	2.5	9.00±1.5	9.50±1.25	9.25±1.75	9.00±1.25
Container C	60	2.5	8.75±1.5	8.00±1.25	8.25±1.5	9.00±1.75
Control	--	2.5	7.25±1.5	7.00±1.25	7.75±1.5	8.25±1.75
Aroma			1	4	7	10
Container A	60	1.5	8.50±1.25	9.00±1.75	8.75±1.5	10.00±1.25
Container B	60	1.5	8.75±1.5	9.75±1.5	9.00±1.25	11.00±1.75
Container C	60	1.5	9.50±1.25	10.50±1.5	10.75±1.25	10.50±1.5
Control	--	1.5	6.00±1.25	5.50±1.75	7.50±1.5	8.50±1.25
Sweetness			1	4	7	10
Container A	60	1.5	7.00±1.5	7.50±1.25	8.00±1.0	8.75±1.5
Container B	60	1.5	7.50±1.75	8.00±1.25	8.50±1.5	9.50±1.25
Container C	60	1.5	7.50±1.5	8.00±1.25	9.00±1.75	9.50±1.25

Table 13 continued

Control	--	1.5	6.00±1.75	6.50±1.25	7.50±1.5	7.75±1.25
Color			1	4	7	10
Container A	60	1.5	6.50±1.25	7.00±1.5	7.25±1.25	7.50±1.5
Container B	60	1.5	7.00±1.25	7.25±1.25	8.00±1.5	8.50±1.75
Container C	60	1.5	7.50±1.25	7.25±1.25	7.50±0.75	8.75±0.75
Control	--	1.5	6.00±1.25	5.75±1.5	6.75±0.75	7.00±0.25
Firmness			1	4	7	10
Container A	60	1.5	8.00±1.0	7.00±1.0	6.75±0.75	6.50±0.75
Container B	60	1.5	7.25±0.75	7.00±1.25	6.50±0.5	6.00±1.0
Container C	60	1.5	7.00±0.5	6.50±1.5	6.00±1.0	5.75±1.0
Control	--	1.5	8.00±0.5	7.50±1.0	6.50±1.0	6.50±1.25
Overall Quality			1	4	7	10
Container A	60	1.5	7.00±0.75	7.25±0.5	7.25±1.0	7.50±1.25
Container B	60	1.5	8.50±1.5	9.00±1.75	8.75±1.5	8.50±1.5
Container C	60	1.5	8.25±0.25	7.50±1.5	7.75±1.5	8.50±1.25
Control	--	1.5	6.75±1.75	6.50±1.75	7.25±1.25	7.75±1.5
Aroma			1	4	7	10
Container A	120	2.5	9±1.25	9.75±1.	10.5±1.	10±1.0
Container B	120	2.5	8.5±0.5	9.75±1.25	11±1.0	11.25±1.
Container C	120	2.5	8±1.0	8.75±0.5	9.5±1.25	10.5±1.0
Control	--	2.5	6±0.5	6.5±1.0	7.75±0.5	8±1.25
Sweetness			1	4	7	10
Container A	120	2.5	7.25±1.	7.25±1.	8±1.	8.5±1.
Container B	120	2.5	9±1.	9.25±1.	10.5±1.	10.75±1.
Container C	120	2.5	8.5±1.	9.25±1.	10.5±1.	11.25±1.
Control	--	2.5	7±1.	6.5±1.	7.25±1.	8±1.
Color			1	4	7	10
Container A	120	2.5	7±0.5	7.5±0.75	7.25±1.	7.5±0.75
Container B	120	2.5	8.25±	9±0.5	8.75±1.25	9.25±0.75
Container C	120	2.5	8±0.25	9.25±0.75	9±0.5	9.25±0.25
Control	--	2.5	6±0.75	6.25±1.	7±0.75	7.25±0.5
Firmness			1	4	7	10
Container A	120	2.5	8.00±0.75	8.25±0.25	7.25±1.25	7.75±0.75
Container B	120	2.5	8.25±0.25	8.00±1.5	7.25±0.5	7.50±0.75
Container C	120	2.5	8.00±1.0	7.75±0.75	7.25±0.75	7.00±1.25
Control	--	2.5	8.50±0.25	8.25±	8.50±	8.00±0.5

Table 13 continued

Overall Quality			1	4	7	10
Container A	120	2.5	8.50±1.25	9.25±1.	9.25±1.25	9.00±1.0
Container B	120	2.5	9.00±0.25	10.00±1.25	9.50±1.5	9.50±1.25
Container C	120	2.5	9.50±0.25	9.50±1.5	8.50±1.25	8.75±1.25
Control	--	2.5	7.00±1.	7.25±1.25	7.00±1.	7.75±1.25
Aroma			1	4	7	10
Container A	120	1.5	8.75±0.25	9.25±1.0	9.00±1.0	10.25±1.25
Container B	120	1.5	9.00±0.25	10.00±0.25	9.25±1.0	11.25±1.25
Container C	120	1.5	9.75±1.0	10.75±1.25	11.00±0.25	10.75±1.0
Control	--	1.5	6.25±1.25	5.75±1.25	7.75±1.5	8.75±0.25.
Sweetness			1	4	7	10
Container A	120	1.5	7.25±0.25	7.75±1.5	8.25±1.0	9.00±0.25
Container B	120	1.5	7.75±1.25	8.25±1.25	8.75±0.5	9.75±0.5
Container C	120	1.5	7.75±1.0	8.25±0.25.	9.25±0.25	9.75±1.0
Control	--	1.5	6.25±1.	6.75±1.0	7.75±1.5	8.00±1.25
Color			1	4	7	10
Container A	120	1.5	6.75±1.25	7.25±0.25	7.50±1.0	7.75±0.25
Container B	120	1.5	7.25±1.0	7.50±0.5	8.25±1.25	8.75±1.0
Container C	120	1.5	7.75±0.25	7.50±0.25	7.75±0.75	9.00±0.75
Control	--	1.5	6.25±1.25	6.00±1.75	7.00±1.0	7.25±1.5
Firmness			1	4	7	10
Container A	120	1.5	7.75±0.5	6.75±0.25	6.50±1.0	6.25±1.0
Container B	120	1.5	7.00±0.25	6.75±1.0	6.25±0.25	5.75±0.25
Container C	120	1.5	6.75±1.0	6.25±0.5	5.75±0.75	5.50±0.25
Control	--	1.5	7.75±1.25	7.25±0.25	6.25±0.25	6.25±0.25
Overall Quality			1	4	7	10
Container A	120	1.5	6.50±0.25	6.75±1.0	6.75±1.0	7.00±1.0
Container B	120	1.5	8.00±1.5	8.50±0.25	8.25±1.5	8.00±1.25
Container C	120	1.5	7.75±1.0	7.00±1.25	7.25±1.0	8.00±0.25
Control	--	1.5	6.25±0.25	6.00±0.25	6.75±1.5	7.25±1.5

APPENDIX H

Table 14.Trained panel response (n=6) on effect of fruit dice size and transport vibration on sensory characteristics of fresh-cut cantaloupe packaged in container A, B and C stored in 4°C

Attributes	Vibration Test Time (mins)	Container	Days			
Aroma			1	4	7	10
Size-2.5cm	60	A	9.00±1.25	9.75±0.75	10.50±1.0	9.50±1.25
Size-1.5cm	60	A	7.10±1.33	7.25±1.0	8.50±1.25	9.75±1.0
Control	--	A	5.75±1.25	6.00±1.25	7.25±1.0	8.25±0.5
Sweetness			1	4	7	10
Size-2.5cm	60	A	7.10±0.85	7.25±0.25	8.50±0.25	9.75±0.5
Size-1.5cm	60	A	7.00±0.5	7.50±0.25	8.00±0.25	8.75±0.5
Control	--	A	6.25±0.5	6.65±1.36	7.38±1.25	7.88±1.25
Color			1	4	7	10
Size-2.5cm	60	A	6.25±0.25	7.50±0.25	7.25±0.25	7.75±0.25
Size-1.5cm	60	A	6.50±0.25	7.00±0.25	7.25±0.25	7.50±0.25
Control	--	A	5.75±1.25	5.75±1.25	6.63±0.35	7.38±0.25
Firmness			1	4	7	10
Size-2.5cm	60	A	9.00±0.25	8.75±1.25	8.50±0.5	8.50±1.25
Size-1.5cm	60	A	8.00±0.25	7.00±0.25	6.75±1.25	6.50±0.75
Control	--	A	8.38±0.25	8.13±0.36	7.50±0.25	7.25±0.25
Overall Quality			1	4	7	10
Size-2.5cm	60	A	7.50±0.25	7.75±0.25	7.75±0.25	8.00±1.0
Size-1.5cm	60	A	7.00±0.25	7.25±0.25	7.25±0.25	7.50±0.25
Control	--	A	7.00±0.25	6.75±1.25	7.50±0.25	8.00±0.25
Aroma			1	4	7	10
Size-2.5cm	60	B	8.50±0.25	9.75±0.25	9.25±0.25	10.75±1.0
Size-1.5cm	60	B	8.75±0.25	9.75±0.25	9.00±0.25	11.00±0.5
Control	--	B	5.75±1.25	6.00±1.25	7.25±	8.25±1.25
Sweetness			1	4	7	10
Size-2.5cm	60	B	8.00±0.5	8.75±	9.50±0.25	10.50±1.25
Size-1.5cm	60	B	7.50±0.25	8.00±0.25	8.50±0.25	9.50±0.75
Control	--	B	6.25±1.25	6.65±0.65	7.38±0.48	7.88±1.23
Color			1	4	7	10
Size-2.5cm	60	B	6.50±0.25	6.75±0.25	7.25±0.5	8.00±0.25
Size-1.5cm	60	B	7.00±0.75	7.25±0.75	8.00±0.25	8.50±0.75
Control	--	B	5.75±1.25	5.75±1.25	6.63±0.58	7.38±1.21

Table 14 continued

Firmness			1	4	7	10
Size-2.5cm	60	B	8.50±0.25	8.00±0.5	8.25±0.5	8.00±0.25
Size-1.5cm	60	B	7.25±0.25	7.00±0.75	6.50±0.75	6.00±0.75
Control	--	B	8.38±0.5	8.13±0.32	7.50±1.25	7.25±0.5
Overall Quality			1	4	7	10
Size-2.5cm	60	B	9.00±0.25	9.50±0.5	9.25±0.75	9.00±0.5
Size-1.5cm	60	B	8.50±	9.00±0.5	8.75±0.25	8.50±0.5
Control	--	B	7.00±	6.75±1.25	7.50±	8.00±0.25
Aroma						
Size-2.5cm	60	C	9.25±0.25	10.25±0.5	10.75±0.25	11.00±0.5
Size-1.5cm	60	C	9.50±0.25	10.50±0.5	10.75±0.5	10.50±0.25
Control	--	C	5.75±1.25	6.00±1.25	7.25±0.75	8.25±0.75
Sweetness			1	4	7	10
Size-2.5cm	60	C	8.00±0.5	8.50±0.5	9.75±0.5	10.00±0.5
Size-1.5cm	60	C	7.50±0.25	8.00±0.25	9.00±0.25	9.50±0.25
Control	--	C	6.25±0.5	6.65±0.5	7.38±	7.88±0.25
Color			1	4	7	10
Size-2.5cm	60	C	6.75±0.25	7.00±0.5	7.75±0.5	8.75±0.5
Size-1.5cm	60	C	7.50±0.5	7.25±0.25	7.50±0.25	8.75±0.25
Control	--	C	5.75±1.25	5.75±1.25	6.63±0.73	7.38±0.85
Firmness						
Size-2.5cm	60	C	9.00±0.25	7.75±0.5	7.25±0.5	7.25±0.75
Size-1.5cm	60	C	7.00±0.5	6.50±0.75	6.00±0.25	5.75±1.25
Control	--	C	8.38±0.38	8.13±0.68	7.50±0.5	7.25±0.25
Overall Quality			1	4	7	10
Size-2.5cm	60	C	8.75±0.5	8.00±0.5	8.25±0.75	9.00±0.75
Size-1.5cm	60	C	8.25±0.25	7.50±0.25	7.75±0.5	8.50±0.25
Control	--	C	7.00±0.75	6.75±0.5	7.50±0.25	8.00±0.25

APPENDIX I

Table 15. Effect of container design and transport vibration on CIE L*, a* and b* color values of fresh-cut cantaloupe packaged in container A, B and C, stored in 4°C

Container Type	Vibration Test Time (mins)	Dice Size (cm)	Days			
			L*			
			1	4	7	10
A	60	2.5	58.78±1.3	57.09±	57.90±1.1	57.46±1.1
B	60	2.5	57.97±1.4	55.44±1.5	55.63±1.1	55.02±1.5
C	60	2.5	54.90±1.2	54.23±1.	54.10±1.4	54.17±1.2
Control	--	2.5	59.80±1.5	58.96±1.	58.90±1.2	58.70±1.1
			a*			
			1	4	7	10
A	60	2.5	16.89±1.4	16.10±1.2	15.90±1.1	15.40±1.4
B	60	2.5	16.39±1.6	16.12±1.1	15.80±1.3	15.07±1.2
C	60	2.5	17.80±1.2	17.56±1.3	17.50±1.8	17.40±1.1
Control	--	2.5	17.59±1.3	17.50±1.4	17.45±1.4	16.89±1.2
			b*			
			1	4	7	10
A	60	2.5	33.60±1.3	33.40±1.5	33.30±1.1	32.50±1.4
B	60	2.5	32.86±1.5	32.98±1.4	32.54±1.5	30.50±1.4
C	60	2.5	31.29±1.3	31.20±1.1	31.25±1.8	31.27±1.1
Control	--	2.5	34.67±1.3	33.98±1.	33.70±1.1	33.60±1.8
			L*			
			1	4	7	10
A	60	1.5	56.78±0.9	55.09±0.5.	55.90±1.1	55.46±1.3
B	60	1.5	56.90±1.4	54.50±0.8	54.10±0.4	54.02±1.8
C	60	1.5	53.20±1.2	52.90±1.1	52.70±0.9	52.17±1.2
Control	--	1.5	58.80±1.4	57.96±1.1	57.90±0.6	57.70±1.9
			a*			
			1	4	7	10
A	60	1.5	15.39±0.4	14.60±0.7	14.40±0.9.	14.20±0.8
B	60	1.5	15.30±1.4	14.90±1.3	14.40±1.2	13.90±1.6
C	60	1.5	16.10±1.1	15.75±0.1	15.59±0.5	15.20±0.8
Control	--	1.5	15.84±1.2	15.75±1.3	15.70±1.4	15.14±1.3
			b*			
			1	4	7	10
A	60	1.5	32.10±0.4	32.40±0.5	31.80±0.9	32.00±0.9
B	60	1.5	31.46±1.3	30.90±0.7	31.04±0.4	29.50±1.1
C	60	1.5	29.40±1.2	29.19±1.3	28.92±1.2	28.90±1.1

Table 15 continued

Control	--	1.5	32.92±0.6	32.23±0.7	31.95±0.8	31.85±1.2
			L*			
			1	4	7	10
A	120	2.5	57.76±0.5	56.94±1.1	56.25±1.4	55.72±0.8
B	120	2.5	52.49±1.1	53.13±0.8	52.64±0.7	51.06±1.5
C	120	2.5	53.40±1.2	53.20±1.2	52.00±0.9	51.00±0.9
Control	--	2.5	59.80±0.9	58.96±1.1	58.90±1.2	58.70±0.8
			a*			
			1	4	7	10
A	120	2.5	17.50±0.7	16.70±1.5	16.50±1.8	16.30±0.7
B	120	2.5	17.46±1.5	16.78±1.6	16.95±1.1	16.71±1.8
C	120	2.5	18.43±1.3	18.29±0.3	18.27±0.4	18.12±1.1
Control	--	2.5	17.59±0.2	17.50±1.1	17.45±1.1	16.89±0.4
			b*			
			1	4	7	10
A	120	2.5	33.40±0.8	32.93±0.9	32.10±1.3	31.98±1.2
B	120	2.5	33.34±1.3	31.15±1.3	31.73±1.2	31.21±1.1
C	120	2.5	31.38±1.3	30.96±0.8	30.89±0.9	30.80±0.7
Control	--	2.5	34.67±0.8	33.98±1.2	33.70±0.6	33.60±1.1
			L*			
			1	4	7	10
A	120	1.5	55.76±0.7	54.94±0.4	54.25±1.2	53.72±0.9
B	120	1.5	51.32±1.2	52.05±1.3	51.64±0.5	50.00±1.5
C	120	1.5	51.40±1.1	51.00±0.2	50.70±1.	49.72±1.2
Control	--	1.5	58.80±0.8	57.96±1.6	57.90±1.1	57.70±1.4
			a*			
			1	4	7	10
A	120	1.5	15.70±0.6	14.90±1.4	14.70±0.6	14.50±0.7
B	120	1.5	15.43±1.3	15.30±1.1	15.20±1.4	14.91±1.3
C	120	1.5	16.40±0.5	16.14±1.4	15.90±0.3	16.02±1.6
Control	--	1.5	15.84±0.1	15.75±1.1	15.70±1.6	15.14±1.1
			b*			
			1	4	7	10
A	120	1.5	31.60±0.8	32.10±0.7	31.40±0.4	30.89±1.1
B	120	1.5	31.20±1.4	30.50±1.3	31.08±1.2	29.20±1.3
C	120	1.5	29.28±0.9	28.80±1.2	28.20±0.4	27.95±1.3
Control	--	1.5	32.92±1.2	32.23±0.7	31.95±0.8	31.85±0.9

APPENDIX J

Table 16. Effect of fruit dice size and transport vibration on CIE L*,a* and b* color values of fresh-cut cantaloupe packaged in container A, B and C, stored in 4°C

Dice Size (cm)	Vibration Test Time (mins)	Container Type	Days			
			L*			
			1	4	7	10
Size-2.5	60	A	58.78±1.6	57.09±1.4	57.90±1.2	57.46±1.8
Size-1.5	60	A	56.78±1.5	55.09±1.3	55.90±1.3	55.46±1.1
Control	--	A	59.80±1.9	58.96±1.4	58.90±1.5	58.70±1.3
			a*			
			1	4	7	10
Size-2.5	60	A	16.89±1.2	16.10±1.1	15.90±1.9	15.40±1.2
Size-1.5	60	A	15.39±1.7	14.60±1.4	14.40±1.2	14.20±1.4
Control	--	A	17.59±1.8	17.50±1.7	17.45±1.7	16.89±1.1
			b*			
			1	4	7	10
Size-2.5	60	A	33.60±1.2	33.40±1.9	33.30±	32.50±1.1
Size-1.5	60	A	32.10±1.3	32.40±2.1	31.80±1.8	32.00±2.1
Control	--	A	34.67±1.4	33.98±1.1	33.70±1.2	33.60±1.3
			L*			
			1	4	7	10
Size-2.5	60	B	57.97±1.6	55.44±1.3	55.63±1.1	55.02±1.8
Size-1.5	60	B	56.90±1.2	54.50±1.5	54.10±1.7	54.02±1.1
Control	--	B	56.27±1.5	57.09±1.	56.67±1.2	56.88±1.7
			a*			
			1	4	7	10
Size-2.5	60	B	16.39±1.5	16.12±1.4	15.80±1.6	15.07±1.7
Size-1.5	60	B	15.30±1.6	14.90±1.7	14.40±1.4	13.90±1.2
Control	--	B	17.30±1.1	17.10±1.3	17.05±1.3	16.22±1.6
			b*			
			1	4	7	10
Size-2.5	60	B	32.86±1.6	32.98±1.3	32.54±1.8	30.50±1.2
Size-1.5	60	B	31.46±1.4	30.90±1.6	31.04±1.8	29.50±1.2
Control	--	B	33.61±1.1	33.59±1.6	33.45±1.8	31.64±1.9
			L*			
			1	4	7	10
Size-2.5	60	C	54.90±1.2	54.23±1.5	54.10±1.7	54.17±1.5
Size-1.5	60	C	53.20±1.3	52.90±1.6	52.70±1.9	52.17±1.5
Control	--	C	55.80±1.3	56.90±1.6	56.34±1.9	56.58±1.6

Table 16 continued

			a*			
			1	4	7	10
Size-2.5	60	C	31.29±1.6	31.20±1.8	31.25±1.2	31.27±1.8
Size-1.5	60	C	29.40±1.2	29.19±1.9	28.92±1.5	28.90±1.9
Control	--	C	32.67±2	32.89±1.8	32.75±1.1	32.10±1.4
			b*			
			1	4	7	10
Size-2.5	60	C	31.29±1.9	31.20±1.9	31.25±1.4	31.27±1.6
Size-1.5	60	C	29.40±1.6	29.19±1.3	28.92±1.4	28.90±1.2
Control	--	C	32.67±1.4	32.89±1.7	32.75±1.9	32.10±1.7

APPENDIX K

Table 17. Effect of container design and transport vibration on firmness values of fresh-cut cantaloupe packaged in container A, B and C, stored in 4°C

Container Type	Vibration Test Time (minutes)	Dice Size (cm)	Days			
			Force (Newtons)			
			1	4	7	10
A	60	2.5	68.90±1.4	65.80±1.6	63.10±1.1	63.40±1.2
B	60	2.5	68.70±1.5	62.80±2.3	60.40±1.9	58.90±2.1
C	60	2.5	60.90±2.3	58.40±2.5	54.80±2.9	51.70±2.8
Control	--	2.5	70.50±1.9	68.40±2.1	67.40±1.9	67.10±1.3
A	60	1.5	52.83±1.9	50.80±1.4	45.76±2.1	48.40±1.9
B	60	1.5	50.48±2.3	45.29±1.9	45.40±1.5	43.90±1.3
C	60	1.5	44.93±2.1	35.89±2.5	37.23±1.9	31.30±2.1
Control	--	1.5	57.00±2.2	54.00±2.1	52.70±1.9	50.19±1.7
A	120	2.5	70.90±2.4	66.50±2.1	64.90±2.4	60.20±2.5
B	120	2.5	70.50±1.75	64.90±2.34	61.40±1.78	56.30±2.78
C	120	2.5	56.80±2.39	48.09±1.83	46.07±1.98	45.08±1.23
Control	--	2.5	70.50±1.94	68.40±1.5	67.40±1.1	67.10±1.6
A	120	1.5	49.39±2.1	47.57±	48.29±2.13	46.38±
B	120	1.5	45.90±1.93	43.40±2.1	39.80±2.96	36.70±2.0
C	120	1.5	31.80±2.92	23.09±1.92	21.07±1.2	20.08±1.6
Control	--	1.5	57.00±2.34	54.00±2.34	52.70±2.1	50.19±2.67

APPENDIX L

Table 18. Effect of fruit dice size and transport vibration on firmness values of fresh-cut cantaloupe packaged in container A, B and C, stored in 4°C

Dice Size (cm)	Vibration Test Time (mins)	Container Type	Days			
			Force (Newtons)			
			1	4	7	10
Size-2.5	60	A	68.90±2.1	65.80±2.1	63.10±2.0	63.40±2.1
Size-1.5	60	A	52.83±1.5	50.80±2.5	45.76±2.5	48.40±1.1
Control Size-2.5	--	A	70.45±1.2	69.56±1.7	68.98±1.8	66.69±2.2
Control Size-1.5	--	A	56.89±1.5	55.78±1.9	54.39±3.2	51.89±2.1
Size-2.5	60	B	68.70±1.7	62.80±2.3	60.40±2.9	58.90±2.5
Size-1.5	60	B	50.48±3.1	45.29±2.1	45.40±1.8	43.90±2.1
Control Size-2.5	--	B	70.10±2.5	69.54±2.5	67.79±1.7	66.32±2.4
Control Size-1.5	--	B	56.59±2.3	55.21±1.7	53.67±2.4	52.73±1.6
Size-2.5	60	C	60.90±1.8	58.40±1.7	54.80±2.4	51.70±2.2
Size-1.5	60	C	45.90±1.6	43.40±2.5	39.80±2.1	36.70±2.5
Control Size-2.5	--	C	72.34±2.1	69.67±1.7	67.49±2.2	65.79±1.7
Control Size-1.5	--	C	58.67±1.9	57.54±1.8	54.12±1.4	52.67±1.6

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