QUALITY CHANGES OF FRESH MARKET CARROT STICKS DURING CONTROLLED AND MODIFIED ATMOSPHERIC STORAGE

by

Hsiao-Yuan Li

A THESIS

Submitted to

Michigan State University

in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE

Department of Food Science and Human Nutrition

1992

ABSTRACT

QUALITY CHANGES OF FRESH MARKET CARROT STICKS DURING CONTROLLED AND MODIFIED ATMOSPHERIC STORAGE

BY

Hsiao-Yuan Li

Fresh, ready-to-use cut carrots which are widely used in salad bars and other applications have increased convenience and value. Effects of controlled, modified atmosphere storage environments and chemical treatments were evaluated in a series of three studies.

The effects of controlled CO_2 storage condition and peeling treatments were observed in STUDY I. STUDY II evaluated the effect of modified atmosphere (MA) packaging on the quality of three cultivars with selected peeling treatments. The effects of six chemical dipping treatments prior to MA storage on peeled CARO-BEST carrot sticks were evaluated in STUDY III. Physical, chemical analyses and sensory evaluation by QDA were included in the quality evaluation for each study.

MA packaged carrot sticks retained superior textural properties compared to traditionally packed fresh-cut sticks. Less harsh flavor and better appearance were observed in peeled sticks maintained in MA packages. Sodium meta-phosphate dipping was demonstrated to be an effective method to reduce the surface whitening during MA storage.

To my parents

ACKNOWLEDGMENTS

I would like to thank my committee members Drs. J. Cash, B. Harte and J. Staffe for their guidance through my graduate program. I would also like to give special appreciation to Dr. Larry R. Baker from Asgrow Seed Company for his professional encouragement, and for providing research samples. A thank you is extended to Bolthouse Farms Inc. in Grant, Michigan for providing partial funding of my research.

Special thanks is given to my professor, Dr. Uebersax, whose endless patience and assistance provided encouraging atmosphere for completion of my education. He also was a very knowledgeable instructor who provided me insight and support throughout my study. I also appreciated all group members, especially Dr. Shirazi, in 128 lab at Michigan State University for their participation and help in my project.

A very special thanks goes to my dear parents in Taiwan, their love, patience and endless support are very precious to me during my education. I would also like to thank my husband Yee-Yung, for his love and understanding which provided me the energy needed to finish this study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Fruit and vegetables are generally recommended as a good source of vitamins and dietary fiber. Carrots (*Daucus carota* L.) have predominant amounts of beta-carotene, pro-Vitamin A, and complex dietary fiber. Fresh carrots are increasingly consumed as a salad bar vegetable or are mixed with other food ingredients which make them a highly nutritious component of the human diet. Consumer's reaction to food is governed mainly by such characteristics as color, flavor, texture, and appearance. Therefore, improvement of the textural and sensory quality of fresh carrots used in retail markets could increase perceived satiety and overall consumption. Minimized processing of fresh fruit and vegetables could extend shelf-life as well as improve consumer's convenience.

Carrots have many problems during post-harvest storage , such as moisture loss, pathogenic deterioration, off-flavors, and senescence of cut surfaces. The effect of temperature, relative humidity (%RH), and composition of the atmosphere have been investigated and each identified as important factors influencing the carrot storage quality.

The purpose of this study was to investigate various factors influencing the qualities of fresh market prepared carrot sticks. Three individual storage studies were conducted to evaluate quality of carrot sticks.

Additionally, the overall quality of selected carrot cultivars and breeding lines produced in three locations in both Michigan and California was conducted and data are reported in Appendix II.

STUDY I evaluated different controlled atmospheres (CA) with various CO_2 concentrations for selected carrot cultivars and peeling treatments. The effects of peeling treatments (peeled and non-peeled) and CO_2 content in package on carrot stick quality prepared from three cultivars were tested. Carrot sticks were kept in cold room storage (0°C, 98%RH) with preadjusted gas environments prior to physical, chemical, and sensory analyses.

The effect of modified atmosphere packaging (MAP) was evaluated on peeled and non-peeled carrot sticks in STUDY II. This study included three cultivars (CARO-BEST, IMPERATOR-58 and DOMINATOR) produced at El Centro, California. Samples were kept in cold storage for 5 weeks ,and the gas compositions in the packages were monitored each week. After storage, carrot sticks were subjected to physical and chemical analyses and overall sensory evaluation.

STUDY III was performed to evaluate the effects of food grade chemical dipping treatments on the surface senescence and quality enhancement of carrot sticks during storage. Seven different dipping solutions were employed before packaging. These treatments included: 1) citric/ascorbic

acids, 0.01%; 2) calcium chloride, 0.002%; 3) glucose, 0.7%; 4) lecithin, 0.02%; 5) Mixture of 1 to 4; 6) sodium metaphosphate, 0.1%; and 7) deionized (D.I.) water, as control. All samples were evaluated for quality as in previous studies.

REVIEW OF LITERATURE

Carrot description

Carrot (*Daucus carota* L.) is an important vegetable crop which is produced for food processing industries and has always been popular in today's fresh market. This biennial vegetable belonging to the Umelliferae family is comprised of an enlarged edible root and is usually sold in fresh product supermarket. Like most vegetables, most of its composition is water (85-90%). The cellular structure of the root consists of an outer surface, a smooth epidermal surface layer with the interior bulky storage cortex formed from large numbers of thin-walled parenchyma cells. The central portion of the root is comprised of the vascular cambium tissue which forms xylem (inside) and phloem (outside). The water holding capacity of carrot root is highly dependent on its fiber content and has been estimated to be about 23.4 g water/g fiber. The fiber content varies from 1.24 to 2.14 g/100 g fresh root (Dudek et al., 1982). The root retains high cellular turgor pressure and firm texture because it contains relatively high levels of hemicellulose and pectin, which have high water affinity.

Commercial fresh carrots are generally packed in two ways, 1) tied into bunches with foliage intact or 2) topped and placed in perforated plastic bags. Carrot cultivars are readily distinguished for suitability as either fresh market

or processing use. Fresh market varieties generally have long thin profiles, possess high sugar and dark orange color. Processing varieties generally have less color, are short and thick and are used for slicing or cubing.

A recent innovation in carrot marketing designed to increase consumer convenience and reduce preparation time, involves abrasion peeling, cutting and holding pieces in a sealed plastic bag at refrigerated temperatures (Bolin and Huxsoll, 1991). The edible quality of these minimally processed pieces can be maintained for several weeks using appropriate handling conditions.

Nutrient content

The general nutrient composition of carrot root is presented in Table 1. Carrot contains high levels of soluble carbohydrates, mostly sucrose (Alabran and Mabrouk, 1973), and thus differs from most common fruits and vegetables which generally contain more reducing sugars (glucose and fructose). The total soluble solids content of fresh carrot tissue ranges from 7 to 10 ^{o}Brix and this fraction contributes most of the sweet taste. The fat-soluble beta-carotene, pro-vitamin A, gives the root an orange-yellow color. Leveille et al. (1974) found vitamin A in carrot roots is more than sufficient to enable recommendation for daily consumption as a major contributor to the RDA. Ascorbic acid is another major nutrient in

Table 1 Nutrient Content of Raw Carrots (6 varieties)			
Nutrients	units	Range low	high
Moisture	g/100 g	88.46	88.88
Ash	g/100 g	0.62	0.92
Fat	g/100 g	0.09	0.18
Protein	g/100 g	0.78	1.03
Carbohydrates	g/100 g	9.18	9.98
Fiber (Non digestable)	g/100 g	1.24	2.14
Calories	Cal/100 g	39.45	41.83
Ascorbic acid (Vit. C)	mg/100 g	2.03	2.55
Vitamin A	I.U./100 g	23,716	32,670
Thiamin	mg/100 g	0.034	0.041
Riboflavin	mg/100 g	0.048	0.058
Vitamin B_6	mg/100 g	0.207	0.252
Folacin	ug/100 g	10.4	18.1
Pantothenic acid	mg/100 g	0.211	0.299
Niacin	mg/100 g	0.35	0.46
Ca	mg/100 g	29.3	33.5
Cr	mg/100 g	-	0.02
Co	mg/100 g	0.01	0.01
Cu	mg/100 g	0.06	0.12
Fe	mg/100 g	0.31	0.75
Mg	mg/100 g	10.3	14.6
Mn	mg/100 g	0.43	0.65
Mo	mg/100 g	-	0.02
P	mg/100 g	30.8	36.3
K	mg/100 g	184	260
Se	mg/100 g	-	0.005
Na	mg/100 g	42.0	69.1
Zn	mg/100 g	0.28	0.39

(Dudek et al.,1982)

carrot but is very sensitive to heat and light. Fresh carrot used as a salad bar vegetable is the most nutritious form for consumption, therefore, storage qualities of carrot roots are very important.

Aroma and flavor compound

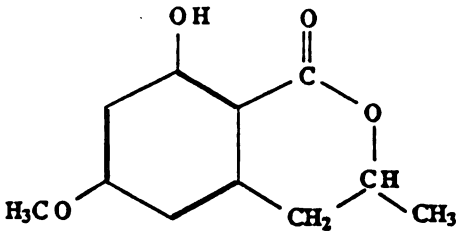
Raw carrot has a particular aroma which was defined by many investigators using different descriptive words such as earthy, turpentine-like, fruity, hay-like, etc. (Martens et al., 1979; Kaminski et al., 1986). Terpinolene has been found to be the major volatile component in carrot root oil, however no single component is responsible for carrot aroma (Buttery et al., 1968; Simon et al., 1980c; Mclellan, 1981). Rather than aroma, flavor was assumed to be the most effective factor in acceptance of carrots. Sweetness and harshness or bitterness have been used as the most important parameters in sensory evaluations (Simon et al., 1980b). One possible cause of harshness (or bitterness) in carrots was found to be associated with accumulation of total phenolic compounds (Phan et al., 1973; Sarkar and Phan, 1974). However, most of these phenolic compounds were found in the peel region of the carrot.

Bessey (1957) studied the bitter flavor of carrots which developed when stored with apples by detecting the fluorescence intensity in root tissues. He found increased fluorescence associated with increased phenolic compounds in

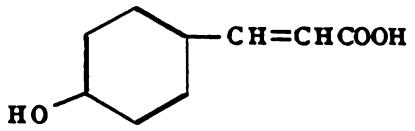
carrots held under commingled storage conditions. The bitter flavor was investigated and found to be caused by the presence of several compounds (Sondheimer, 1957). The predominate compound was identified as 3-methyl-6-methoxy-8-hydroxy-3,4-dihydroisocoumarin (Figure 1), which is generally termed "isocoumarin". Conversely, Carlton et al. (1961) reported this bitter compound as 6-methoxy mellein. Coxon et al. (1973) showed that ethylene stimulated the production of phenolic compounds, primarily 6-methoxy mellein and eugenin. The phenolic compounds in carrots are comprised of chlorogenic acid and some closely related compounds, such as isochlorogenic acid (Phan et al., 1973). Also other structurally similar phenolic compounds have been found by Sarkar and Phan (1974, 1979), including caffeic, ferulic, and p-coumaric acids.

Post-harvest handling for extension of shelf-life

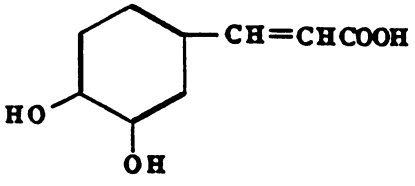
Post-harvest treatments for extending the shelf-life of fruits and vegetables could be achieved by: a) Post-harvest handling: retarding deterioration of physiological processes. b) Food preservation: preserving the tissue by inactivating the physiological processes. Shewfelt (1986) reported several ways to extend the shelf-life of horticultural products, which include: a) minimizing bruising and mechanical damage, b) optimization of environmental storage conditions, and c) application of food



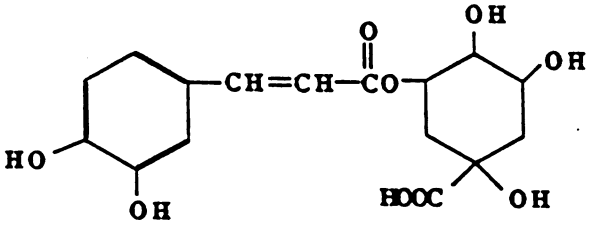
isocoumarin



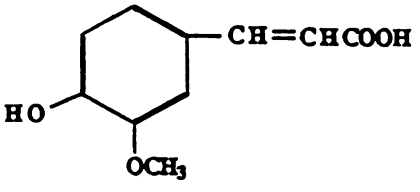
p-coumaric acid



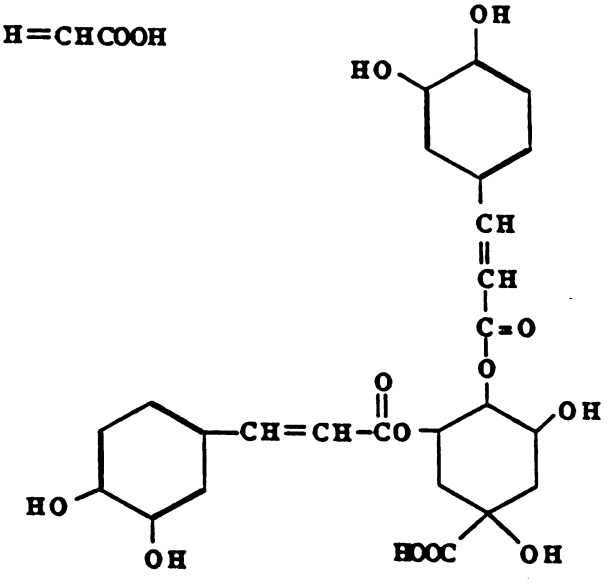
caffeic acid



chlorogenic acid



ferulic acid



isochlorogenic acid

Figure 1. Structures of several common phenolic compounds found in raw carrot

additives. The storage conditions of carrot root are particularly important because the metabolic activity and respiration rate apparently increase after harvest (Kader, 1986; Carlin et al., 1990).

The purpose of storage is to preserve the contents as they exist at the end of the maturation period. Several possible ways to optimize the storage condition were studied intensively during 1970's (Apeland and Hoftun, 1971; Hansen and Rumpf, 1974; Weichmann and Ammerseder, 1974; Stoll, 1974). The basic concepts are to lower respiration rate and reduce microbial growth without inducing physiological injury. Generally, temperature and relative humidity are considered primary factors in preserving high quality storage life, however, other factors such as controlled and modified atmospheres and chemical dipping treatments have also shown significant potential for shelf-life extension of carrots (Bruemmer, 1987; 1988).

Temperature

Low temperature reduces the respiration and transpiration rates, and controls pathogenic microorganisms associated with carrots (Carlin et al., 1990). Van den Berg and Lentz (1973) found that temperature has markedly effect on carrot decay and that at 0-3^{o}C carrots retained much better quality than those stored at higher temperature. For long term storage, topped carrots were recommended to be

stored under 0 to 1°C conditions (Phan et al., 1973; Apeland and Hoftun, 1971; Stoll, 1974; Abdel-Rahman and Isenberg, 1974; Hansen and Rumpf, 1974; Baumann, 1974; Salunkhe and Desai, 1984). Carrot tissue and its components will generally maintain stability to a freezing point of -10°C without adverse quality defects.

Relative Humidity (RH)

The main physical change that occurs with carrots is loss of moisture and has been characterized as one of the most serious problems in carrot storage (Phan et al., 1973). Carrots stored at 1°C lost up to 50% of their fresh weight when held under a relative humidity of 75% for 5 months. The loss of moisture does not result only in a wilted, shrivelled and poor appearance, but also has a bearing on the resistance of the tissues to microorganisms. With shrivelling there are always signs of fungal and bacterial damage, with a higher rate of isocoumarin formation and its associated off-flavor development (Lafuene et al., 1989). Isocoumarin and 6-methoxy mellein have been shown to be responsible for the bitter taste of canned carrots (Carlton, 1961; Lafuene et al., 1989).

High relative humidity (98-100%) has been suggested for long term storage of fresh carrots. Reeleder et al. (1989) reported a better textural quality for carrots stored in high relative humidity. Usually, 95-98%RH is used for both

fresh bunched carrots, and topped carrots which are packaged in perforated plastic bags.

Controlled and Modified atmospheric environment

Controlled (CA) and modified (MA) atmospheres have been studied for use in storage of carrots and results demonstrate considerable variation in the quality of the stored product. Stoll (1974) showed that most root crops are not tolerant of high CO_2 environments (for carrot, greater than 4% CO_2). The optimum oxygen and carbon dioxide combination for maximum shelf-life of carrots still remains uncertain and appears to be variety dependent and greatly influenced by other physical conditions of storage. Basically, low O_2 tension can reduce the respiration rate, however, carrots are very susceptible to anaerobic fermentation when O_2 is below 1% (Kader, 1986). Apeland and Hoftun (1971) found the critical concentration of O_2 at 0°C is between 5-10%. Hansen and Rumpf (1974) determined the optimum gas mixture to be 3% O_2 and 3-6% CO_2. Positive effects were found with controlled atmospheric stored carrots in the retention of sucrose (Weichmann and Ammerseder, 1974). In addition to sugar preservation, low O_2 level also reduced the rate of microbial growth (Baumann, 1974). However, some studies have demonstrated negative effects of CA storage for carrots due to the development of external whitening and senescence (Weichmann and Ammerseder,

1974).

Higher Carbon dioxide concentrations generally reduce the respiration rate of fruits and vegetables. CO_2 level within the range of 1-5% was found most beneficial to CA and MA stored carrots (Bruemmer, 1988; Abdel-Rahman and Isenberg, 1974). Stoll reported increase of rots and odor on carrots stored in 3% CO_2. The atmosphere of 2.5% carbon dioxide and 2.5% oxygen was found to partially control the off-flavor development and damage that resulted during storage (Bruemmer, 1988). Other researchers suggested that the regulation of both O_2 and CO_2 was appropriate to extend the quality of stored carrots (Weichmann, 1973a, 1973b).

Treatment of carrots with high ethylene concentrations for several days exposure caused the total phenolic content to increase (Sarker and Phan, 1974). Isochlorogenic acid increased markedly upon exposure to ethylene, and appeared to be the major compound formed. Other phenolic compounds included 6-methoxy mellein and eugenin. Lafuente et al. (1989) has shown that isocoumarin also increases with larger ethylene concentrations. Anaerobic treatment with nitrogen gas was found to inversely inhibit the synthesis of 6-methoxy mellein (Carlton et al., 1961). These anaerobic treatments did not eliminate tissue respiration, which is reasonable because carrot root is normally exposed to lower oxygen concentrations than that present in the atmosphere. However, the specific biosynthetic pathway leading to

phenolic accumulation is still unknown.

Modified atmosphere storage has been used to retard the physiology deterioration of post-harvest carrots. The principle is based on reducing the respiration rate of produce and thus slowing down physiological aging (O'Beirne, 1987). Modified Atmosphere Packaging (MAP) systems are now used in fresh, ready-to-use fruits and vegetables (Bruemmer, 1988; Carlin et al., 1990), and carrots show potential for enhanced shelf-life through use of appropriate MAP systems.

Chemical treatments

The storage problems of cut carrots include physiological decomposition, microbial deterioration and senescence of cutting surfaces. Bruemmer (1987) used many chemicals to preserve the quality of cut carrots, including antimicrobial reagents, antioxidants, and some cellular constituent metabolites. Senescence of carrots could be observed as the whitening of cut surfaces, and Bolin and Huxsoll (1991) reported this "whitening" to be lignin. Positive effects on texture and flavor had been found in citric acid or $CaCl_2$ immersed carrots compared to no dipped controls. Slight acidification was beneficial to carrots and provided good quality control (Juliot et al., 1989). Generally calcium chloride treatments are used commercially as dips for apples, and citric and ascorbic acids are

effective antimicrobial and antioxidants in a wide variety of foods. Lecithin is important in cell wall structure, possesses strong emulsification properties and has been applied as a surface dip to enhance the storage of carrot sticks (Bruemmer, 1987). Chiang et al. (1971) found texture improvement in canned cherries with EDTA or sodium metaphosphate, and the potential use in carrots was also illustrated by Salunkhe and Desai (1984). Further work on the use of selected chemical treatments of fresh-cut carrots to extend high quality shelf-life during storage has been warranted.

Physical evaluation of carrot quality

The physical qualities of fresh fruits and vegetables are very important to consumers, especially when they are used for fresh consumption, e.g., salad bar vegetables. Mackey et al. (1973) reported that most consumers stated "freshness", "firmness", and "ripeness" to be the most important factors in their selection of fresh fruits and vegetables. These quality characteristics are related to texture and therefore, many current physical analyses are used for quantitating and distinguishing the textural attributes of the product.

There are several factors that may indicate the freshness of a vegetable, such as firmness and water content of the product. Water status and resultant cellular turgor

pressure is one of the most prominent factors determining softness and hardness of plant product tissue (Amerine et al., 1965).

Moisture

The harvested carrot root has grown as an underground tissue within full metabolic activity until dug out of the soil. Carrot roots possess a physiological tendency to absorb water from the soil and to store absorbed nutrients (photosynthate) produced from its green plant parts, therefore, it normally maintains a high moisture content (88-91%). Although carrot adapts itself to a wide range of growing environments, it thrives best in cool climates.

Low temperatures of about 0°C and high relative humidity (90-98%) have been recommended to store carrots for up to 6 months to maintain marketable conditions (Van den berg and Lentz, 1973; Salunkhe and Desai, 1984; Reeleder et al., 1989). In high humidity conditions, carrots remain firm and crisp and possess the most valuable texture characteristics attractive to the consumers. Van den berg and Lentz (1973) found that the rate of decay of carrots was much less at high relative humidity. Also the shelf life of carrots was greatly increased by "topping" (removal of the green parts) and packaging, because both procedures greatly reduce transpiration of water and the subsequent loss of product weight (Hardenburg et al., 1953; Salunkhe and Desai,

1984).

Texture

The texture of foods has been defined as "the disposition or manner of union of the particles of a body or substance" (Kramer, 1964). Kramer (1964) illustrated that this definition is inadequate for a workable or understandable terminology in food science. He suggested that the definition be limited to sense of feel and to that phase of rheology dealing with deformation of matter by forces greater than gravity, e.g. compression, tensile strength, cutting force and shearing force (Kramer, 1972). Szczesniak (1963) considered texture as "the composite of the structural elements of food and the manner in which it registers with the physiological senses". According to her classification, the textural characteristics were classified as follows:

a) mechanical: reaction of food to stress.

b) geographical: related to size and shape of particles and orientation.

c) other: primarily moisture and fat content related.

Texture of fruits and vegetables involves the whole tissue, including structure and chemical composition of intercellular substances, cell walls, and intracellular materials. Physical properties of the cell wall are influenced by pectic substances, cellulose, other

polysaccharide and encrusting compounds such as lignin (Hard et al., 1977). Texture is also influenced by the metabolism of the tissue, including respiration rate and enzymatic activity. Wasserman et al. (1986) stated the importance of texture for the quality of fruits and vegetables and they considered two primary factors associated with effect of texture to be: a) turgor and b) cell wall rigidity.

Many instruments have been utilized for measuring food texture and rheological properties. These have been traditionally product specific devices including: a) penetrometer, b) compressimeter, c) shear press, and d) bending devices. However, these instruments have limited utility and applications and have been replaced by fewer basic test machines with multiple dimensions used for textural interpretations. For example, the Texture Press (TMS-90, Food Technology Co., MA) can be used to establish different kinds of texture measurements by changing the testing cells. Current criteria for all texture measuring instruments include a consistent means of measuring deformation and time. These instruments can be divided into three classes depending on the type of method used: 1) fundamental, 2) empirical, and 3) imitative (Wilson, 1989). The results of fundamental methods are used to directly relate the nature of the specimen to rheological theories. Empirical methods are the most common used and include instruments like the Warner-Bratzler meat shear and the

Kramer Shear Press (Kramer, 1972). The total force or deformation profile can be a combination or sequence of stresses like compression, tension, shear flow, or extrusion. Imitative methods are designed to simulate conditions that food might undergo such as chewing, biting, or kneading. The forces are very complex and theoretical analysis is most difficult. Bourne (1975, 1977) explained the difficulties of measuring food texture by only rheology theories. Multiple reactions occur following the first bite of food product, thus, the simple theories and rheological models do not readily apply.

In measuring texture of carrots, Kostaropoulos (1981) found empirical methods were most feasible and compression and shearing devices within that class were the most popular. He also recommended use of several best known universal testing devices, including Texturometer, Kramer Shear Press, and Instron Machine. Howard and Heinz (1970) investigated whether carrot texture, as measured using compression or shear, could be correlated with sensory evaluations of compressibility and flexibility. Sensory evaluations of compressibility and flexibility agreed very well with compression measured as a change in diameter. Szczesniak et al. (1970) found the shear press to be a useful instrument to objectively qualify those factors related to textural parameters. However, Segerlind et al. (1977) found the agreement between sensory evaluations and

shear measurements was poor for carrots. Hard et al. (1977) and Mackey et al. (1973) further demonstrated that the shear results correlated poorly with sensory scores for crispness in raw carrots, but they found the Instron instrument was effective and non-destructive for measuring flexibility and compressibility. These investigations indicated that the perceived texture of carrots is more closely related to a compression force than to a shear force.

In addition, Kapsalis et al. (1972) developed a method to measure the rheological property of bending by using a Bending Tester. These researchers defined several mathematical methods to determine the bending rigidity of solid foods. Compared to compression and penetration, the bending tests could be used as better means to interpret the texture of plant-origin food. However, several difficulties need to be concerned in testing fruits or vegetables, such as heterogeneous specimens, fiber orientation and asymmetry of the sample.

The Instron Testing Machine (Instron Engineering Co., MA), a fundamental method, was often employed for carrot texture analysis but is not feasible in many testing situations (Segerlind et al., 1977). Another popular and versatile texture measuring instrument is the Kramer Shear Press, developed at the University of Maryland (Kramer, 1972). Szczesniak et al. (1970) reported this machine as a quality control tool primarily for fresh vegetables. The

system is driven hydraulically and the force is measured by a transducer ranging from a 0 to 3,000 pound capacity. The simplest format used for compression is a 2-piece parallel plate (top and bottom) cell, termed "TPA-1". The texture press is probably the most widely used texture instrument in fruit and vegetable research.

This texture press can be used to interpret physical measurements of the corresponding subjective texture profiles, such as hardness, cohesiveness, adhesiveness, springiness, stringiness, chewiness and gumminess (Bourne, 1968; Massey, 1973; Kostaropoulos, 1981). Massey et al. (1973) reported that the most sophisticated method of tissue texture measurement developed is that based on the texture profile analysis (TPA). TPA of food is a two bite method of texture analysis in which the food is compressed twice and a complete texture profile of the sample is calculated from the data recorded. Although TPA is very useful in evaluating the textural quality of foods when parameters can be correlated with sensory assessments, Breene (1975) elucidated the inconsistency of testing conditions which comes from the differences in foods as to the size, shape, homogeneity of structure and composition. Thus, TPA analyses are empirical and require extensive attention to analytical detail and adequate replication.

Chemical Evaluation

Recent developments in high-pressure liquid chromatography (HPLC) equipment and micro-particulate column packing allow direct and rapid determination of sugars and phenolic compounds in food and beverage matrices (Conrad and Palmer, 1976; Senter et al., 1989). In HPLC, components of a sample mixture will have characteristic retention times within the separation column. Solvent from an external reservoir is pumped at high pressure to an injector, which is used to introduce the sample into the solvent stream. The solvent and sample then enter the column, where separation of the sample takes place. The resolved components are detected by a differential refractometer (or spectrophotometer) whose output is transmitted to a strip-chart recorder. Retention times and peak responses can be qualitively and quantitatively assessed from known standards. All of the samples must be extracted with defined protocols and should be filtered through a membrane filter (0.2-0.45 um pore) prior to injection into the HPLC.

Total soluble solids and sugar analysis

Soluble solids has been related to the fresh-market quality in a number of vegetable crops. Stommel and Simon (1989) indicated that quality of carrots for fresh market is influenced by total dissolved solids (TDS). High sugar content was found desirable in fresh-market carrots because most of them were eaten raw. Sugar, which is the major

stored carbohydrate in the root of carrot, and volatile terpenoids are two principle components contributing to carrot flavor. Four free sugars were identified in fresh carrots. Sucrose accounts for 44% of the total free sugar content; the reducing sugars (alpha-, beta-glucose and fructose) amount to 54% of the total free sugars (Alabran, 1973). Some efforts have been made in the selection of carrot varieties based on TDS alone (Scheerens, 1976), but they were ineffective for improving eating quality because harsh flavor tended to increase with TDS. Simon et al. (1980a) indicated that "harshness" and "sweetness" contributes more to the overall preference rather than flavor. The improvement of carrot flavor depended on root sugar content and sugar type (Stommel and Simon, 1989). High reducing sugar may be desirable for improving flavor of raw carrots (Simon et al., 1980a).

A specific quality problem has been associated with high sugar content carrots. An increase in growth cracks and brittleness for high sugar lines existed compared to low sugar lines (Carlton and Peterson, 1963). Further, a negative correlation was found between dry matter and reducing sugar content.

Phan et al. (1973) reported a rapid decrease of total soluble sugars during storage. The ratio of non-reducing sugars to reducing sugars exhibited a sharp decrease after 14-18 weeks of storage. This decrease was suggested to be

the enzymatic reaction of invertase in stored carrots. Paper chromatographic analysis showed that much more oligosaccharide species, primarily raffinose, was formed. Glucose and fructose, both reducing sugars, are generally present in equimolar concentrations (Freeman and Simon, 1983). He also stated the appearance of an association between mild, sweet flavor and high reducing sugar content. The ratio of sucrose to reducing sugars increases with root maturity, but decreases following harvest and during cold storage.

Simon et al. (1980b) demonstrated that a negative correlation exists between reducing sugars and certain volatiles responsible for harsh flavor. Fructose was found to possess a blocking effect in harsh flavor development in carrots. High levels of terpenoids can mask the sweetening effects of a high percentage of reducing sugar (Freeman, 1983). Thus, the interaction of sugar with volatiles was important in sensory ratings (Simon, 1980b).

Volatiles and phenolic compounds

Carrots have fairly high levels of volatiles relative to other vegetables (Simon et al., 1980b, 1980c). A steam volatile oil obtained from carrot root has been analyzed using Gas-Liquid Chromatography by Buttery et al. (1968). These steam stripped hydrocarbons had been demonstrated to maintain high correlations to sensory quality properties.

The identification and quantitation of volatile components of food were conducted by GC analysis using porous polymer traps (Tenax GC) (Simon et al., 1980; Mclellan, 1981). Terpinolene, the major monoterpene, was found to be more than 60% of the total hydrocarbon fraction (Buttery et al. 1968) and isolated mostly in crown and phloem of the root (Simon et al., 1980c); while terpinen-4-ol and *r*-bisabolenes, which are oxygenated volatiles found mostly in the xylem. However, no single compound was found that could be considered solely responsible for carrot aroma (Kaminski et al., 1986). These analytical methods have not been sufficient to segregate how much a particular component contributes to the total odor of the food. Most of these volatile compounds have additive and interactive effects.

The summed effect of all volatiles may elicit a negative organoleptic response when they are in high concentration (Simon et al., 1980b). However, correlation of these volatiles with an undetermined harsh compound could also explain this observation.

Spectrophotometric methods have been used to determine the phenolic compounds in plant tissue (Sondheimer et al., 1956; Senter et al., 1989). In addition, paper and thin-layer chromatography have been frequently used for identification as well as quantitation (Jaworski et al., 1973; Phan et al., 1973; Sarkar and Phan, 1974). Gas-Liquid Chromatography and HPLC (High-Pressure Liquid

Chromatography) were efficient and accurate in phenolic acid analysis (Krzysztof et al., 1982; Sarkar and Phan, 1974). Delcour et al. (1989) combined HPLC and fluorescence intensity (I_f) for better separation of natural phenolic acids. In spite of the availability these techniques and much work on the relationship of phenolic compounds with sensory assessment, for example, further harsh flavor research in carrots needs to be conducted.

Sensory evaluation

Physical and chemical methods for food testing are often useful in conjunction with sensory methods to elucidate the reasons for differences detected by sensory evaluation. Chemical and physical measurements may be used to replace the sensory methods if the correlation with a specific sensory test is high. Several designs of sensory analyses have been applied to determine whether foods are significantly different in one or more qualities. Triangle test, duo-trio test, paired-comparison, ranking and scoring, etc., are commonly used in description or difference testing situations (Palmer, 1972).

Quantitative Descriptive Analysis

Recent approaches in sensory measurement have employed a new method of data analysis called "Quantitative Descriptive Analysis" (QDA) (Scheerens, 1976; Simon et al.,

1980a). Stone et al. (1974) defined QDA as:

"...one of the methods involving category scales in which the individual used either words or numbers to characterize the specific sensory attributes of a product. QDA requires trained individuals to identify and quantify the sensory properties of a product or an ingredient in order of occurrence. QDA is based on the psychophysical aspects of perception and the application of an internal scaling technique to the problem of flavor characterization. These data enable development of the appropriate product multidimensional models in a quantitative form that is readily understood in both marketing and research and development environments."

Van Elbe et al. (1977) found the major influence in determining carrot quality would be the textural and flavor characteristics. In predicting an acceptable texture of fresh carrot, Howard and Heinz (1970) found highest correlations between compression force from the Instron with sensory texture evaluation. Several model equations were used to predict the correlation between instrumental and sensory evaluations. However, these evaluations were all determined by compressing and bending of samples with fingers or hands and evaluating their resistance and flexibility. Mastication evaluations can produce better results if the desired product characteristics are defined and measured properly. Bourne (1975, 1977) explained the drawbacks of using only rheology to interpret the food textural problems. Segerlind et al. (1977) suggested the defining of the relationship between standard engineering results and a sensory panel to be an area of research needed to enhance storage evaluations of carrots. Wilson (1989) used QDA in bean products and demonstrated TPA to be a

reliable basis for estimating sensory textural response in cooked beans. Thus, a QDA of a masticatory texture evaluation of carrot pieces warrants studied further.

In the study of carrots (Simon et al., 1980a, 1980b), panelists evaluated samples using QDA scales for harsh flavor, sweetness, overall flavor, and overall preference. Also there were several determinations in the evaluation of storage condition and modified atmosphere packaging, such as total soluble solids, bitterness or harshness, and sensory textural profiles. Brummer (1988) used sensory evaluation to determine the control of carrot senescence. Some important quality assessments in sensory were evaluated, such as appearance, texture, and flavor (Reeleder et al., 1989). Simon et al. (1980b) found both sugars and volatile compounds are important in determining raw carrot flavor. In addition, Mclellan (1981) used qualitative sensory methods to describe and measure individual sensory parameters and showed significant differences among carrot varieties. However, this author concluded that the aroma constituents of raw carrots were less important compared to the taste parameters in the overall acceptance of carrots. Therefore, further studies have been needed to focus on the relationship between quality and taste of raw carrots.

Sweetness is found most apparent at the tip of the tongue (Kramer and Twigg, 1974). Harshness is defined as the strong, burning, turpentine-like flavor most strongly

perceived at the back of the throat during or after chewing (Sondheimer, 1957). Sarkar and Phan (1979) found most of the phenolic compounds exist in carrot peel. Also Shattuck et al. (1988) illustrated that the outer peel possessed a more bitter flavor compared to other tissues. However, few investigators have studied the relationship between sensory harshness and phenolic compounds.

MATERIALS AND METHODS

Source, identification and preparation of raw materials

Carrots provided by Asgrow Seed Company (Kalamazoo, MI) were obtained from two major production regions, Michigan and California, and were received during the period August 1990 though April 1991. Carrot samples were grown at 3 locations, in each region: Michigan, a) Kalamazoo, b) Cedar Springs, and c) Grant; and California, a) Cuyama, b) Bakersfield, and c) El Centro. Carrots from each growing location were harvested by hand, held in large polyethylene (PE) plastic bags (10 to 12 carrots per bag) twisted and express shipped to Michigan State University (MSU), Fruit and Vegetable Processing Laboratory. Approximately 15 to 22 cultivars per shipment were received according to the schedule presented in Table 2.

Immediately upon receipt, raw carrots were washed with running tap water (room temperature) to remove the surface soil. After washing, all foliage was cut from the carrot tops, carrots were drained, placed in clean polyethylene (PE) plastic bags twisted and stored at 40°F (4°C) for not more than one week prior to further preparation.

To evaluate and compare the quality differences among cultivars, three clean carrots were randomly selected from each bag (cultivar/breeding line) and used to conduct the appropriate physical and chemical analyses. The results of

Table 2 Sample array of carrot cultivars or breeding lines produced in three locations each within Michigan and California

Region	Michigan			California		
Location	Kalamazoo	Cedar Spring	Grant	Cuyama	Bakersfield	El Centro
Harvest date	8/90	8/90	10/90	10/90	3/91	4/91
Cultivar/line						
APACHE	X	X	X	X	X	---
BLT#1	---	---	---	X	X	X
BLT#2	X	X	X	X	X	X
BLT#3	X	X	X	X	X	X
CARO-BEST	X	X	X	X	X	X
CAROBRITE	X	X	X	---	---	---
CARO-CHOICE	X	X	X	X	X	X
CARO-GOLD	X	X	X	---	---	---
CARO-PAK	X	X	X	X	X	X
CARO-PRIDE	X	X	X	X	X	X
CELLOBUNCH	X	X	X	X	X	X
CHANCELLOR	X	X	X	X	X	---
DOMINATOR	---	---	---	X	X	X
FANCIPAK	---	---	---	X	X	X
FLAME	---	---	---	X	X	---
GOLDMINE	---	---	---	X	X	---
LONG IMP-58	---	---	---	X	X	X
PARAMOUNT	X	X	X	---	---	---
SIX PAK	X	X	X	X	X	X
SIX PAK 2	---	---	---	X	X	---
SIX PENCE	---	---	---	X	X	X
TX GOLDSPIKE	---	---	---	X	X	---
XPH 3485	X	X	X	---	---	---
XPH 3504	X	X	X	---	---	---
XPH 3507	X	X	X	---	---	---
XPH 3624	X	X	X	---	---	---
XPH 3649	---	---	---	X	X	---
XPH 3706	---	---	---	X	X	X
XPH 3708	X	X	X	X	X	X
Field numbers	M1033 to M1048	M6001 to M6018	M1037 to M1054	C1001 to C1022	C3025 to C3048	C5001-C5002 C5005-C5006 C5008-C5011 C5013-C5016 C5020-C5022

"X" cultivar/line sample entry evaluated for location

"---" cultivar/line sample was not available for study

these quality evaluations are reported in APPENDIX II. During cultivar quality evaluation, carrots were divided into two groups, one for the physical tests and the other for the chemical analyses. Three carrots were selected for physical tests and were left whole to be used in the breaking test. Another three were cut into 2.3 cm-diameter and 2.3 cm-long cylinders for the TPA (Texture Profile Analysis) test.

Extended shelf-life storage studies

After breeding line evaluation, three cultivars (CARO-BEST, IMPERATOR-58 and DOMINATOR), were selected according to their physical and chemical characteristics and were used in each of three storage studies. These studies included: STUDY I, controlled atmospheres (CA); STUDY II, modified atmosphere (MA); and STUDY III, dipping pre-treatments. The conditions for these extended shelf-life studies are presented in the Methodology of each study: 1) CA storage: Carrots were packaged and stored for up to 4 weeks at 0-1^{o}C and at pre-adjusted flow through gas environments in a glass jar (1500 cc.). 2) MA storage: A specified amount (122 g) of sliced carrot sticks per bag were stored at 0-1^{o}C, 97-98%RH under modified gas conditions for 5 weeks. 3) Dipping treatment storage: Five food-grade chemicals (citric acid/ascorbic acid, $CaCl_2$, glucose, lecithin and sodium metaphosphate) and their mixture (Table 3) were applied to

TABLE 3 TREATMENT DESIGNATION OF STUDY III			
#	dipping chemicals	conc. (%)	treatment description
1	citric/ascorbic acids	0.01	combined citric and ascorbic acids, monohydrate
2	calcium chloride ($CaCl_2$)	0.002	dihydrate salt ($\cdot 2H_2O$)
3	glucose	0.7	dextrose anhydrous powder
4	lecithin	0.02	bean lecithin
5	Mixture	---	combined #1-4 chemicals with the same concentrations
6	sodium meta-phosphate	0.1	monohydrate
7	deionized water	---	as control

the surface of carrot sticks by total submersion dipping prior to storage at 0-1°C, 97-98%RH for 3 weeks.

Preparation of packages

Packaging material used for CA and MA storage was 2 mil Polyethylene (PE) #550 film (Dow Chemical Co.). The O_2 and CO_2 permeability of this film are 7.11E-9 and 3.65E-8 mmole.cm/cm^2/hr/kpa, respectively. Film was cut into 20 cm x 24 cm (960 cm^2 surface area) plastic bags and heat sealed using a Magneta Heat Sealer-621 series (Packaging Aids Co., CA). One end of each bag was left open until filled with carrot samples and then heat sealed. Bags used for MA storage were first checked to ensure freedom from any scratches or flaws and then each bag was fitted with a sampling septum using a small portion of silicon previously cured on a short strip of polyvinyl chloride (PVC) tape to be used for multiple gas sampling. Bags used for CA storage were punched with 40 needle holes (20 gauge) each to ensure efficient gas flow through the package with minimum desiccation to the carrot sticks.

Preliminary storage test

Washed carrots of mixed cultivars were cut into 6 cm-long sticks, rinsed, and weighed into 20, 60, 100, 150, 250, and 400 gram lots then placed separately in 20cm x 20cm PE plastic bags, sealed, fitted with silicon septums, and

stored in 0-1°C chamber. Gas compositions (oxygen and carbon dioxide percentages) were measured following 1, 2, 5, 7, 9, 13, 14, and 15 days of storage with a CO_2 infrared **Gas Analyser (ADC-225-MK3)** which was coupled in series with an oxygen analyser S-3A/II equipped with an oxygen sensor N-37 (METEK Co., Pittsburgh, PA). Headspace gas samples (0.5 ml) were taken from the bags, by inserting a plastic syringe (50 units) through the silicon septum, removing the aliquot and then injecting into the gas analyzer. The results for gas composition (O_2 and CO_2) were obtained using a strip chart recorder (Linear 1200). After the storage period, the equilibrium respiration rates and respiration quotient (RQ) value of carrot sticks were calculated and used for determining the optimum sample weight per surface area of PE bag (Appendix I).

Methodology of Quality evaluation

Carrot quality has been evaluated by numerous workers (Mackey et al., 1973; Hard et al., 1977) and some of the quality parameters which they have defined were used in our studies.

The outline for the quality evaluation of fresh carrots is presented in Figure 2. Physical, chemical analysis and sensory evaluation have been viewed as the major quality factors for fresh market vegetables. For ready-to-use carrot sticks the following quality evaluation methods were

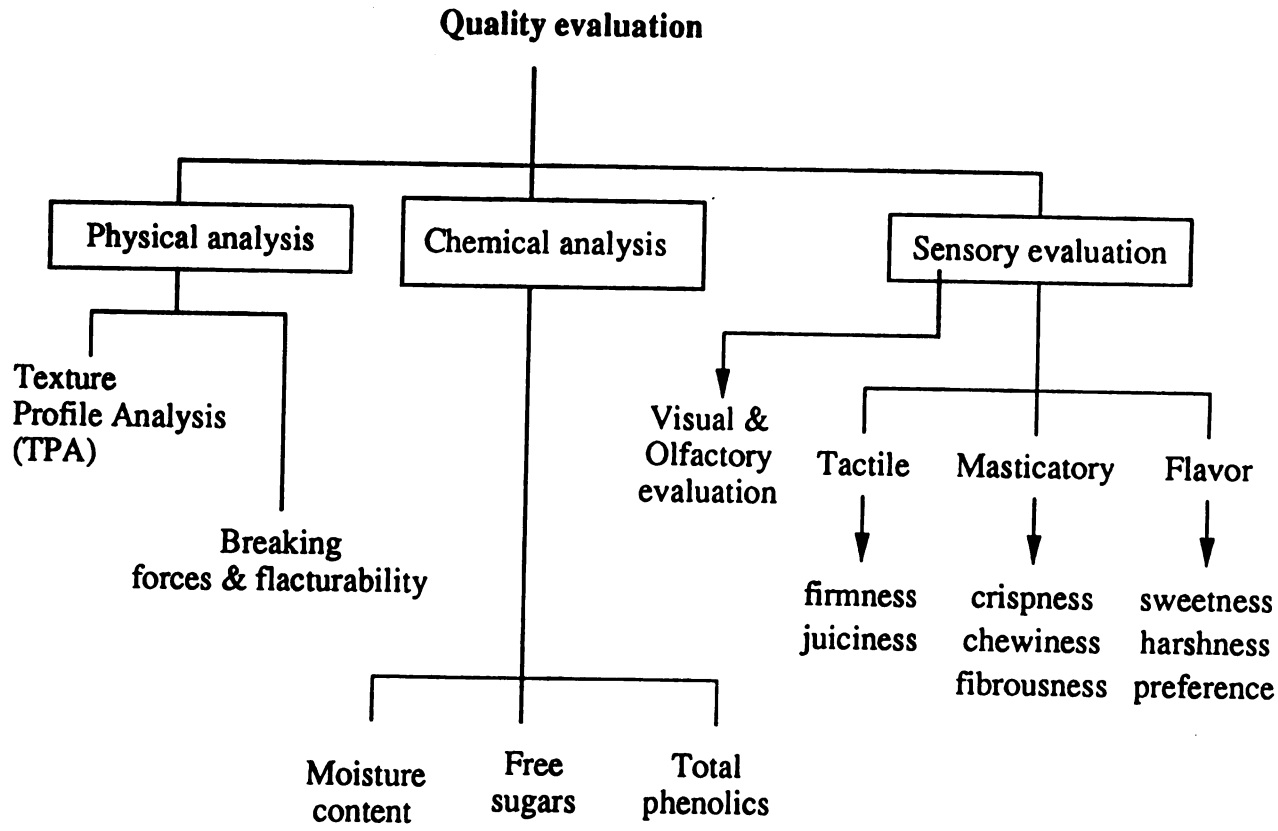


Figure 2. Flow chart of the quality evaluation of carrot sticks used in all studies

used.

Physical analysis

1) Breaking Test: Three whole carrots of each cultivar were analyzed in this test using the **TMS-90 Texture Press** system (Food Technology Corporation, Maryland). A breaking jig using stainless steel breaking rods was fabricated in the MSU, Department of Agriculture Engineering, machine shop (Figure 3). Carrots were first measured for overall length (centimeter from crown to tip) then placed between the supporting rods just prior to moving the upper transducer mounted breaking bar downward. The breaking point was set at the middle 1/3 portion of the whole carrot; and the carrot diameter (cm) at breaking point could be estimated by moving the upper rod (connected with the transducer ram) down to just touch the carrot surface. Breaking test of the carrot sticks was established by placing the 6-cm stick between the supporting rods. The mechanism and calculations of these points are presented in Figure 4. The speed of the transducer was kept at 0.5-0.6 cm/sec and operated in the manual mode so that the transducer could be stopped manually following sample breakage and the maximum force and breaking force-distance curve would be plotted and data recorded. These data were collected to calculate the breaking failure and the force per cross section area expressed as Newton (N) per square centimeter.

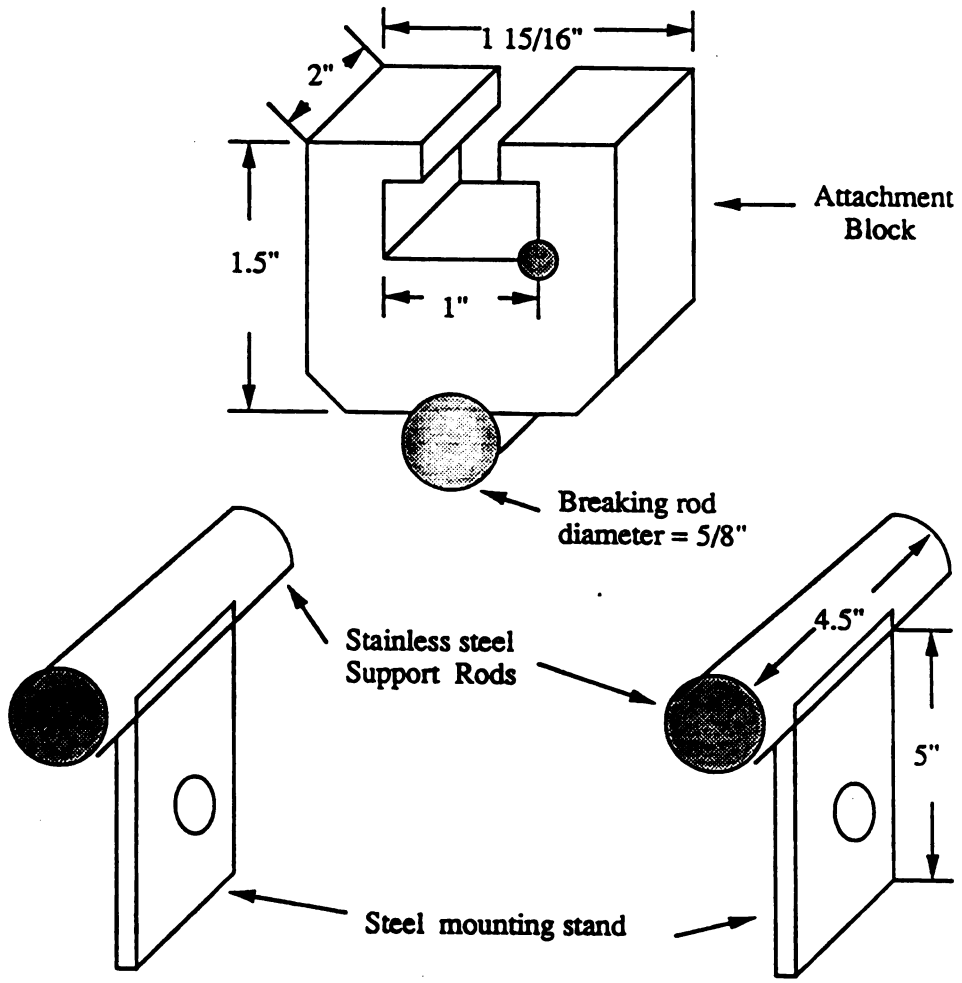
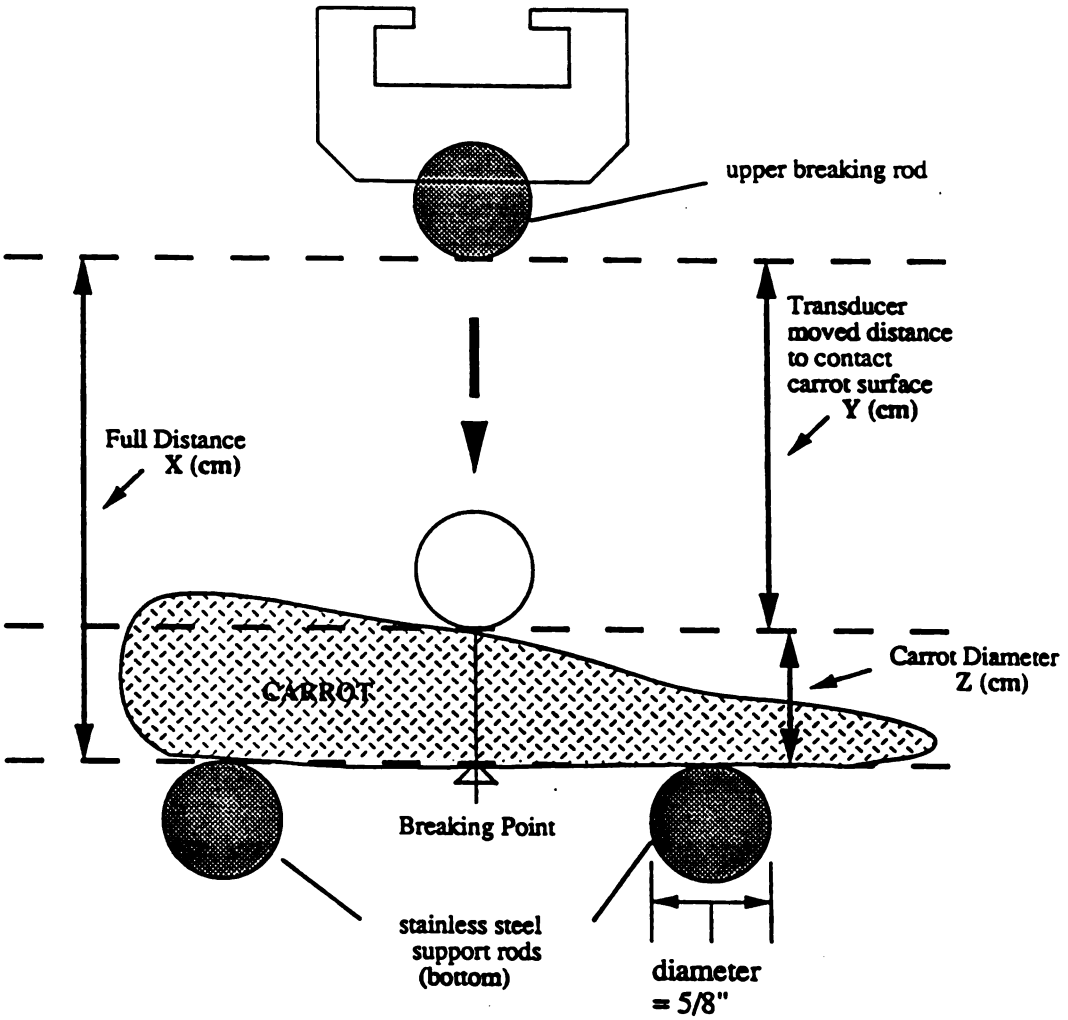


Figure 3. The Breaking Test Cells made by Dept. of Agriculture Engineering; modified from Food Technology Co. BC-1 cell



CALCULATION EQUATION:

CARROT DIAMETER (cm) (at Breaking Point)
= Full Distance (X) - Transducer distance to contact (Y)

Figure 4. The mechanism and simple calculation used in the breaking test

2) Texture Profile Analysis (TPA): Texture Press **TMS-90** was used in this test, equipped with a parallel plate compression cell **TPA-1** (Food Technology Corporation, Maryland) (Figure 5). TPA test is a two-bite compression mode previously programmed to a specified percentage of deformation. Carrot cylinders from the middle portion of whole carrots (middle 1/3) were cut into pieces 2.3 cm in diameter and 2.3 cm in length. Three cylinders from each cultivar were placed at the center of the lower compression plate with cross-section area facing the front side. Compression tests were thus conducted as a composite of three carrot pieces compressed parallel to the longitudinal axis. Initially the transducer (upper compression plate) was moved down to about 1 cm above the sample, then by pressing the "RUN" command the carrot cylinders would be compressed twice with a designated 10% compression distance. After each two stage compression sequence, the TPA force-distance curve and complete TPA analysis data was plotted directly (TMS-90 Control Panel). A typical TPA force-distance curve is found in Figure 6. The hardness (N) of TPA parameters was recorded to be used in the textural interpretation of the cultivar evaluation.

Chemical analysis

Carrots used for chemical analysis were cut into discs immediately after physical tests. Three (3) carrot roots

THE TPA-1 CELL

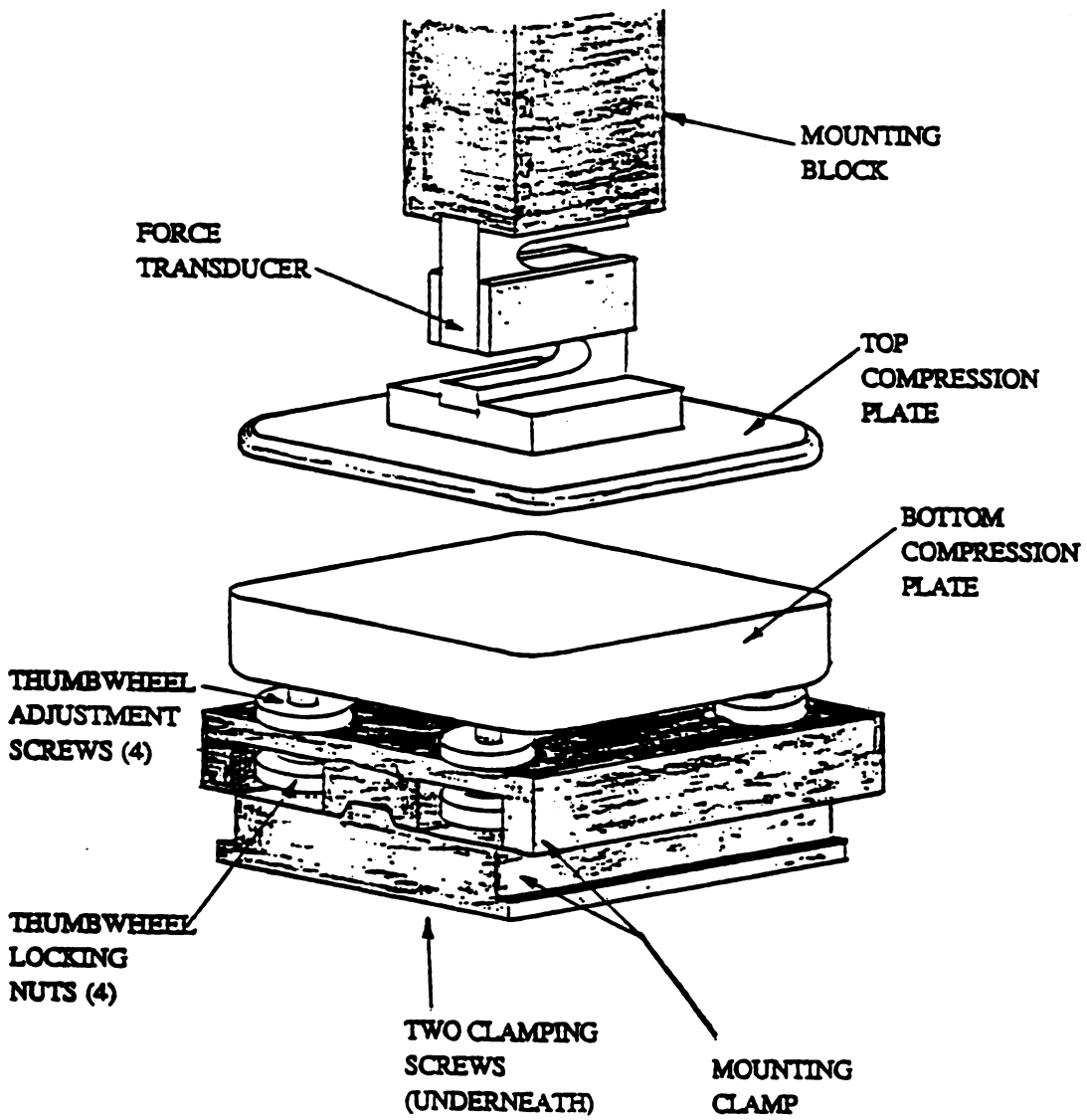
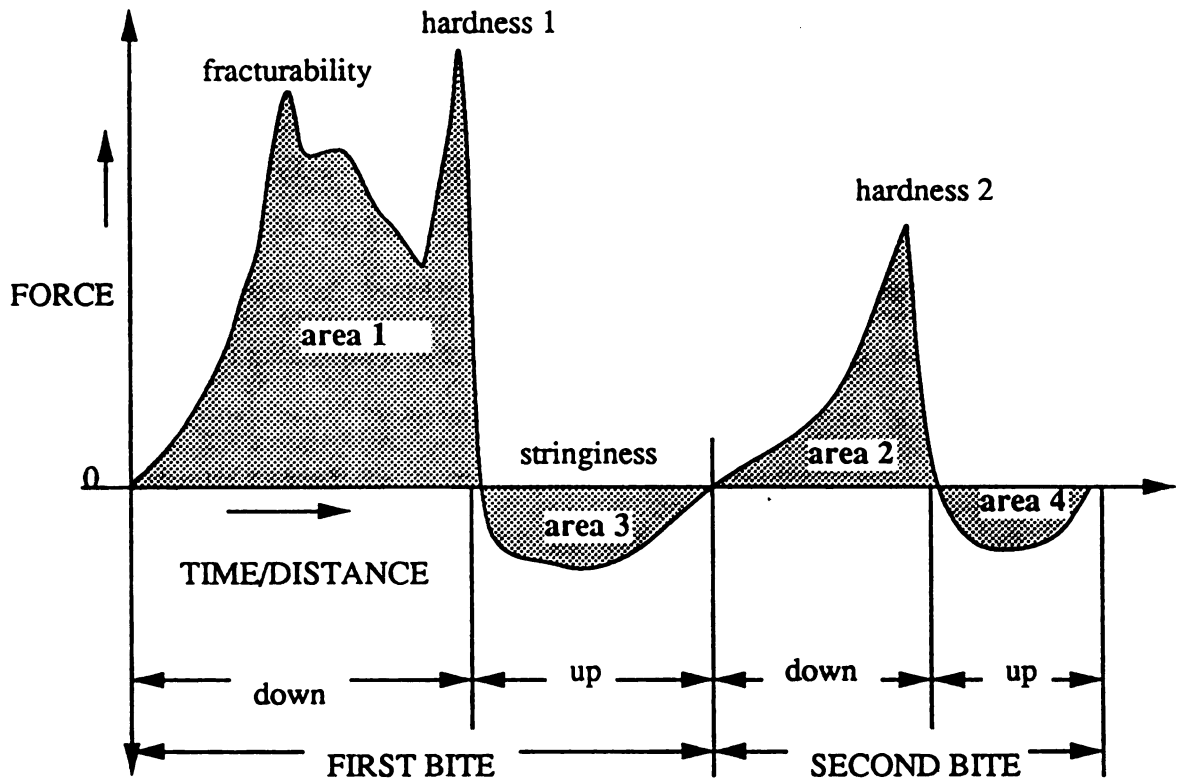


Figure 5. The TPA-1 Cell used in Texture Profile Analysis (TPA test); from Food Technology Co., Maryland



PARAMETER	FORMULA	UNITS
HARDNESS	value of hardness1	lb or Newton
COHESIVENESS	area 2/area 1	-
ADHESIVENESS	area 3	in-lb or N-cm
STRINGINESS	distance of area 3	in or cm
GUMMINESS	hardness x cohesiveness	-
CHEWINESS	gumminess x springiness	-
SPRINGINESS	distance of area 2	in or cm
FRACTURABILITY*		

* Operator calculated from the graph chart.

Figure 6. Typical TPA curve for objective evaluation of food texture (from manual of TMS-90 Texture Press, Food Technology Co., Maryland)

were randomly selected from each cultivar, and the middle 1/3 of the roots were cut into 6 mm-thick slices using a food processor (Cuisinart DLC-7FPC, NJ). Cut slices were packed into a clean polyethylene plastic bag and held at -10°C prior to use for direct analyses or for subsequent freeze drying. Frozen samples were used to determine the total soluble solids; and freeze-dried samples were used for the analyses of sugar and total phenol content.

Approximately 40 g of frozen carrot slices were randomly picked from each bag, placed on an aluminum tray and lyophilized in a freeze-drier (Virtis Co. Inc., Gardiner, NY). The shelf temperature was set at 80-100°F, and the carrot samples were lyophilized for about 48 hours. Dry slices were milled into powder by passing through a Wiley mill (Arthur H. Thomas Co., PA) equipped with a 30 mesh sieve. Milled carrot powders were held in glass vials, stored over $CaCO_2$ in a desiccator, and maintained at 4°C prior to analyses.

1) Moisture content: Broken carrots after the breaking test were used to determine the moisture content. About 5 g of carrot slices were cut from fresh carrots. These carrot slices were weighed to $\pm$0.01 g and the fresh weights recorded. Samples were vacuum-dried at 70°C for at least 20 hours in vacuum oven (model 5831, NAPCO, Oregon). Dried samples were weighed again, and the % moisture content were calculated as :

$$\% \text{ moisture} = \frac{(\text{fresh initial weight}) - (\text{final weight})}{(\text{initial sample weight})} \times 100\%$$

2) Total Soluble Solids: Frozen slices were randomly selected from each bag and thawed at room temperature for 5 minutes. Total soluble solids were measured by manually pressing the thawed carrot slices and directly applying the extruded juice to a hand-held refractometer (0-32%, Fisher Scientific co., Chicago). The readings on the refractometer were recorded as ^{o}Brix.

3) Free Sugars: Sucrose, glucose and fructose (Sigma Chemical Co., MO) were used as free sugar standards. The preparation procedures of standards and samples are outlined in Figure 7. Free sugars were analyzed by High-Pressure Liquid Chromatography (HPLC) according to the modified method of Freeman and Simon (1983). The HPLC system contained a 6000A solvent delivery pump (Waters assoc. Inc., MA), an U6K liquid chromatograph injector (Waters, MA), a Differential Refractometer R401 (Waters, MA), and a 300 x 4.1 mm C18 Carbohydrate analytical column (10 u) (Alltech assoc. Inc., IL). 25 ul sample extracts were injected, and the flow rate was adjusted to 1.5 ml/min. Refractometer was set at 8X to resolve desirable peaks, and the results plotted by a M730 Data Module (Waters, MA). Samples were expressed as mg/g on a dry weight basis.

4) Total Phenol Content: The method used in the analysis was modified from Goldstein and Swain (1963), with

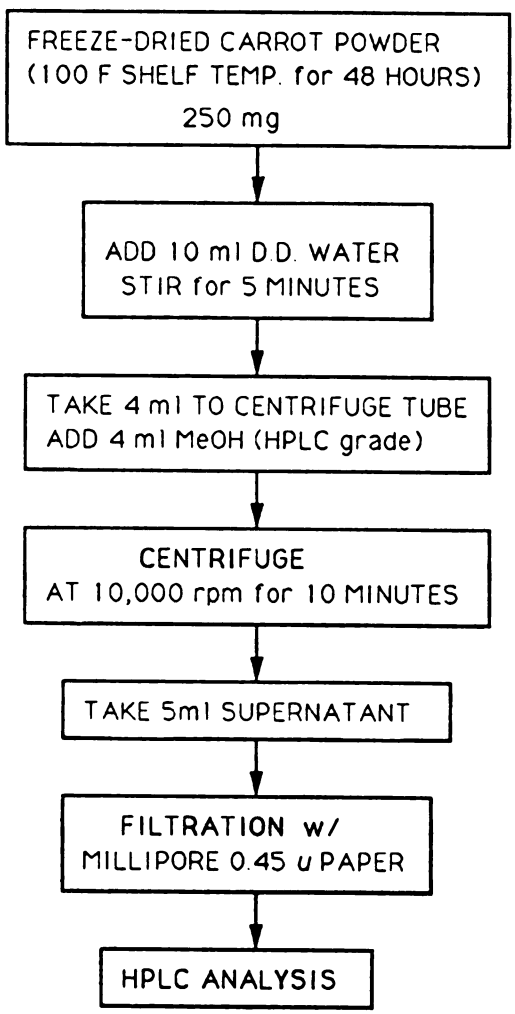


Figure 7. The Flow chart of Sugar extraction and analyses of carrot root tissue (dry powder)

Folin-Denis reagent replaced by Folin-Ciocalteau reagent (Sigma Chemical Co., MO) according to the procedures of Senter et al. (1989). The analytical procedure used is presented in Figure 8. Carrot powder held less than 2 days at 4°C was extracted in methanol by sonication in a Bransonic-3200 sonicator (Branson Ultrasonics co., CT) and centrifuged by Sorvall RC-5B refrigerated centrifuge (Du Pont Inc., IL) at 10,000 r.p.m. for 10 minutes. The absorbance was measured spectrophotometrically with a Spectronic-70 (Bausch & Lomb, IL) at a wave length of 725 nm. The experimental results were recorded as mg/g dry carrot powder.

A standardization curve was generated using chlorogenic acid as the standard phenolic compound. Twenty (20) milligrams chlorogenic acid were dissolved in 100 ml deionized water and made to volume in a volumetric flask. Aliquots of 1 to 10 ml standard solution were pipetted into 100 ml volumetric flasks containing 50 ml of deionized water. 5 ml of Folin-Ciocalteau reagent and 10 ml of 1 N sodium carbonate solution were added to those flasks, diluted to mark with deionized water and mixed well. These standard solutions were held at room temperature for 1 hour to ensure full reaction (the color turned to its maximum intensity) prior to spectrophotometric reading at 725 nm. The absorbance was determined for each solution, and the standard curve was plotted by absorbance against milligram

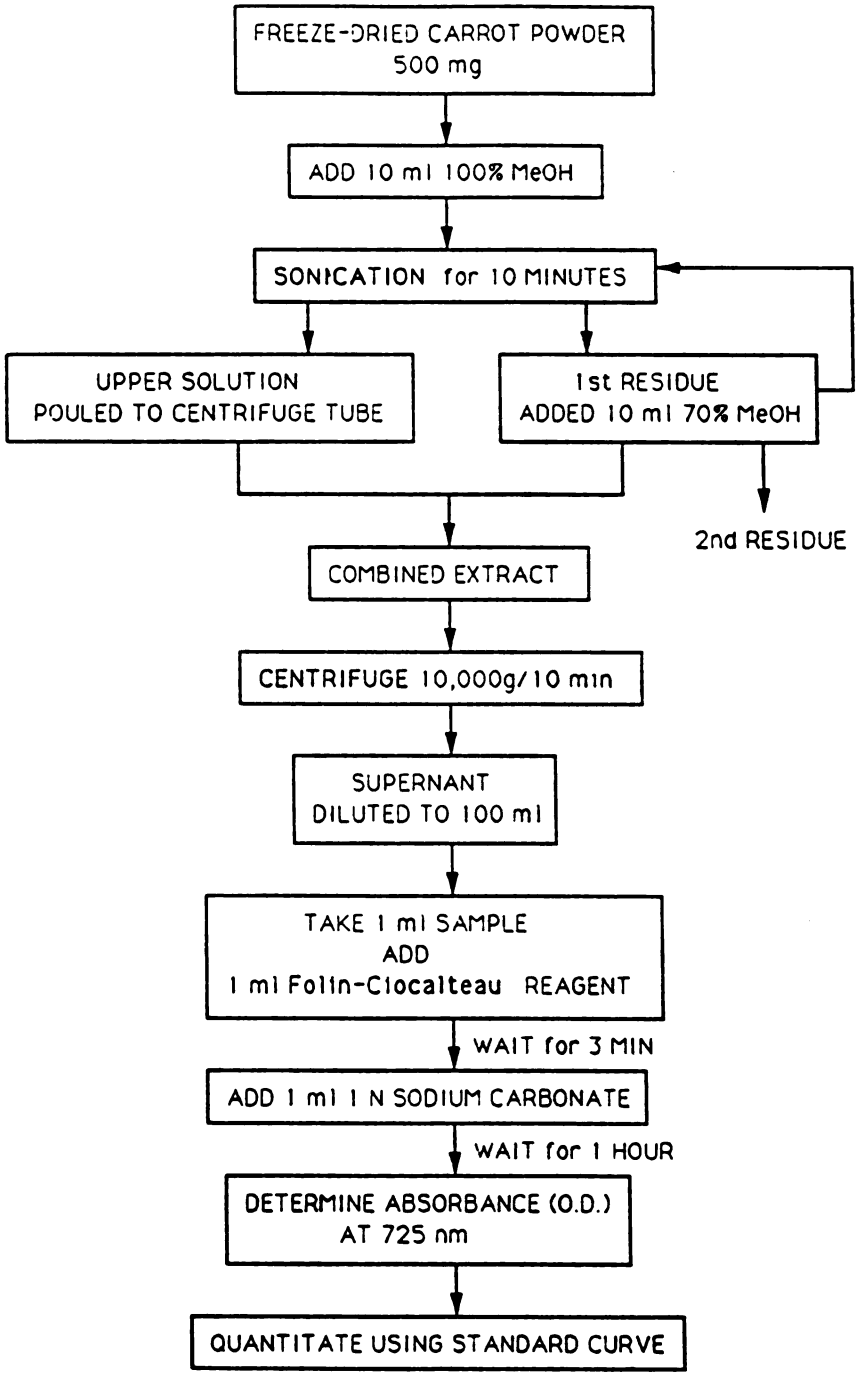


Figure 8. The Flow chart of total phenolic compound extraction and analyses of carrot root tissue (dry powder)

of chlorogenic acid per ml solution (Figure 9). All the measurements were done in duplicate.

Sensory Evaluation

Quantitative Descriptive Analysis (QDA) was developed according to the basic outline of the technique as described by Stone et al. (1974), which includes a uniform product language (terminology and descriptors), a standardized evaluation procedure, panelist training, statistical evaluation of panelist data, and the graphical interpretation of results. This analysis was used through out this work (STUDY I, II and III).

Four panelists were trained two days prior to evaluation by group discussion to identify and quantify the sensory properties of the product in order of occurrence. A score sheet (Figure 10) was developed using a ten centimeter unstructured line with key anchor words or phrases at each end describing the product attributes. The panelists were asked to evaluate each series of samples by marking the line where it best represented the perceived attribute. Values were assigned by measuring the distance from the "least anchor point" (left) in cm. Two to three carrot sticks were given to each panelist, also napkins and rinsing water were provided. An example of the graphical presentation used for QDA results is found in Figure 11.

Reference (Figure 12) and score sheets were provided to

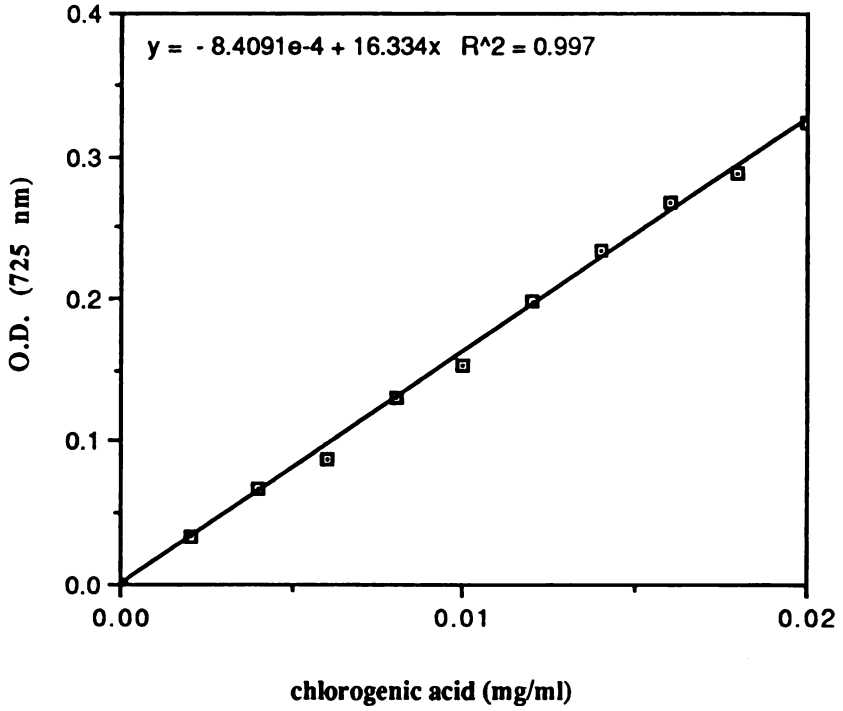


Figure 9. Standard curve of total phenolic compound analysis using chlorogenic acid as standard.

CARROT SENSORY EVALUATION
QUANTITATIVE DISCRIPTIVE ANALYSIS

The sensory profile panel consists of three separate evaluations involving tactile (feel), masticatory (chewing), and flavor evaluation. The following instructions and guidelines to help you understand the testing procedures and terminology used in a sensory profile.

Please taste the sample and answer each question in sequence, placing a vertical line across the horizontal line at the point that best discribes that property in the sample.

NAME_____ SAMPLE CODE_____ DATE_____

TACTILE

1. firmness — soft ——— firm
2. juiciness — dry ——— juicy

MASTICATORY

3. crispness — rubbery ——— crisp
4. chewiness — soft ——— hard
5. fibrousness — smooth ——— fibrous

FLAVOR

6. sweetness — weak ——— strong
7. harshness — mild ——— strong
8. overall preferance — dislike ——— like very much

Figure 10. The score sheet used in sensory evaluation; scales = 0 (left, least) to 10 (right, most)

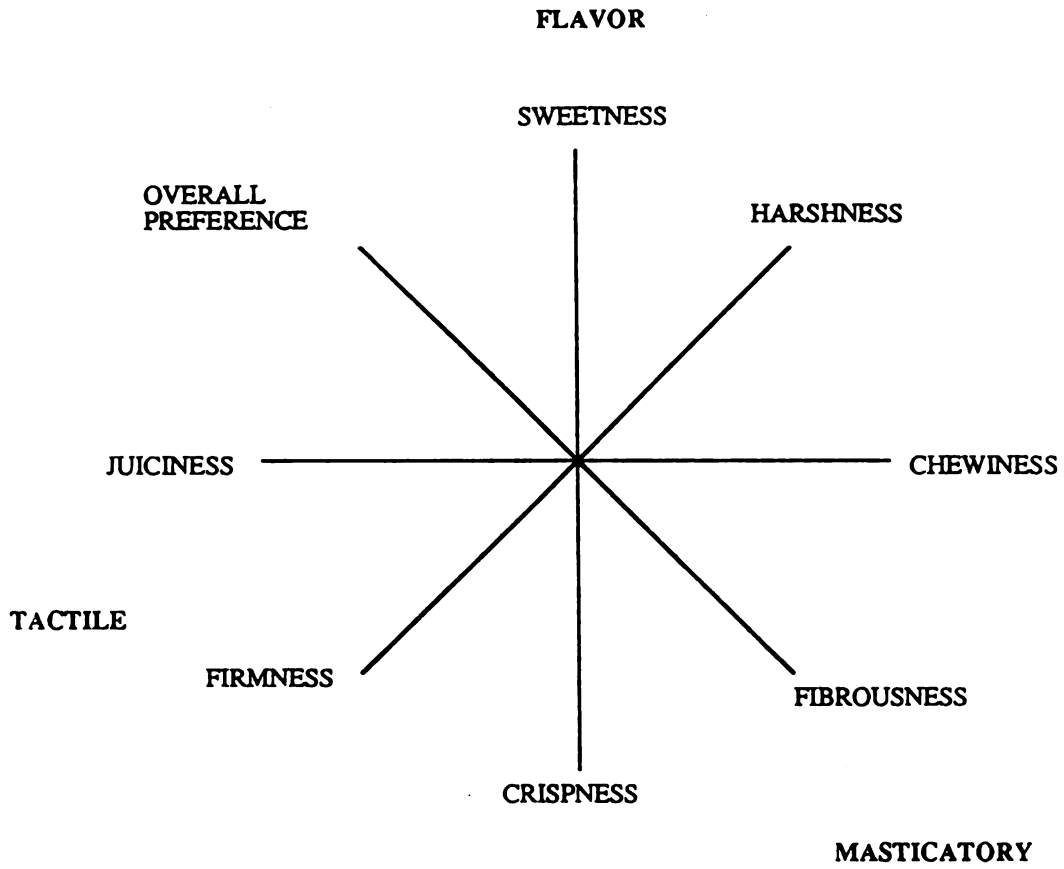


Figure 11. The Quantitative Descriptive Analysis (QDA) diagram used in final sensory expression; each line start from center: 0 (least) to 10 (most); adjacent parameters have higher correlation coefficient

Carrot Texture and Flavor Descriptive Analysis

The sensory profile panel consists of three separate evaluations involving tactile (feel), masticatory (chewing), and flavor evaluation. The following are instructions and guidelines to help you understand the testing procedures and terminology used in a sensory profile panel.

Please taste the sample and answer each question in sequence, placing a vertical line across the horizontal line at the point that best describes that property in the sample:

1. **Tactile** This test is performed with 2 or 3 individual carrot sticks. Place one stick between your thumb and forefinger. Apply pressure and twist fingers a little to the right to evaluate the following:
   a) **firmness** the amount of force required to compress the sticks
   b) **juiciness** use thumbnail to test the ease and amount of juice squeezed out of the sticks

2. **Masticatory** Pick up 2 carrot sticks and press them between your teeth to evaluate for:
   a) **crispness** ease of teeth biting into the carrot
   b) **chewiness** resistance of the product to compression and shearing action of the teeth
   c) **fibrousness** presence of an inedible residue remaining in the mouth after mastication

3. **Flavor** Chew 1 or 2 sticks in mouth and taste aroma and flavor
   a) **sweetness** sweet taste feel from the tip of the tongue
   b) **harshness** strong, burning, turpentine-like flavor most perceived at the back of the throat during or after chewing.

4. **Overall preference**
   combine the texture and flavor performance and score the overall preference

Figure 12. The instruction sheet used in sensory evaluation

panelist for the sensory textural and flavor evaluation of carrot sticks. Tactile and masticatory techniques were used to evaluate the textural characteristics and subsequent tasting was used for assessment of flavor characteristics of fresh-cut carrot sticks. Tactile evaluation was done by compressing the carrot sticks manually between the index finger and the thumb and rating the response for (1) firmness and (2) juiciness. Masticatory evaluation including (3) crispness, (4) chewiness and (5) fibrousness required the panelists to chew each piece with their molars to compress and break the carrot pieces in order to evaluate the perceived mouth feel and resistance of texture. While chewing the carrots, panelists were requested to evaluate the flavor aspects as (6) sweetness and (7) harshness prior to swallowing or expectoration. Finally the (8) overall preference was rated by the expression of an overall composite of all previous parameters.

Statistical Analysis

The "LOTUS123" and "MSTAT" computer programs were used for data computation and statistical analyses.

Two-way and three-way analyses of variance were determined using the subprogram FACTOR. Mean squares were reported after rounding, and significant probability levels were set at $p \leq 0.05$ (*), $p \leq 0.01$ (**). Coefficient of variation (%CV) which expresses the standard deviation as a

percent of the mean was calculated.

Least significant difference (LSD) mean separations were used for single classification analyses by the subprogram RANGE. These were used to compare selected cultivar and treatment differences. The standard deviation was presented with each mean, and $LSD_{0.05}$ values were indicated to show the significant differences between means.

STUDY I. Effect of controlled CO_2 concentrations in atmosphere on quality changes of prepared carrot sticks

Hypothesis (Ho): Ho.1-1) Different controlled storage environments created by changing carbon dioxide concentration will not improve the quality of carrot sticks. **Ho.1-2)** The sample peeled and non-peeled treatments and cultivars will not affect their overall quality.

Objectives

The goal of this study was to evaluate the effectiveness of different CO_2 concentration, peeling treatments, and cultivars for improving the physical, chemical and sensory quality through extended controlled environmental storage.

Methodology

Samples of three cultivars (CARO-BEST, IMPERATOR-58 and DOMINATOR) were obtained from California (Asgrow Seed Co.) for this storage study.

A brief flow-chart of the experimental design of this study is presented in Figure 13. After preliminary preparation of raw material, washed carrots were divided for two groups of treatment, non-peeled and peeled carrots. Both carrot groups were cut into 6-cm-long, 1-cm^2 cross-section-area sticks. After cutting, these sticks were

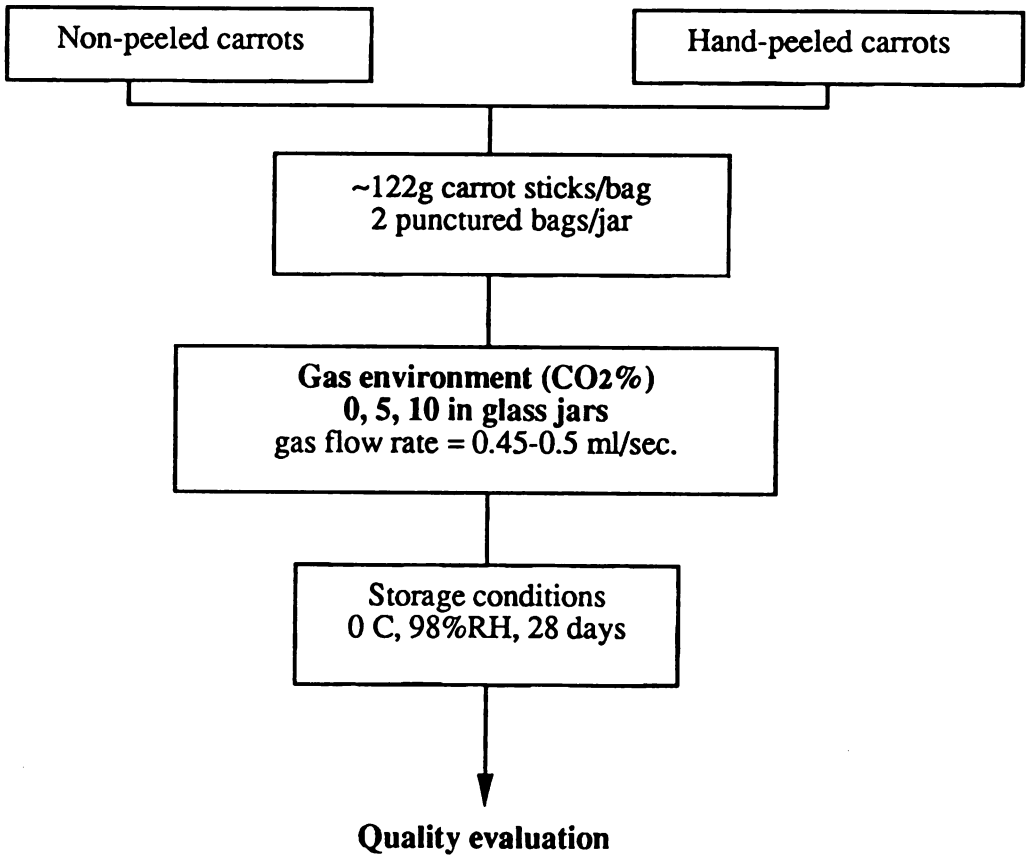


Figure 13. Flow chart of the experimental design of controlled atmospheric storage study (STUDY I)

rinsed with tap water (at room temp.) prior to packaging. In order to prevent the moisture loss, 20cm X 20cm PE plastic bags were prepared to hold these sticks in the scale of 122 g carrot sample per bag. Two bags were held per glass gas flow storage jar (1500 cc.) each equipped with inlet and outlet rubber tubes inserted through the lid. These plastic bags were punched with 20 needle holes in each side to ensure the flow of controlled gases. In individual storage chambers, gases with different percentage CO_2 (0, 5 and 10%) were adjusted and each maintained at the same percentage O_2 (5%). Nitrogen was used in each treatment as the carrier gas. These controlled gases were well mixed in a small vial with flow rate about 0.45-0.50 ml/sec prior to flow into the sample jars. Jars were sealed with silicon gel, and the gas concentrations and flow rate were monitored and adjusted if necessary.

Following 28 days of storage at 0-1°C and 97-98%R.H., these CA carrot sticks (4 replicate bags/ treatment) were used for the sensory evaluation, physical, and chemical analyses as in previous MATERIALS AND METHODS in sequence in order to evaluate the effect of controlled atmospheres on the storage stability and quality.

Results and discussion

Physical Analysis

Analysis of variance, mean values and standard

deviations, and Least Significant Difference (LSD) mean separations for physical tests (breaking force and breaking failure) of peeled and non-peeled carrot sticks prepared from CARO-BEST, IMPERATOR-58 and DOMINATOR are summarized in Table 4 and Table 5.

The mean squares for 3 cultivars and 2 peeling treatments, held under 3 different CO_2 concentration environments indicate no significant difference for breaking force per cross section area (force/CSA) among the various carrot cultivars, nor among all treatments. Figure 14 shows there was no significant effect of cultivars over all the treatments. However, a significant difference is observed in the breaking failure among the peeling treatments (Table 4). Peeled carrot sticks showed higher breaking failure (1.11 cm) than non-peeled sticks (1.01 cm) (Figure 15). That is, lower breaking stress/strain (slope) was found with peeled carrot sticks under controlled atmospheric storage. According to the typical breaking curve, higher breaking failure (longer distance from touch to break) partially represents less fragile texture. The reasons for this observation could be the moisture loss in carrot sticks.

The effect of CO_2 concentration was not significant among all treatments in the physical evaluation. No microbial problem was observed among the CO_2 environments, however, some "whitening" did develop. This whitening has been investigated and attributed to be the result of certain

Table 4. ANALYSIS OF VARIANCE FOR PHYSICAL BREAKING TEST OF CARROT STICKS HELD UNDER CA STORAGE AT 0-1°C, 97-98%RH FOR 28 DAYS

source of variance	df	Breaking force/CSA (N/cm^2)	Breaking failure (cm)
		MEAN SQUARES[1]	
Main Effects			
cultivar	2	39.84	0.01
treatment[2]	1	46.03	0.21*
CO_2 (%)	2	38.46	0.04
Two Way			
cultivar x treatment	2	3.71	0.02
cultivar x CO_2 (%)	4	25.14	0.03
treatment x CO_2 (%)	2	48.80	0.16*
Three Way			
cultivar x treatment x CO_2 (%)	4	18.64	0.05
Error	71	43.83	0.04
%CV		41.19	19.54

1. n = 5, * = significant at $p \leq 0.05$
2. treatments included peeled and non-peeled carrot sticks.

TABLE 5 MEAN VALUES[1] OF PHYSICAL BREAKING TEST OF CARROT STICKS HELD UNDER CA STORAGE AT 0-1°C, 97-98%RH FOR 28 DAYS WITH DIFFERENT CO_2 CONCENTRATION ENVIRONMENTS

cultivar/ treatment	carbon dioxide concentrations (CO_2 %)					
	0		5		10	
	force/CSA (N/cm^2)	breaking failure (cm)	force/CSA (N/cm^2)	breaking failure (cm)	force/CSA (N/cm^2)	breaking failure (cm)
CARO-BEST						
peeled	17.28±9.83	1.05±0.16	11.41±3.68	1.08±0.36	15.47±11.7	1.29±0.34
non-peel	15.93±3.89	1.08±0.13	14.41±7.36	0.95±0.17	15.72±5.25	1.01±0.12
IMPERATOR						
peeled	17.65±5.67	1.14±0.11	14.66±4.98	1.03±0.22	16.67±6.50	1.03±0.14
non-peel	17.82±8.45	1.12±0.23	20.18±7.16	0.98±0.24	16.90±6.73	1.00±0.03
DOMINATOR						
peeled	15.38±3.72	0.99±0.14	14.57±7.25	1.11±0.12	15.14±4.95	1.27±0.39
non-peel	20.14±6.38	1.14±0.14	18.32±5.61	0.98±0.14	11.67±3.87	0.87±0.14
Mean separation						
$LSD_{0.05}$	8.37	0.25	8.37	0.25	8.37	0.25

1. n = 5, Least significant difference (LSD) mean separation, significant at $p \leq 0.05$

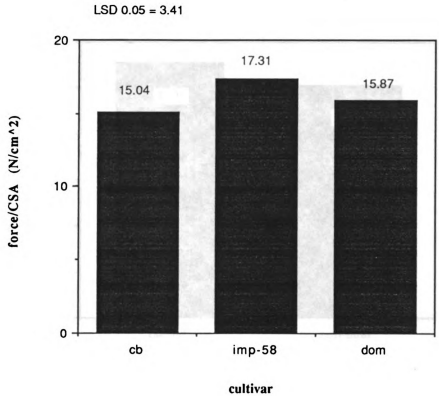


Figure 14. Mean values of the breaking force/CSA for carrot sticks of 3 cultivars (CARO-BEST, IMPERATOR-58, DOMINATOR) over all treatments and CO_2 concentrations in CA storage at 0-1°C, 97-98%RH for 28 days; means followed by like letters are not significantly different ($p < 0.05$)

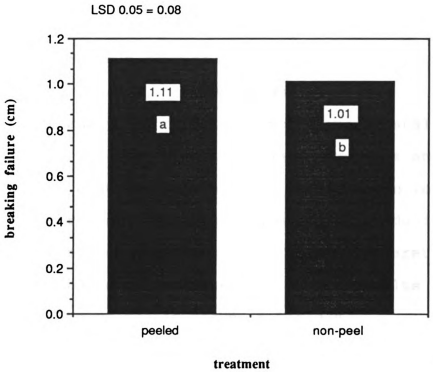


Figure 15. Mean values of the breaking failure for carrot sticks of peeled and non-peeled treatments over all cultivars and CO_2 concentrations in CA storage at 0-1°C, 97-98%RH for 28 days; means followed by like letters are not significantly different ($p < 0.05$)

reactions of phenolic compounds and cell membrane/cell wall during controlled atmospheric storage (Weichmann and Ammerseder, 1974). Since cut carrots are more subject to textural softening and surface "whitening", we found the controlled atmospheric storage in this study was not suitable for cut carrots.

Chemical Analysis

The analysis of variance for chemical analysis, including sucrose, reducing sugars (fructose and glucose) and total phenolic compound, is presented in Table 6. Table 7 presents the mean values, standard deviations, and Least Significant Difference (LSD) mean separations for sucrose and reducing sugars, while the results of total phenolic compounds is shown in Table 8.

Significant differences were found for cultivars, treatments, and different CO_2 concentrations. The effect of cultivar over all the treatments for sucrose was found to be significant (Figure 16). CARO-BEST generally had higher sucrose content (9.62 mg/g dry wt.) than the other two cultivars (7.70 mg/g for IMPERATOR-58 and 7.88 mg/g for DOMINATOR). Lower reducing sugars for CARO-BEST (2.89 mg/g) compared to IMPERATOR-58 (4.47 mg/g) and DOMINATOR (4.13 mg/g) shows CARO-BEST may be the sweetest cultivar in this study and thus possesses desirable qualities for fresh consumption (Figure 17).

Peeled and non-peeled carrot sticks are also

Table 6. ANALYSIS OF VARIANCE FOR CHEMICAL ANALYSES OF CARROT STICKS HELD UNDER CA STORAGE AT 0-1°C, 97-98%RH FOR 28 DAYS

source of variance	df	sucrose	reducing sugars	total phenolics
			MEAN SQUARES[1]	
Main Effects				
cultivar	2	20.09**	12.47**	8.92**
treatment[2]	1	38.12**	1.65	152.36**
CO_2 (%)	2	8.75	0.43	3.04**
Two Way				
cultivar x treatment	2	1.29	0.06	16.54**
cultivar x CO_2 (%)	4	19.43**	0.50	0.42**
treatment x CO_2 (%)	2	15.55**	5.69*	1.12**
Three Way				
cultivar x treatment x CO_2 (%)	4	9.49**	2.79	2.05**
Error	36	2.58	1.48	9.44E-4
%CV		19.14	31.73	0.57

1. n = 3; * = significant at $p \leq 0.05$, ** = significant at $p \leq 0.01$
2. treatments included peeled and non-peeled carrot sticks.

TABLE 7 MEAN VALUES[1] OF SUGAR ANALYSIS OF CARROT STICKS HELD UNDER CA STORAGE OF 0-1°C, 97-98%RH FOR 28 DAYS AT DIFFERENT CO_2 CONCENTRATION ENVIRONMENTS

cultivar/ treatment	carbon dioxide concentration (CO_2 %)					
	0		5		10	
	sucrose[2]	reducing sugars	sucrose	reducing sugars	sucrose	reducing sugars
CARO-BEST						
peeled	6.24±0.35	2.92±0.90	13.69±2.66	1.96±1.18	10.81±1.99	4.48±1.14
non-peel	7.35±0.58	2.35±0.99	7.39±2.12	1.65±0.42	12.21±3.45	3.96±0.87
IMPERATOR						
peeled	9.30±0.84	4.12±0.75	8.25±0.68	5.99±0.73	8.98±1.63	3.82±0.43
non-peel	7.51±1.32	5.04±0.64	6.22±0.93	4.16±0.43	5.95±1.29	3.68±2.10
DOMINATOR						
peeled	6.98±0.51	4.48±2.38	9.83±1.13	3.50±1.86	9.06±2.29	4.75±1.88
non-peel	8.29±0.91	3.94±0.41	6.45±0.89	4.85±1.31	6.65±1.44	3.25±0.50
Mean separation						
$LSD_{0.05}$	2.67	2.01	2.67	2.01	2.67	2.01

1. n = 3, Least significant difference (LSD) mean separation, significant at $p \leq 0.05$
2. All units are presented as mg/g db. (dry bases).

TABLE 8 MEAN VALUES[1] OF TOTAL PHENOLIC COMPOUND[2] ANALYSIS OF CARROT STICKS HELD UNDER CA STORAGE AT 0-1°C, 97-98%RH FOR 28 DAYS AT DIFFERENT CO_2 CONCENTRATION ENVIRONMENTS

cultivar/ treatment	Carbon dioxide concentrations (%)		
	0	5	10
CARO-BEST			
peeled	4.11±0.06	4.10±0.03	3.45±0.03
non-peeled	7.69±0.04	8.64±0.03	6.04±0.03
IMPERATOR			
peeled	3.50±0.01	3.06±0.03	3.19±0.03
non-peeled	9.01±0.05	8.03±0.05	7.93±0.03
DOMINATOR			
peeled	3.67±0.03	4.72±0.01	3.21±0.01
non-peeled	5.72±0.02	4.48±0.03	5.44±0.03
Mean separation $LSD_{0.05}$	0.06	0.06	0.06

1. n = 3, Least significant difference (LSD) mean separation, significant at $p \leq 0.05$
2. All units are presented as mg/g db. (dry bases).

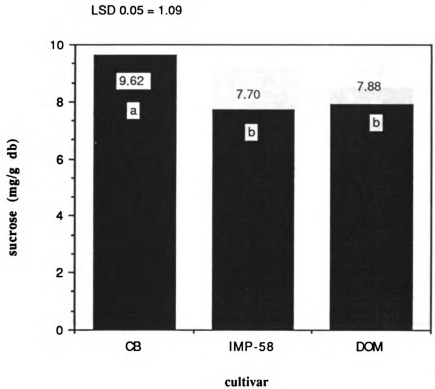


Figure 16. Mean values of the sucrose amount for carrot sticks of 3 cultivars (CARO-BEST, IMPERATOR-58, DOMINATOR) over all treatments and CO_2 concentrations in CA storage at 0-1°C, 97-98%RH for 28 days; means followed by like letters are not significantly different ($p < 0.05$)

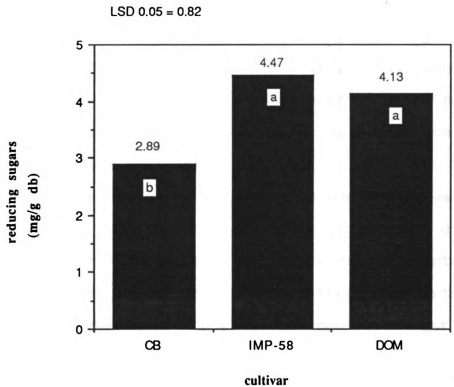


Figure 17. Mean values of the reducing sugars for carrot sticks of 3 cultivars (CARO-BEST, IMPERATOR-58, DOMINATOR) over all treatments and CO_2 concentrations in CA storage at 0-1°C, 97-98%RH for 28 days; means followed by like letters are not significantly different ($p < 0.05$)

significantly different in sucrose amount. Figure 18 showed higher sucrose retention (9.24 mg/g db.) in peeled compared to non-peeled sticks (7.56 mg/g). These results illustrated some relationship between carrot peel condition and carbohydrate metabolism, which was previously studied by Sarkar and Phan (1979). Much higher total phenolic content was observed in non-peeled sticks than in peeled products (Table 8), which demonstrated carrot peel contains most of the phenolic compounds.

Table 6 also shows the difference for chemical analyses among all CO_2 concentrations. No significant differences among main effects were found in sucrose retention and reducing sugar content, however, there were interactions of CO_2 with cultivars and with treatments. Slightly higher sucrose was found in high CO_2 treated sticks (5 and 10%), and these results (Figure 19) are similar to those obtained in the previous study of Weichmann and Ammerseder (1974). Significant differences were found within CO_2 treatments for total phenolic content (Figure 20). Lower total phenolic content was observed in higher CO_2 (10%) treated carrot sticks. Generally, higher sucrose retention and lower phenolic compound formation has been found in samples held under high CO_2 environments.

Sensory Evaluation

The analyses of variance for different sensory profiles presented in Table 9 showed no significant differences

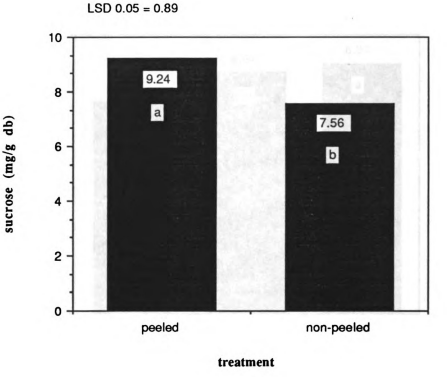


Figure 18. Mean values of the sucrose amount for carrot sticks of peeled and non-peeled treatments over all cultivars and CO_2 concentrations in CA storage at 0-1°C, 97-98%RH for 28 days; means followed by like letters are not significantly different ($p < 0.05$)

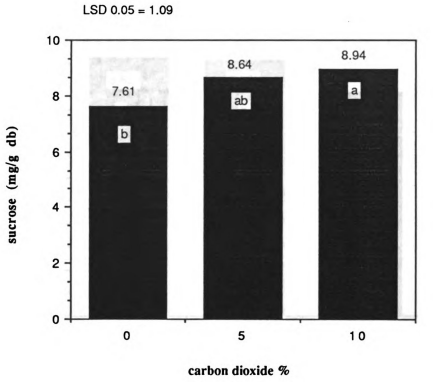


Figure 19. Mean values of the sucrose amount for carrot sticks of 3 CO_2 concentrations (0, 5, and 10%) over all cultivars and treatments in CA storage at 0-1°C, 97-98%RH for 28 days; means followed by like letters are not significantly different ($p < 0.05$)

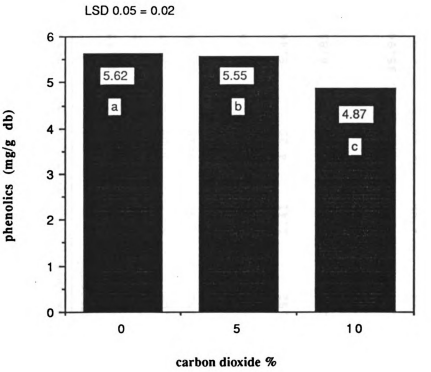


Figure 20. Mean values of the total phenolic compound for carrot sticks of 3 CO_2 concentrations (0, 5, and 10%) over all cultivars and treatments in CA storage at 0-1^{o}C, 97-98%RH for 28 days; means followed by like letters are not significantly different ($p < 0.05$)

Table 9. ANALYSIS OF VARIANCE FOR SENSORY EVALUATION OF CARROT STICKS HELD UNDER CA STORAGE AT 0-1°C, 97-98%RH FOR 28 DAYS

		Sensory Parameters							
		Tactile		Masticatory			Flavor		Overall
	df	firmness	juiciness	Crispness	chewiness	fibrous.	sweetness	harshness	preference
		MEAN SQUARES[1]							
Main Effects									
cultivar	2	4.01	1.09	14.54	5.07	4.61	2.79	13.69	2.39
treatment[2]	1	2.59	5.87	21.07	0.86	0.85	4.21	2.00	0.16
CO_2 (%)	2	2.13	2.99	1.44	0.08	6.11	1.25	2.27	0.71
panelists	3	5.22	1.57	0.15	11.62	7.60	5.18	2.29	7.69
Two Way									
cultivar x treatment	2	2.00	5.53	7.18	4.15	0.02	0.53	6.18	1.08
cultivar x CO_2 (%)	4	3.41	0.93	9.51	1.52	1.41	4.20	5.46	9.71*
treatment x CO_2 (%)	2	10.34	2.47	0.94	11.34	14.02	0.65	6.85	3.18
Three Way									
cultivar x treatment x CO_2 (%)	4	5.72	3.88	2.26	3.02	2.29	8.77	15.94*	1.09
Error	51	4.68	7.94	6.08	5.17	4.78	5.18	6.21	3.39
%CV		33.23	51.16	29.28	35.06	31.72	38.46	49.96	30.20

1. n = 4, * = significant at $p \leq 0.05$
2. treatments include peeled and non-peeled carrot sticks

either among cultivars, treatments or CO_2 concentrations. However, significant interactions were observed in "overall preference" between cultivar and CO_2 concentrations and three-way interactions in "harshness". The mean values, standard deviations, and LSD mean separations for sensory characters are presented in Table 10 and Table 11, and the QDA diagrams of these sensory results are summarized in Figure 21. No apparent relationships were found between objective methods and sensory results. This is attributed in part to the high coefficient of variation (%C.V.) indicating high diversity among panelists, which indicated that the training might not be sufficient.

Conclusions

The data obtained in this study indicated that there were no effect of cultivars, peeling treatments, and CO_2 concentrations on the samples breaking force/CSA. However, peeled samples showed higher breaking failure than non-peeled carrot sticks. Significant differences were also observed in cultivars and peeling treatments for sugars and total phenolic compound analyses, respectively. CARO-BEST had the highest sucrose/reducing sugars ratio among all cultivars, and peeled carrot sticks developed less total phenolic content than non-peeled treatment. Additionally, high CO_2 storage conditions reduced sucrose degradation and limited the formation of total phenolic compounds.

TABLE 10 MEAN VALUES[1] OF SENSORY EVALUATION[2] OF CARROT STICKS HELD UNDER CA STORAGE AT 0-1°C, 97-98%RH FOR 28 DAYS WITH DIFFERENT CO_2 CONCENTRATION ENVIRONMENTS

cultivar/ treatment	Tactile		Masticatory			Flavor	
	firmness	juiciness	crispness	chewiness	fibrousness	sweetness	harshness
			CO_2 = 0%				
CARO-BEST							
peeled	5.35±2.79	5.57±3.38	4.75±0.48	4.17±2.50	4.20±2.50	4.73±2.33	2.54±2.99
non-peel	7.79±2.01	6.31±2.55	7.93±2.28	6.43±2.23	6.63±3.61	5.86±2.73	7.40±0.52
IMPERATOR							
peeled	6.18±1.67	4.30±1.05	5.03±3.66	5.19±2.65	6.13±2.15	4.10±1.28	5.58±2.36
non-peel	7.69±0.60	7.34±0.70	7.40±1.58	7.14±0.88	6.90±0.70	3.65±1.20	5.00±1.56
DOMINATOR							
peeled	6.04±1.57	6.93±1.09	8.51±1.55	5.28±1.78	4.08±2.51	3.98±0.98	6.60±2.42
non-peel	7.29±3.71	5.40±3.48	7.46±3.10	6.19±3.96	5.99±3.03	5.65±3.09	4.05±1.36
			CO_2 = 5%				
CARO-BEST							
peeled	5.64±1.09	5.43±3.49	4.09±1.26	5.89±2.34	6.31±1.50	4.30±3.28	7.85±3.83
non-peel	4.64±1.73	5.13±2.26	5.03±0.98	5.60±1.85	5.73±1.09	4.38±1.95	5.10±3.12
IMPERATOR							
peeled	6.90±1.84	5.60±3.56	6.99±3.40	6.55±1.46	5.95±1.91	4.48±2.46	5.78±1.18
non-peel	7.58±2.28	5.36±3.45	7.66±2.09	6.60±3.28	7.59±2.25	4.30±2.47	5.60±1.44
DOMINATOR							
peeled	5.78±2.58	5.29±3.40	6.95±2.45	5.11±2.91	5.95±2.70	5.09±2.00	4.85±2.69
non-peel	6.98±1.66	5.40±3.14	7.48±2.66	5.23±1.16	5.79±1.83	6.78±1.33	3.25±2.26
Mean separation $LSD_{0.05}$	3.01	4.04	2.73	2.90	2.56	2.67	3.64

TABLE 10 (Con't..)

cultivar/	Tactile		Masticatory			Flavor	
treatment	firmness	juiciness	crispness	chewiness	fibrousness	sweetness	harshness
			CO_2 = 10%				
CARO-BEST							
peeled	5.33±1.93	4.83±1.75	5.40±2.43	4.45±2.91	5.53±0.89	5.50±1.53	5.89±2.40
non-peel	6.73±2.45	4.70±3.34	6.90±1.65	5.89±2.62	4.18±1.51	4.91±2.47	6.29±3.27
IMPERATOR							
peeled	6.30±2.93	4.79±3.20	6.74±2.06	7.15±1.72	6.21±1.89	3.79±2.14	5.60±2.83
non-peel	5.31±1.55	7.01±0.79	8.31±2.38	5.19±2.01	4.43±2.63	6.81±3.36	3.73±2.85
DOMINATOR							
peeled	8.21±2.03	4.81±3.07	5.90±2.66	7.40±1.17	5.93±2.81	5.86±2.36	3.01±2.47
non-peel	5.14±2.55	6.03±2.41	5.93±3.59	4.90±2.50	5.01±2.18	3.83±2.14	4.28±1.95
Mean separation $LSD_{0.05}$	3.01	4.04	2.73	2.90	2.56	2.67	3.64

1. n = 4 panelists, Least significant difference (LSD) mean separation, significant at $p \leq 0.05$.
2. scale for all parameters: 0 = least; 10 = most.

TABLE 11 MEAN VALUES[1] OF THE "OVERALL PREFERENCE"[2] IN SENSORY EVALUATION OF CARROT STICKS HELD UNDER CA STORAGE AT 0-1°C, 97-98%RH FOR 28 DAYS WITH DIFFERENT CO_2 CONCENTRATION ENVIRONMENTS

cultivar/ treatment	carbon dioxide concentrations (%)		
	0	5	10
CARO-BEST			
peeled	5.68±2.26	3.83±2.90	4.10±2.02
non-peel	4.98±1.99	3.44±1.35	5.21±1.63
IMPERATOR			
peeled	3.68±0.50	4.10±2.68	4.55±2.80
non-peel	3.05±1.10	4.41±1.25	6.53±3.08
DOMINATOR			
peeled	4.95±1.75	5.95±1.49	4.50±2.59
non-peel	4.74±1.89	5.70±1.24	4.11±1.15
Mean separation			
$LSD_{0.05}$	1.99	1.99	1.99

1. n = 4 panelists, Least significant difference (LSD) mean separation, significant at $p \leq 0.05$.
2. scale for all parameters: 0 = least; 10 = most.

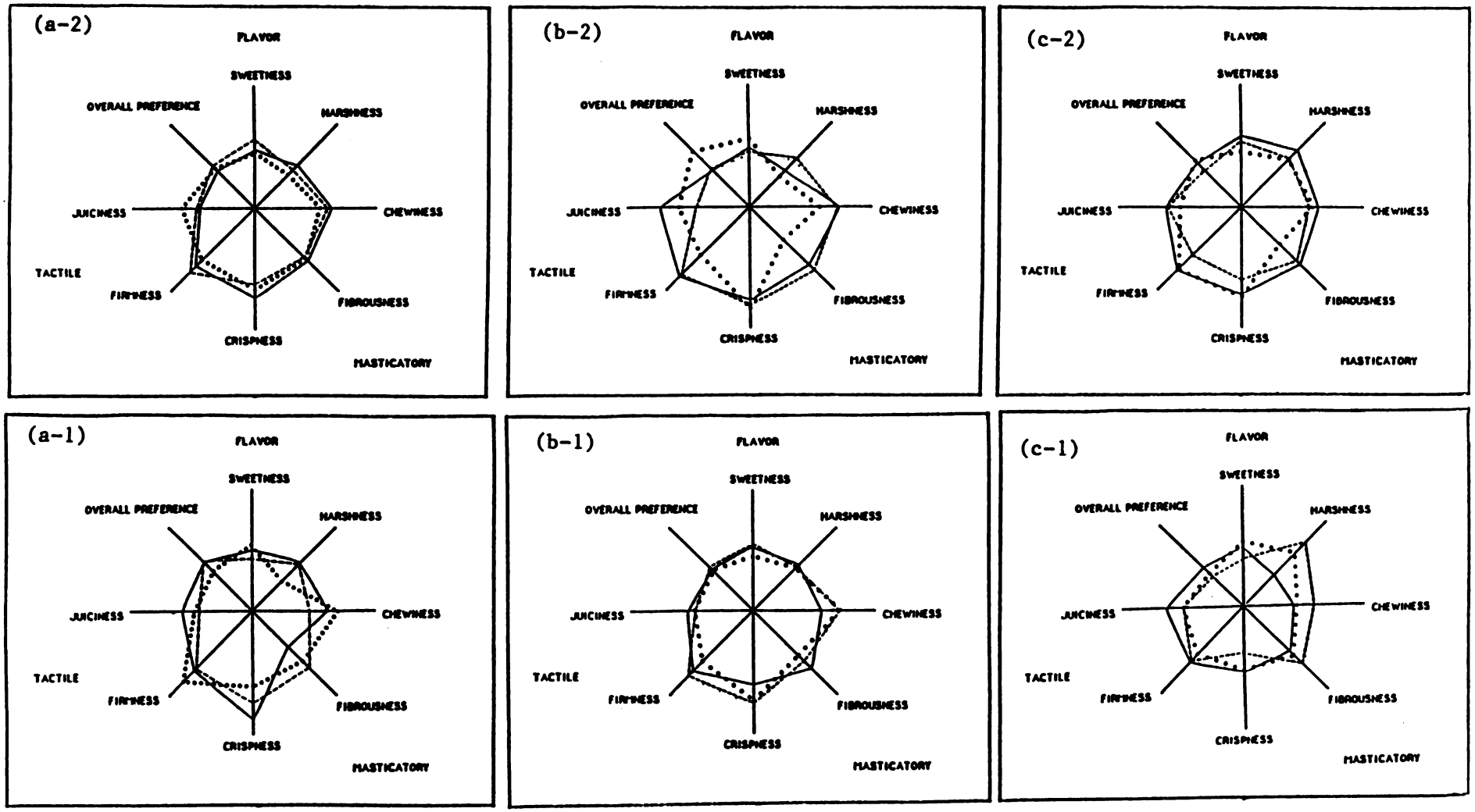


Figure 21. The Quantitative Descriptive Analysis (QDA) diagram of sensory evaluation for CA stored (0-1°C, 97-98%RH for 28 days) carrot sticks under different CO_2 concentration: ——— 0%, ----- 5%, ... 10%; (a) CARO-BEST, (b) IMP-58, (c) DOMINATOR; (1) peeled, and (2) non-peeled

Therefore, the hypothesis **Ho.1-1** and **Ho.1-2** were rejected according to the observations of this study.

STUDY II. Effect of modified atmosphere on quality changes of prepared carrot sticks

Hypothesis (Ho.2): Different modified atmosphere composition established by preadjusted packaging and peeled and non-peeled sample treatments will not affect the quality of carrot sticks.

Objectives

The major goal of this study is to evaluate the effectiveness of modified atmosphere packaging, peeling treatments, and cultivars for improving the physical, chemical and sensory qualities of carrot sticks through modified environmental storage.

Methodology

Three cultivars (CARO-BEST, IMPERATOR-58 and DOMINATOR) of peeled and non-peeled carrots were cut into sticks and rinsed with tap water as in STUDY I. A brief flow-chart of the experimental design of this study is presented in Figure 22. Polyethylene (PE) plastic bags (20 cm X 24 cm) were prepared to hold 122 g sample. According to the preliminary study curves (Appendix I), this package size can generate the optimum gas environment of 4-6% CO_2 and 2-4% O_2. This gas combination was assumed suitable for storing carrots as stated by many researchers (Hansen and Rumpf, 1974; Bruemmer, 1988). In order to monitor the gas change within

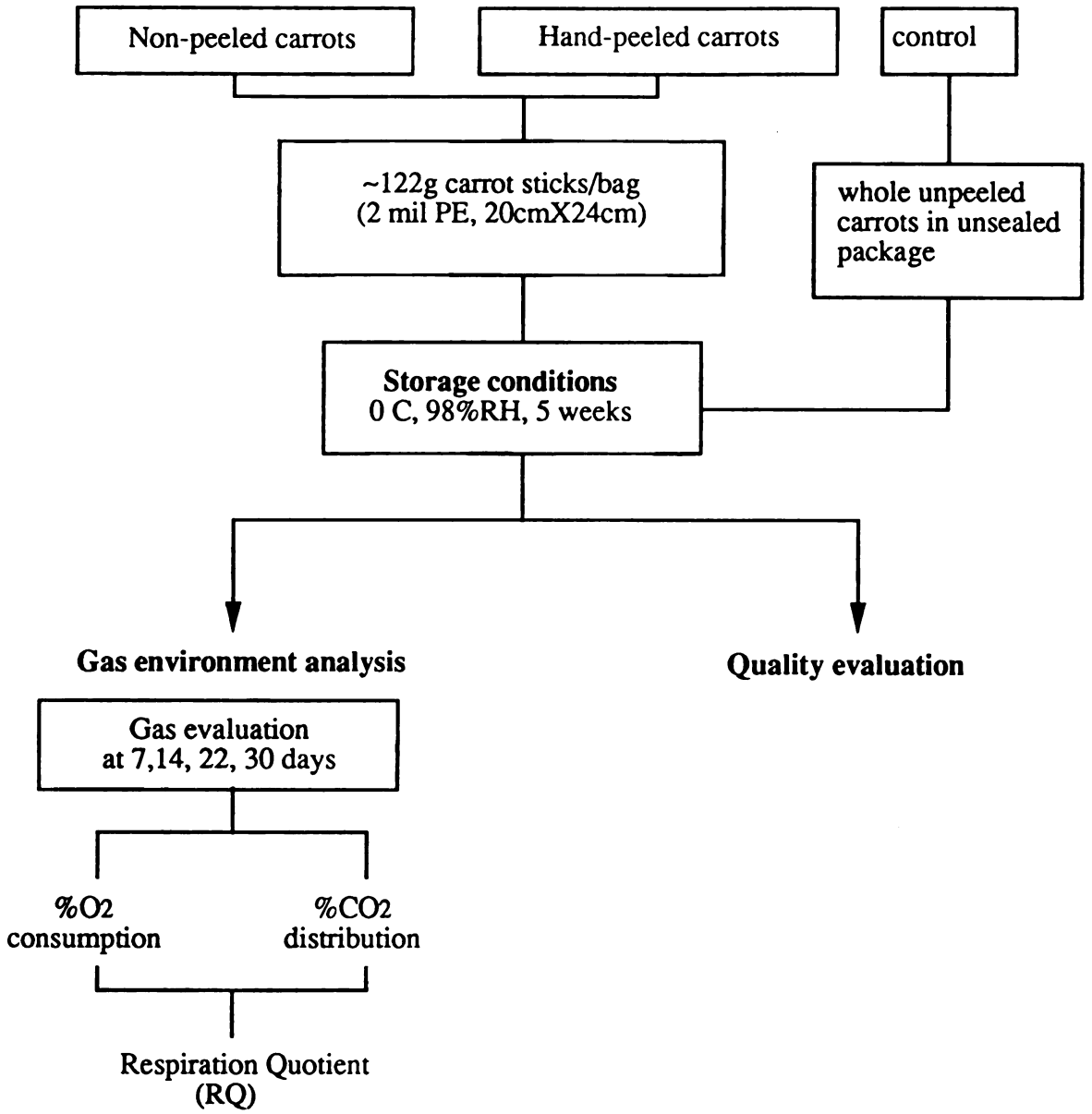


Figure 22. Flow chart of the experimental design of modified atmospheric storage study (STUDY II)

these packages, a silicon resealable tape was put on each bag for multiple sampling. Simultaneous O_2 and CO_2 analysis were done by Gas Analyser ADC-225-MK3, and the results were calculated and presented as respiration quotient (RQ) as defined by Wills et al. (1981):

$$RQ = \frac{CO_2 \text{ production rate}}{O_2 \text{ consumption rate}}$$

The CO_2 production and O_2 consumption rate are calculated using following equation: mmole CO_2 (O_2)/g/hr =

$$\frac{\underset{(\%)}{CO_2/O_2} \times \text{Film permeability} \times \underset{(kpa)}{\text{Air pressure}} \times \underset{(cm^2)}{\text{Package surface area}}}{\underset{(cm)}{\text{Thickness of film}} \times \underset{(gram)}{\text{Sample weight per package}}}$$

Film permeability for CO_2 = 3.65E-8 (mmole/cm-kpa-hr)
O_2 = 7.11E-9
Film (PE) thickness = 5.08E-3 cm (2 mil)
Air pressure = 101.33 kpa
Package surface area = 960 cm^2
Sample weight per package = 122 g

RQ measurement provides the guide to the type of substrate that is being respired. For the complete oxidation of glucose, RQ = 1, whereas for malate RQ = 1.3, and for fatty acids (stearic acid) RQ = 0.7. RQ values have been useful as indicators of the relative extent of aerobic and anaerobic respiration (Hultin and Milner, 1978). A very high RQ is generally indicative of fermentation reactions.

Whole carrots from each cultivar were washed and held in perforated plastic (PE) bags then stored under the same conditions. These carrots were cut prior to evaluation and

analyzed as controls.

Following 5 weeks of storage at 0-1°C and 97-98%R.H., 5 replicate bags of each treatment were opened for sensory evaluation, physical and chemical analyses as in MATERIALS AND METHODS.

Results and discussion

A. Gas Environment Analysis

The respiration quotient (RQ) curves for both peeled and non-peeled treatment are presented in Figures 23 and 24. The analysis of variance and mean values are provided in Table 12 and Table 13, respectively. No significant differences were found among cultivars at 6, 13 and 30 days of storage. There were significant differences between peeled and non-peeled treatments on 13 and 21 days of storage. After 13 days of storage, peeled samples were found to have lower RQ than non-peeled samples, however, there were no differences between treatments on 30 days' RQ values. RQ = 1 represents normal respiration (complete glucose oxidation). In this study, organic acid oxidation was observed to be the major supply of respiratory energy. No treatment showed anaerobic respiration under MA storage.

B. Quality Evaluation

Physical Analysis

Analysis of variance for physical tests (breaking

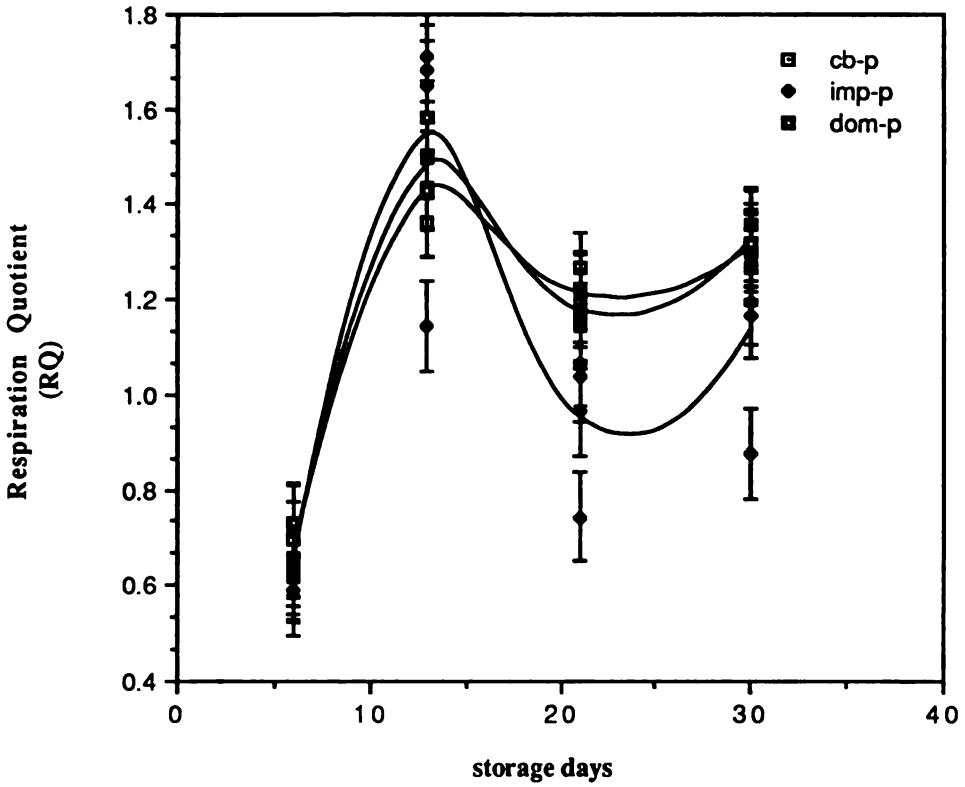


Figure 23. The Respiration Quotient (RQ) curves of peeled carrot sticks under MA storage at 0°C, 98%RH from each cultivar: RQ vs. storage days

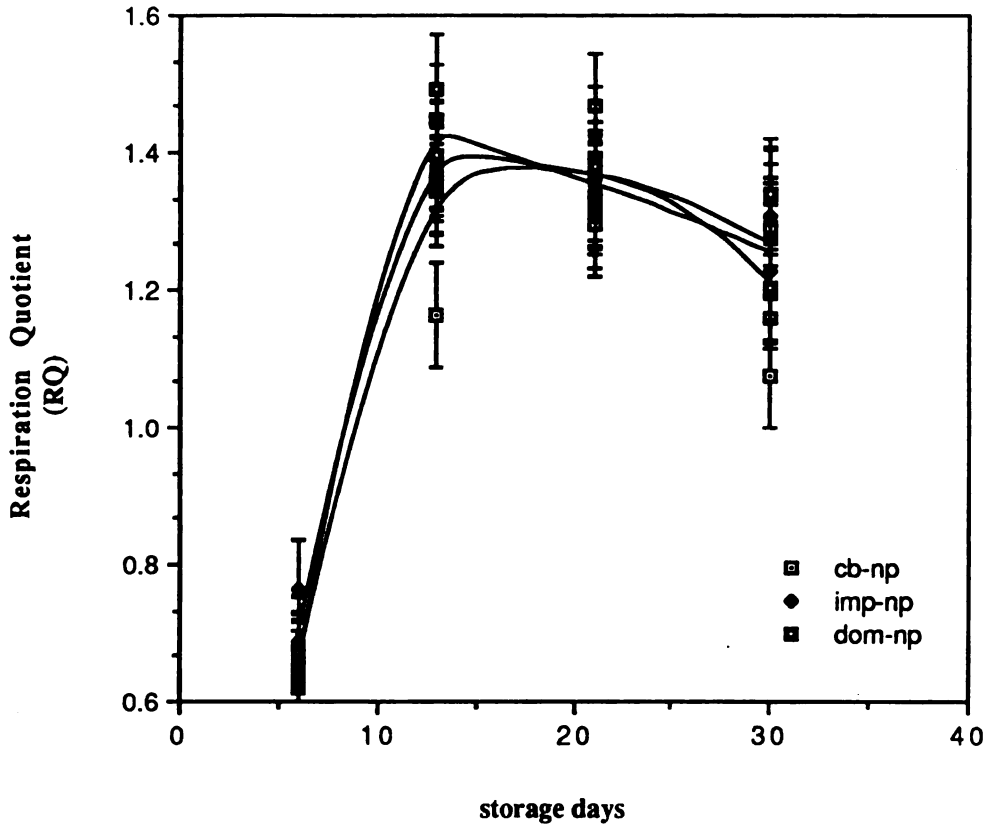


Figure 24. The Respiration Quotient (RQ) curves of non-peeled carrot sticks under MA storage at 0°C, 98%RH from each cultivar: RQ vs. storage days

TABLE.12 ANALYSIS OF VARIANCE OF RESPIRATION QUOTIENT (RQ) OF CARROT STICKS HELD UNDER MA STORAGE AT 0-1°C, 97-98%RH.

source of variation	df	storage days at 0-1°C			
		6	13	21	30
		MEAN SQUARES[1]			
Main Effect					
cultivar	2	0.000	0.018	0.038**	0.016
treatment	1	0.001	0.087*	0.369**	0.001
Two Way					
cultivar X treatment	2	0.004	0.006	0.041**	0.032
error	18	0.001	0.016	0.005	0.009
%C.V.		5.66	8.83	5.95	7.75

1. n = 4, * significant at $p \leq 0.05$; ** significant at $p \leq 0.01$.

TABLE.13 MEAN VALUES[1] OF RESPIRATION QUOTIENT (RQ) ANALYSIS OF CARROT STICKS HELD UNDER MA STORAGE AT 0-1°C, 97-98%RH.

cultivar/ treatment	storage days at 0-1°C			
	6	13	21	30
CARO-BEST				
peeled	0.67±0.02	1.43±0.05	1.21±0.04	1.31±0.04
non-peeled	0.65±0.01	1.32±0.10	1.37±0.07	1.21±0.12
IMPERATOR				
peeled	0.64±0.06	1.55±0.27	0.95±0.15	1.13±0.18
non-peeled	0.70±0.05	1.37±0.01	1.37±0.04	1.27±0.06
DOMINATOR				
peeled	0.66±0.05	1.49±0.07	1.18±0.03	1.32±0.02
non-peeled	0.65±0.02	1.42±0.06	1.35±0.04	1.25±0.07
Mean separation				
$LSD_{0.05}$	0.05	0.19	0.11	0.14

1. n = 4, Least significant difference (LSD) mean separation , significant at $p \leq 0.05$.

force/CSA and failure) of peeled and non-peeled carrot sticks from CARO-BEST, IMPERATOR-58 and DOMINATOR are presented in Table 14. The mean values, standard deviations and Least Significant Difference (LSD) mean separations for breaking force and breaking failure are presented in Table 15.

The mean squares for the breaking force/CSA (cross section area) and breaking failure showed significant differences in the treatment main effect. It was observed (Table 15 and Figure 25) that fresh-cut carrot sticks (control) had higher resistant force to breaking than those packed sticks which were cut prior to storage. Figure 26 also showed significant differences between fresh-cut and packed carrot sticks because fresh-cut sticks possessed higher breaking failure, i.e., more rubbery. The reasons for causing these differences are possibly the moisture loss shown in Figure 27, although the relative humidity (%RH) remained almost saturated (98%) during the storage period. These results indicated that modified atmospheric packaging was more effective in preventing cut carrots from becoming "rubbery" than did standard commercial perforated packing.

The ANOVA in Table 14 showed no differences among cultivars for breaking failure. The overall effects of cultivar for breaking force are presented in Figure 28. CARO-BEST had less breaking resistance than the other two cultivars and lower moisture content than DOMINATOR (Figure

Table 14. ANALYSIS OF VARIANCE FOR PHYSICAL BREAKING TEST OF CARROT STICKS HELD UNDER MA STORAGE AT 0-1°C, 97-98%RH FOR 5 WEEKS

source of variance	df	Breaking force/CSA (N/cm^2)	Breaking failure (cm)
		MEAN SQUARES[1]	
Main Effects			
cultivar	2	81.07*	0.05
treatment[2]	2	402.69**	0.70**
Two Way			
cultivar x treatment	4	66.85**	0.01
Error	27	16.21	0.04
%CV		24.35	19.39

1. n = 4; * = significant at $p \leq 0.05$, ** = significant at $p \leq 0.01$
2. treatments included peeled, non-peeled and unsealed, fresh-cut carrot sticks.

TABLE 15 MEAN VALUES[1] OF PHYSICAL BREAKING TEST OF CARROT STICKS HELD UNDER MA STORAGE AT 0-1°C, 97-98%RH FOR 5 WEEKS WITH PEEL AND NON-PEEL TREATMENTS

cultivar/ failure treatment	force/CSA (N/cm^2)	breaking (cm)
CARO-BEST		
peeled	11.91±3.90	0.90±0.08
non-peel	14.03±1.56	0.95±0.13
control	15.10±4.75	1.37±0.19
IMPERATOR		
peeled	13.17±3.71	0.82±0.12
non-peel	12.60±3.02	0.92±0.32
control	25.69±4.88	1.26±0.26
DOMINATOR		
peeled	11.89±4.74	0.89±0.16
non-peel	15.79±3.42	1.10±0.14
control	28.63±5.73	1.38±0.32
Mean separation		
$LSD_{0.05}$	5.84	0.30

1. n = 4, Least significant difference (LSD) mean separation , significant at $p \leq 0.05$

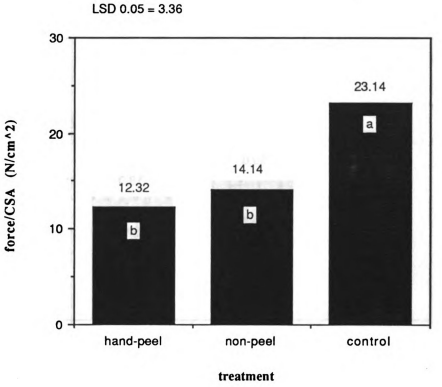


Figure 25. Mean values of the breaking force/CSA for carrot sticks of peeled, non-peeled and control treatments over all cultivars in MA storage at 0-1°C, 97-98%RH for 5 weeks; control = unsealed, fresh-cut carrot sticks; means followed by like letters are not significantly different ($p < 0.05$)

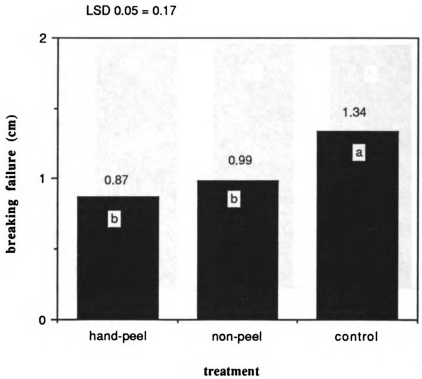


Figure 26. Mean values of the breaking failure for carrot sticks of peeled, non-peeled and control treatments over all cultivars in MA storage at 0-1°C, 97-98%RH for 5 weeks; control = unsealed, fresh-cut carrot sticks; means followed by like letters are not significantly different ($p < 0.05$)

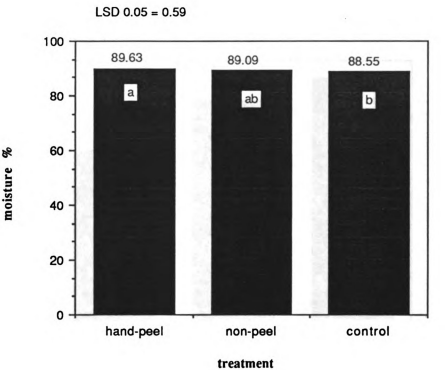


Figure 27. Mean values of the moisture content for carrot sticks of peeled, non-peeled and control treatments over all cultivars in MA storage at 0-1°C, 97-98%RH; control = unsealed, fresh-cut carrot sticks; means followed by like letters are not significantly different ($p < 0.05$)

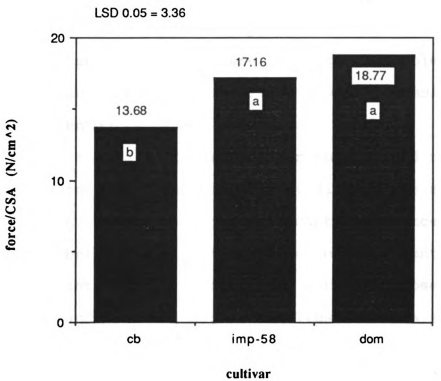


Figure 28. Mean values of the breaking force/CSA for carrot sticks of 3 cultivars (CARO-BEST, IMPERATOR-58, DOMINATOR) over all treatments in MA storage at 0-1°C, 97-98%RH for 5 weeks; means followed by like letters are not significantly different ($p < 0.05$)

29).

Chemical Analysis

The analyses of variance for all chemical analysis data are summarized in Table 16. The mean values, standard deviations, and LSD mean separations for sucrose and reducing sugars analyses are presented in Table 17. The mean values for total phenolic compound and moisture content are presented in Table 18.

The analysis of variance for sucrose and reducing sugars content showed significant differences among cultivars. There was no significant difference in sugar content between peeled and non-peeled treatments. Significant cultivar differences were also observed for both sucrose and reducing sugars as illustrated in Figure 30 and Figure 31, respectively. CARO-BEST had higher sucrose (11.04 mg/g db.) and lower reducing sugars (3.77 mg/g) than the other two cultivars. The same results had been previously observed in the controlled atmospheric (CA) storage (STUDY I).

The mean values of total phenolic content and moisture are presented in Table 18. Peeled carrot sticks had much less phenolic compounds (3.46 mg/g db.) than non-peeled samples (6.65 mg/g db.) (Figure 32). These results indicated that peeled cut carrots possessed improved qualities compared to non-peeled carrots during MA storage. Elevated phenolic compounds (8.65 mg/g db.) also was

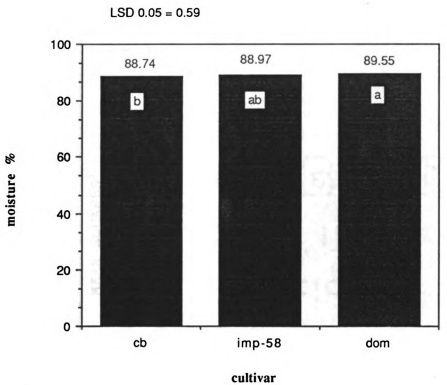


Figure 29. Mean values of the moisture content for carrot sticks of 3 cultivars (CARO-BEST, IMPERATOR-58, DOMINATOR) over all treatments in MA storage at 0-1°C, 97-98%RH; means followed by like letters are not significantly different ($p < 0.05$)

Table 16. ANALYSIS OF VARIANCE FOR CHEMICAL ANALYSES OF CARROT STICKS HELD UNDER MA STORAGE AT 0-1°C, 97-98%RH FOR 5 WEEKS

source of variance	df	sucrose	reducing sugars	total phenolics	moisture
			MEAN SQUARES[1]		
Main Effects					
cultivar	2	19.67*	38.55**	45.74**	1.58*
treatment[2]	1	4.58	0.04	2.44**	2.60**
Two Way					
cultivar x treatment	2	4.60	2.33	7.78**	2.01**
Error	12	4.66	3.41	2.56E-3	0.36
%CV		22.71	31.84	1.00	0.67

1. n = 3; * = significant at $p \leq 0.05$, ** = significant at $p \leq 0.01$
2. treatments included peeled and non-peeled carrot sticks.

TABLE 17 MEAN VALUES[1] OF SUGAR ANALYSIS OF PEELED AND NON-PEELED CARROT STICKS HELD UNDER MA STORAGE AT 0-1°C, 97-98%RH FOR 5 WEEKS

cultivar/ treatment	sucrose content (mg/g db.)	reducing sugars (mg/g db.)
CARO-BEST		
peeled	12.50±0.39	4.47±0.76
non-peeled	9.58±4.63	3.08±0.61
IMPERATOR		
peeled	7.24±0.31	8.62±1.92
non-peeled	7.77±1.40	8.66±3.45
DOMINATOR		
peeled	10.29±0.79	4.44±0.57
non-peeled	9.65±1.97	5.53±1.89
Mean separation		
$LSD_{0.05}$	3.71	3.18

1. n = 3, Least significant difference (LSD) mean separation, significant at $p \leq 0.05$

TABLE 18 MEAN VALUES[1] OF TOTAL PHENOLIC COMPOUND AND MOISTURE CONTENT OF CARROT STICKS HELD UNDER MA STORAGE AT 0-1°C, 97-98%RH FOR 5 WEEKS

cultivar/ treatment	Total Phenolic compounds (mg/g db.)	Moisture content (%)
CARO-BEST		
peeled	2.83±0.01	88.67±0.41
non-peel	8.65±0.06	89.02±1.02
control[2]	-	88.53±1.19
IMPERATOR		
peeled	3.52±0.07	90.24±0.50
non-peel	5.45±0.06	89.19±0.41
control	-	87.49±0.15
DOMINATOR		
peeled	4.04±0.04	89.96±0.29
non-peel	5.85±0.03	89.06±0.20
control	-	89.64±0.24
Mean separation		
$LSD_{0.05}$	0.09	1.04

1. n = 3, Least significant difference (LSD) mean separation, significant at $p \leq 0.05$.
2. control carrots were stored in non-sealed bags and were cut prior to measurements.

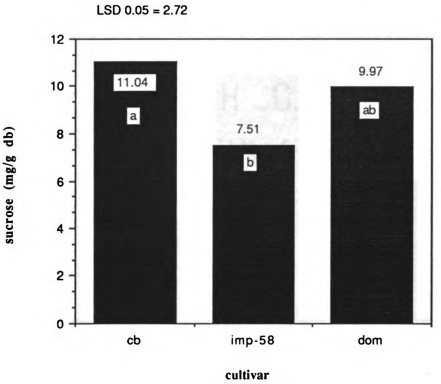


Figure 30. Mean values of the sucrose amount for carrot sticks of 3 cultivars (CARO-BEST, IMPERATOR-58, DOMINATOR) over all treatments in MA storage at 0-1°C, 97-98%RH for 5 weeks; means followed by like letters are not significantly different ($p < 0.05$)

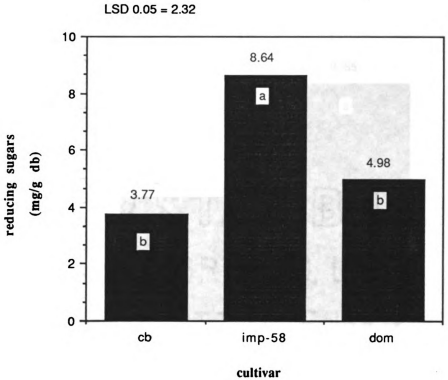


Figure 31. Mean values of the reducing sugars for carrot sticks of 3 cultivars (CARO-BEST, IMPERATOR-58, DOMINATOR) over all treatments in MA storage at 0-1°C, 97-98%RH for 5 weeks; means followed by like letters are not significantly different ($p < 0.05$)

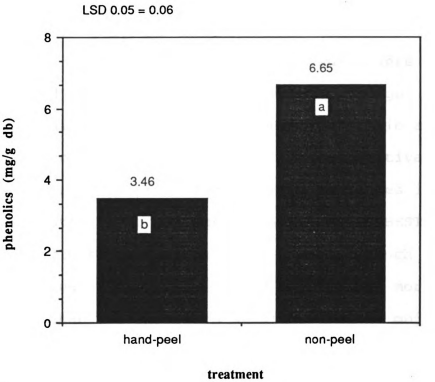


Figure 32. Mean values of total phenolic compound for carrot sticks of peeled and non-peeled treatments over all cultivars in MA storage at 0-1°C, 97-98%RH for 5 weeks; means followed by like letters are not significantly different ($p < 0.05$)

observed in non-peeled CARO-BEST sticks. Significantly higher moisture content was observed in MAP carrot sticks compared to traditional systems.

Generally, high sucrose content and low total phenolic compounds are good quality indicators for fresh market carrots. In this study, positive results were demonstrated in peeled carrot sticks held under MA storage. CARO-BEST had the highest sucrose/reducing sugars ratio and the darkest color compared to the other two cultivars. That is, it might retain better fresh market qualities if held under optimum storage conditions. However, CARO-BEST may be susceptible to greater mechanical damage, such as cracking or breaking, during shipment because it had more tender texture than the cultivars studied. In the objective analyses it was shown that peeled treatment prevented sucrose degradation and reduced phenolic compound formation.

Sensory Evaluation

The analysis of variance for all sensory parameters is presented in Table 19. The mean values for each sensory parameter and for the overall preference are presented in Table 20 and Figure 33. Also the QDA diagrams for sensory evaluation of MAP carrot sticks is provided in Figure 34.

The data indicated significant difference among cultivars for the "firmness" and "crispness" evaluation measures. Table 20 showed CARO-BEST cultivar had the least

Table 19. ANALYSIS OF VARIANCE FOR SENSORY EVALUATION OF CARROT STICKS HELD UNDER MA STORAGE AT 0-1°C, 97-98%RH FOR 5 WEEKS

		Sensory Parameter							
		Tactile		Masticatory			Flavor		Overall
	df	firmness	juiciness	crispness	chewiness	fibrous.	sweetness	harshness	preference
		MEAN SQUARES[1]							
Main Effects									
cultivar	2	24.67*	4.19	23.79*	13.87	2.86	2.22	0.58	0.64
treatment[2]	2	1.06	0.01	6.99	3.54	10.60	10.45*	23.49*	15.65*
panelists	3	9.30	5.39	8.96	5.32	11.13*	12.54*	7.35	5.62
Two Way									
cultivar x treatment	4	2.85	5.62	7.69	2.54	1.52	5.31	1.71	2.23
Error	24	4.89	8.05	6.40	5.72	3.28	2.76	4.24	3.34
%CV		30.19	54.70	42.74	40.77	32.21	45.32	39.71	40.44

1. n = 4, * = significant at $p \leq 0.05$
2. treatments include peeled, non-peeled and unsealed, fresh-cut carrot sticks

TABLE 20 MEAN VALUES[1] OF SENSORY EVALUATION[2] OF CARROT STICKS HELD UNDER MA STORAGE AT 0-1°C, 97-98%RH FOR 5 WEEKS WITH /OR WITHOUT PEEL PREPARATION AND UNSEALED FRESH-CUT CONTROL

cultivar/ treatment	Tactile		Masticatory			Flavor	
	firmness	juiciness	crispness	chewiness	fibrousness	sweetness	harshness
CARO-BEST							
peeled	4.90±3.48	4.65±2.85	4.10±2.79	4.25±2.78	3.73±2.67	5.76±0.89	4.06±1.96
non-peel	5.34±3.22	4.80±2.55	5.10±3.29	4.30±3.31	5.83±2.04	3.99±1.79	5.71±2.53
control	6.55±2.74	5.41±2.40	6.24±3.08	5.75±2.36	6.41±0.34	3.79±1.98	6.41±1.07
IMPERATOR							
peeled	8.03±1.36	3.85±2.51	6.28±2.73	6.06±1.67	3.31±2.04	3.34±1.67	4.78±2.59
non-peel	8.95±1.13	4.58±3.23	9.01±0.72	7.23±1.01	5.48±1.54	2.89±2.04	6.09±2.70
control	7.93±1.55	5.76±2.64	8.58±1.24	7.46±1.72	4.48±1.62	4.75±2.31	6.43±2.11
DOMINATOR							
peeled	8.25±1.60	6.93±1.89	7.26±1.91	6.53±1.80	4.65±2.05	6.00±1.82	2.96±1.85
non-peel	6.85±3.09	6.23±3.34	4.63±3.32	4.75±3.26	5.35±3.12	2.65±2.14	6.18±1.72
control	8.23±0.87	4.39±3.31	7.23±2.81	6.13±2.52	5.60±1.70	3.33±2.55	6.98±2.25
Mean separation							
$LSD_{0.05}$	3.16	4.12	4.03	3.45	2.32	2.67	3.16

1. N = 4, Least significant difference (LSD) mean separation, significant at $p \leq 0.05$
2. scale for all parameters: 0 = least; 10 = most.

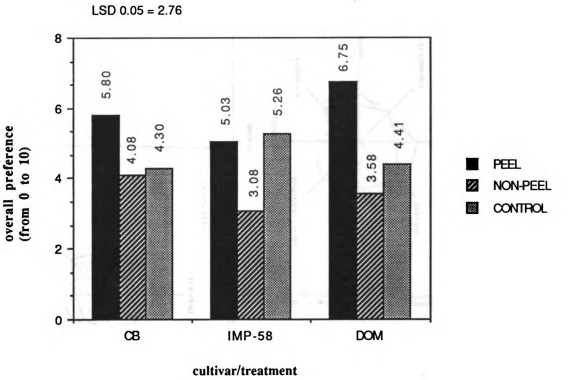


Figure 33. Mean values of "overall preference" in the sensory evaluation of all variety/treatment carrot sticks in MA storage at 0-1°C, 97-98%RH for 5 weeks; scale = 0 to 10; control = unsealed, fresh-cut carrot sticks

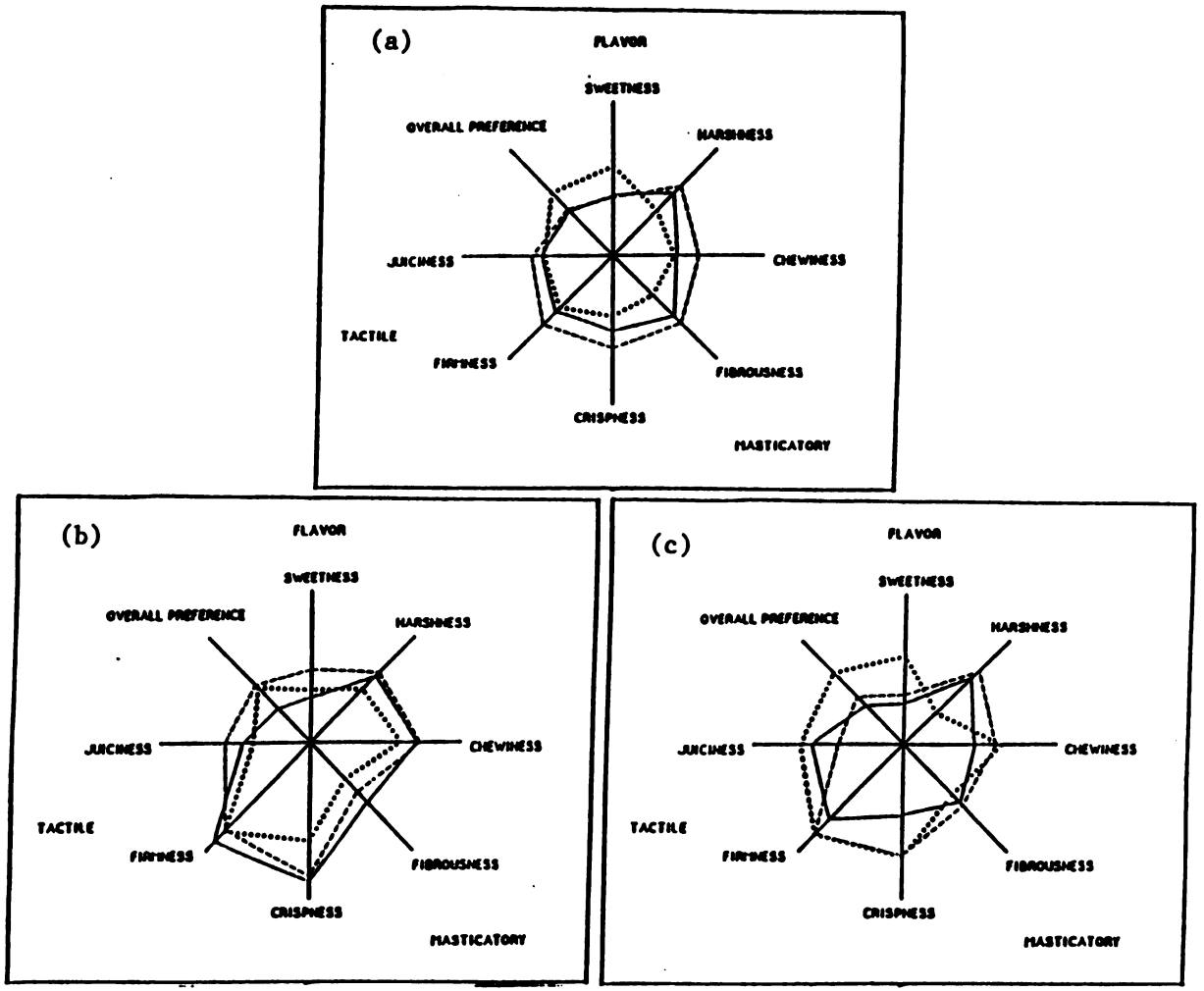


Figure 34. The Quantitative Descriptive Analysis (QDA) diagram of sensory evaluation for carrot sticks under MA storage at 0-1°C, 97-98%RH for 5 weeks: ..... peeled, ——— non-peeled, ----- fresh-cut (control); (a) CARO-BEST, (b) IMP-58, (c) DOMINATOR

firmness and crispness compared to the other two, IMPERATOR-58 and DOMINATOR. These tactile and masticatory differences indicated that CARO-BEST is the most tender cultivar which may be good for freshly use but easy to crack. DOMINATOR and IMPERATOR-58 have similar sensory results of physical properties. However, DOMINATOR has higher sucrose/reducing sugars ratio (Figures 30 and 31) which means it may taste sweeter than IMPERATOR-58, although there were no significant differences found among cultivars in the sensory "sweetness" evaluation. Significant effects of treatments were detected (Table 19) and the QDA diagrams illustrate that peeled sticks (CARO-BEST) held under MAP storage possessed less "fibrousness" than did fresh-cut carrots stored in perforated bags.

The data of "flavor" profile showed significant differences among treatments for the "sweetness" and "harshness" evaluation. Higher sweetness (5.03) and lower harshness (3.93) has been observed in peeled carrot sticks held under MAP storage (Figures 35 and 36). These same results are presented in the sensory QDA diagrams.

Sensory evaluation yielded significant differences among cultivars and among treatments for various sensory parameters. CARO-BEST was found to have the least firmness and crispness performance among all cultivars (Figure 37, 38), and these results highly associated to the physical breaking properties. Peeled carrot sticks with MAP storage

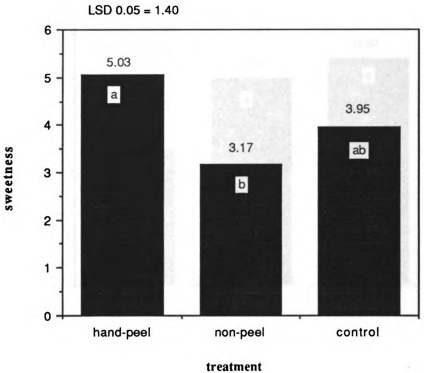


Figure 35. Mean values of "sweetness" in the sensory evaluation for carrot sticks of peeled, non-peeled and control treatments over all cultivars in MA storage at 0-1°C, 97-98%RH for 5 weeks; control = unsealed, fresh-cut carrot sticks; means followed by like letters are not significantly different ($p < 0.05$)

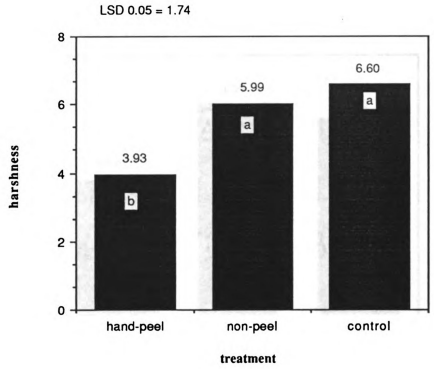


Figure 36. Mean values of "harshness" in the sensory evaluation for carrot sticks of peeled, non-peeled and control treatments over all cultivars in MA storage at 0-1°C, 97-98%RH for 5 weeks; control = unsealed, fresh-cut carrot sticks; means followed by like letters are not significantly different ($p < 0.05$)

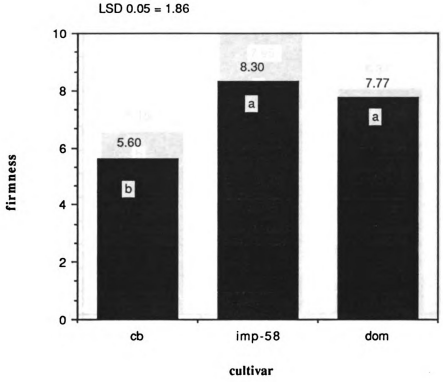


Figure 37. Mean values of "firmness" in the sensory evaluation for carrot sticks of 3 cultivars (CARO-BEST, IMPERATOR-58, DOMINATOR) over all treatments in MA storage at 0-1°C, 97-98%RH for 5 weeks; means followed by like letters are not significantly different ($p < 0.05$)

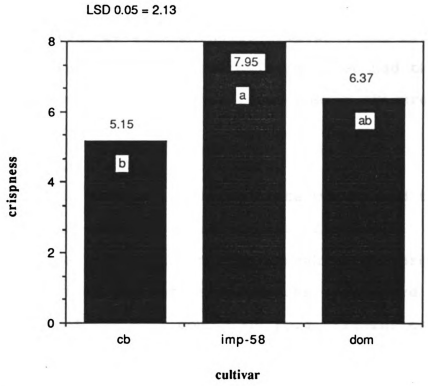


Figure 38. Mean values of "crispness" in the sensory evaluation for carrot sticks of 3 cultivars (CARO-BEST, IMPERATOR-58, DOMINATOR) over all treatments in MA storage at 0-1°C, 97-98%RH for 5 weeks; means followed by like letters are not significantly different ($p < 0.05$)

was found to have the most effectiveness in retaining sweetness and in preventing development of harshness and fibrousness (Figure 39). Association was found between "harshness" and "fibrousness", which might indicate some interactions between phenolic compounds and cell structure. It was also observed that peeled samples had the highest overall preference among all treatments (Figure 40).

Conclusions

In this study, peeled carrots were found to have lower respiration rate at selected days of storage. Significantly higher breaking resistance and breaking failure were observed in fresh-cut carrot sticks. Moisture loss and increase of phenolic compounds (e.g. lignin) could be the reason that caused these carrots to become more "rubbery" than peeled pre-cut sticks under MA storage. It was also observed that CARO-BEST had the highest sucrose/reducing sugars ratio and the softest texture among all cultivars. There are some association shown between "firmness" measure in sensory evaluation and physical tests, as well as among "harshness", "fibrousness" and the total phenolic compound analysis. No significant surface "whitening" was observed in packaged carrot sticks of either treatment, nor among the cultivars. Previous hypothesis **Ho.2** therefore was rejected according to these results.

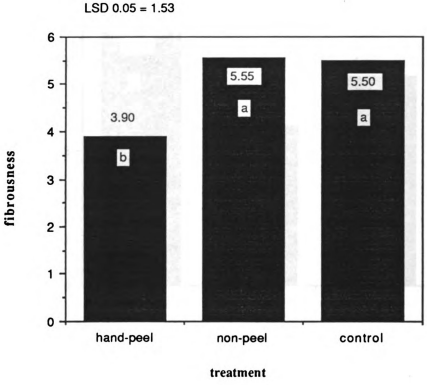


Figure 39. Mean values of "fibrousness" in the sensory evaluation for carrot sticks of peeled, non-peeled and control treatments over all cultivars in MA storage at 0-1°C, 97-98%RH for 5 weeks; control = unsealed, fresh-cut carrot sticks; means followed by like letters are not significantly different ($p < 0.05$)

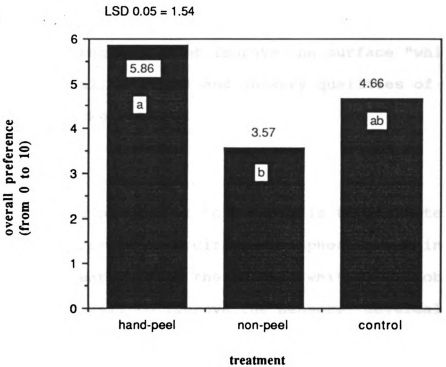


Figure 40. Mean values of "overall preference" in the sensory evaluation of peeled, non-peeled and control carrot sticks over all cultivars in MA storage at 0-1°C, 97-98%RH for 5 weeks; scale = 0 to 10; control = unsealed, fresh-cut carrot sticks

STUDY III. Effect of surface chemical dipping treatments on quality of fresh-market carrot sticks during MA storage

Hypothesis (Ho.3): The chemical treatments of carrot sticks by dipping samples with different food grade solutions prior to MAP storage will not improve the surface "whitening" and the physical, chemical and sensory qualities of fresh-packed carrot sticks.

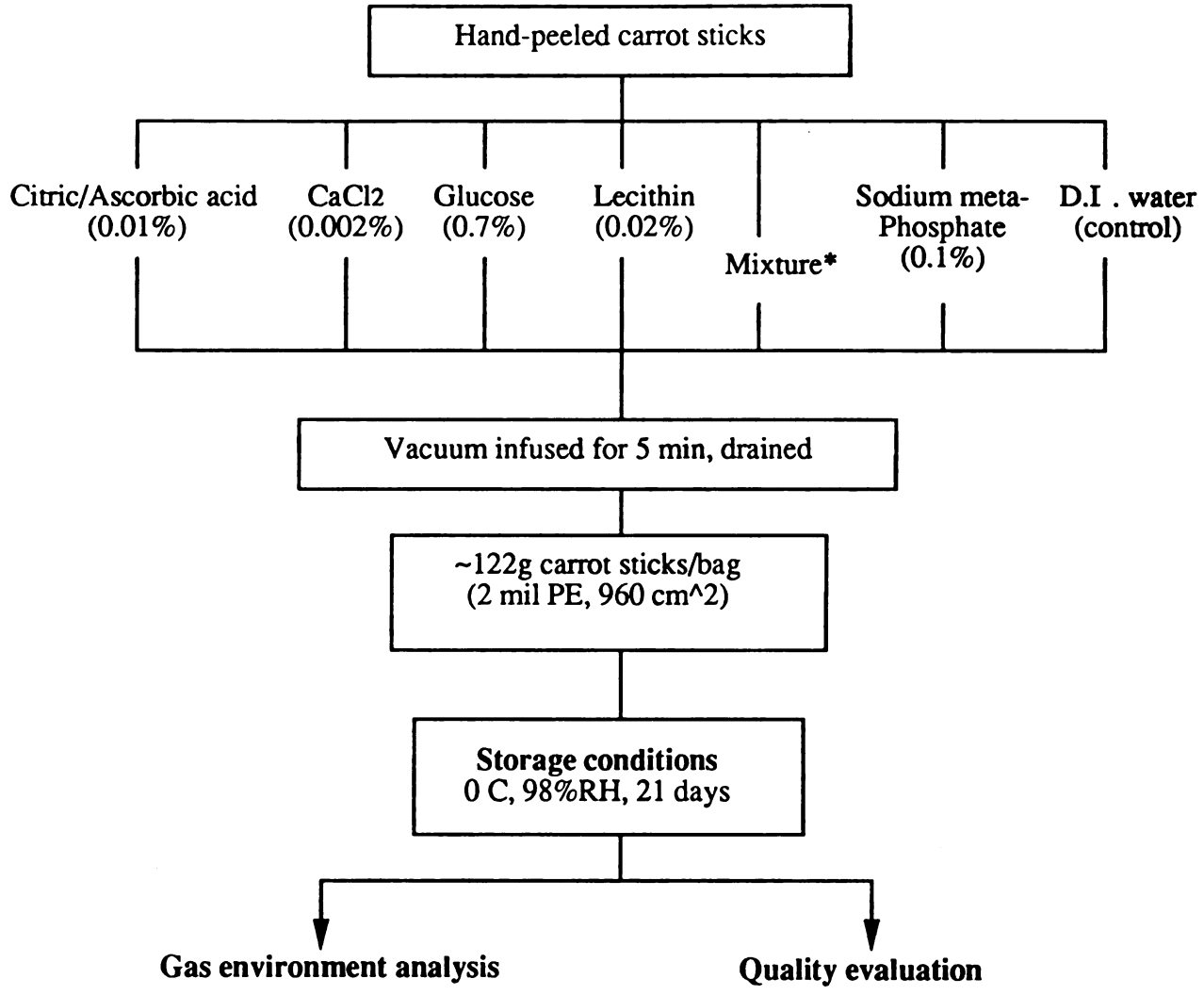
Objectives

The major goal of this study is to evaluate the combined effects of modified atmosphere packaging (MAP) and dipping treatments on the surface whitening problem of cut carrots as well to improve the sensory, physical and chemical quality retention during storage.

Methodology

The cultivar of CARO-BEST and only peeled carrots were used in this study according to the results obtained in STUDY I and STUDY II.

A brief outline of the experimental design is presented in Figure 41. Five different food-grade chemicals were used in this study as different dipping solutions (treatments): 1) citric/ascorbic acids 0.01%, 2) $CaCl_2.2H_2O$ 0.002%, 3) glucose 0.7%, 4) lecithin 0.02%, 5) mixture of 1 to 4 in the same concentrations, 6) Sodium meta-phosphate (Na-mp) 0.1%,



* Mixture contained citric/ascorbic acid, CaCl2, glucose and lecithin with the same concentration.

Figure 41. Flow chart of the experimental design of chemical dipping pre-treatment in MA storage study (STUDY III)

and 7) deionized water as control. These chemicals were obtained from SIGMA and dissolved into 2 liter deionized water at room temperature. Five to six whole carrots were held in perforated plastic bags which were stored under the same conditions (0-1°C, 97-98%RH) and cut prior to evaluations to serve as fresh-cut controls.

Carrot sticks were emersed in these solutions and vacuum treated at 30 mm-Hg for 5 minutes to ensure that the surface was impregnated with dipping chemicals. Following the dipping, samples were drained, packed into plastic bags and heat-sealed prior to storage. Five replicate bags were prepared for each treatment.

Gas environment within these package was monitored immediately upon storage, then at 8, 15, and 21 days after storage to calculate the respiration quotient (RQ) during storage. The RQ results were used to predict the interaction between respiration rates and quality changes. Following 3 weeks storage at 0-1°C and 97-98%R.H., these samples were used for sensory evaluation, physical and chemical analyses. Additionally, a portion of the samples were retained in cold storage for approximately 2 months and used in the physical breaking tests.

Results and discussion

A. Gas Environment Analysis

The respiration quotient (RQ) curves for each treatment

are presented in Figure 42. The analysis of variance and mean values are provided in Table 21 and Table 22, respectively. Significant differences were detected among treatments on the first day, 15 and 21 days of storage. No significant difference was detected on the 8 days of storage, however, there are significant differences among replicated packages. At beginning of the storage period, glucose treated carrot sticks had the highest RQ value (3.61) which was significantly higher than either citric/ascorbic acids, the mixture or sodium meta-phosphate (Na-mp) treated samples.

B. Quality Evaluation

Physical Analysis

Analysis of variance for physical tests (breaking force and breaking failure) of peeled carrot sticks from CARO-BEST with different dipping treatments are presented in Table 23. The mean values and Least Significant Difference (LSD) mean separations for breaking test are presented in Table 24.

Significant differences were observed among treatments and two storage periods (21 and 60 days). No significant interaction occurred among treatments and storage periods. At 21 days of storage, significant differences for breaking force (N/cm^2) were detected between unsealed fresh-cut control and Na-mp and glucose dipped samples. However, the only significant difference detected after 60 days of

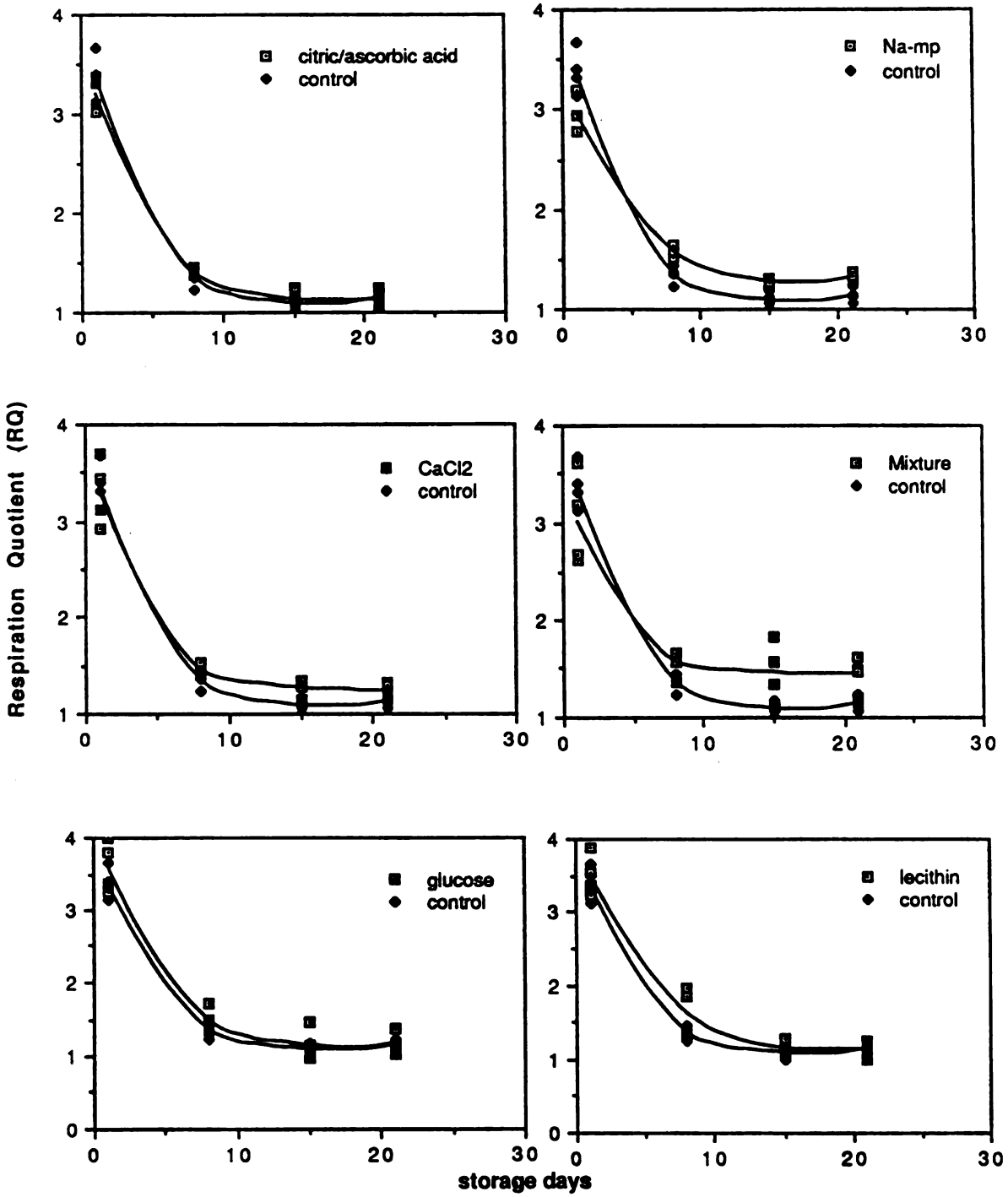


Figure 42. Respiration Quotient (RQ) curves of different dipping treatments in MA storage at 0°C, 98%RH for 21 days: dipping solutions vs. no dip control

TABLE.21 ANALYSIS OF VARIANCE OF RESPIRATION QUOTIENT (RQ) OF DIPPING PRE-TREATED CARROT STICKS HELD UNDER MA STORAGE AT 0-1°C, 97-98%RH.

source of variation	df	storage days at 0-1°C			
		1	8	15	21
		MEAN SQUARES[1]			
Main Effect					
treatment[2]	6	0.267**	0.037	0.069*	0.059**
replication	3	0.317**	0.065*	0.069*	0.025
error	18	0.054	0.018	0.019	0.011
%C.V.		7.02	8.95	11.29	8.56

1. n = 4, * significant at $p \leq 0.05$; ** significant at $p \leq 0.01$.
2. Details of treatment are presented in Table 3.

TABLE.22 MEAN VALUES[1] OF RESPIRATION QUOTIENT (RQ) ANALYSIS OF DIPPING PRE-TREATED CARROT STICKS HELD UNDER MA STORAGE AT 0-1°C, 97-98%RH.

	storage days at 0-1°C			
treatment[2]	1	8	15	21
citric/ascorbic acids	3.21±0.16	1.40±0.04	1.13±0.10	1.13±0.09
$CaCl_2$	3.55±0.35	1.46±0.05	1.27±0.08	1.24±0.08
glucose	3.61±0.35	1.48±0.16	1.14±0.22	1.17±0.15
lecithin	3.51±0.27	1.61±0.34	1.13±0.11	1.12±0.13
Mixture	3.03±0.47	1.56±0.14	1.46±0.31	1.44±0.17
sodium meta-PO_4	2.97±0.16	1.57±0.05	1.28±0.03	1.33±0.03
control (DD water)	3.38±0.22	1.35±0.09	1.09±0.07	1.14±0.07
Mean separation $LSD_{0.05}$	0.35	0.20	0.21	0.16

1. n = 4, Least significant difference (LSD) mean separation , significant at $p \leq 0.05$.
2. Details of treatment are presented in Table 3.

Table 23. ANALYSIS OF VARIANCE FOR PHYSICAL BREAKING TEST OF CARROT STICKS HELD UNDER MA STORAGE AT 0-1°C, 97-98%RH FOR UP TO 60 DAYS WITH DIFFERENT DIPPING PRE-TREATMENTS (AT ROOM TEMPERATURE)

source of variance	df	Breaking force/CSA (N/cm^2)	Breaking failure (cm)
		MEAN SQUARES[1]	
Main Effects			
treatment[2]	7	55.49*	0.21**
storage period (21 vs. 60 days)	1	261.58**	0.17*
Two Way			
treatment x storage period	7	2.05	0.04
Error	64	23.45	0.03
%CV		20.69	17.85

1. n = 5; * = significant at $p \leq 0.05$, ** = significant at $p \leq 0.01$
2. treatments include: 1) citric/ascorbic acids, 0.01%; 2) $CaCl_2$, 0.002%; 3) glucose, 0.7%; 4) lecithin, 0.02%; 5) Mixture of 1 to 4; 6) sodium metaphosphate, 0.1%; 7) no dip control; 8) fresh-cut control

TABLE 24 MEAN VALUES[1] OF PHYSICAL BREAKING TEST OF CARROT STICKS HELD UNDER MA STORAGE AT 0-1°C, 97-98%RH FOR 21 AND 60 DAYS WITH DIFFERENT DIPPING TREATMENTS

treatment[2]	storage days at 0-1°C			
	21		60	
	force/CSA (N/cm^2)	breaking failure (cm)	force/CSA (N/cm^2)	breaking failure (cm)
citric/ascorbic acids	24.93±5.48	1.00±0.19	21.97±4.69	0.91±0.16
CaCl2	23.47±3.82	0.87±0.18	20.48±6.15	0.82±0.15
glucose	22.77±5.83	0.82±0.12	19.99±6.44	0.79±0.23
lecithin	28.50±3.08	1.22±0.13	24.99±5.81	0.88±0.13
Mixture	24.00±5.23	0.84±0.17	19.77±6.38	0.72±0.11
sodium meta-PO_4	22.60±4.83	0.87±0.04	18.58±3.89	0.88±0.14
control (no dip)	26.24±3.11	1.08±0.30	23.24±4.86	0.93±0.19
unsealed control[3]	29.20±2.39	1.19±0.10	23.77±2.55	1.23±0.18
Mean separation $LSD_{0.05}$	6.11	0.21	6.11	0.21

1. n = 5, Least significant difference (LSD) mean separation, significant at $p \leq 0.05$
2. Details of treatment are presented in Table 3.
3. whole carrots were stored in unsealed packages and cut prior to analysis.

storage was between lecithin and Na-mp dipped samples. Generally, both controls (no dip and fresh-cut) was determined to have the greatest breaking resistance than the other dipped samples, with the exception of the lecithin treatment which was greater (Figure 43).

The data in Table 24 and Figure 44 showed significant differences for breaking failure between fresh-cut control and all the other dipping treatments except that obtained for lecithin. These data indicated a significant effect of dipping treatment on cut carrots in MAP storage. Lower breaking failure was observed in dipping treated samples, including citric/ascorbic acids (1), $CaCl_2$ (2), glucose (3), Na-mp (6) and mixture (5) of 1 to 4. Also on 21 days of storage, lecithin dipped samples were found to have significantly higher breaking failure (1.22 cm) than did the other treatments.

The differences for physical properties between two storage periods are presented in Figures 45 and 46. After 60 days of storage, breaking force of all treatments decreased, however, the breaking failure of all treatments were found to be decreased except fresh-cut control. The results from Table 24 indicated that fresh-cut carrot sticks had higher breaking failure compared to the other treatments, i.e., it was found to be more "rubbery". The influence of the vacuum impregnation phase of treatment may have greatly effected the physical structure of the tissue

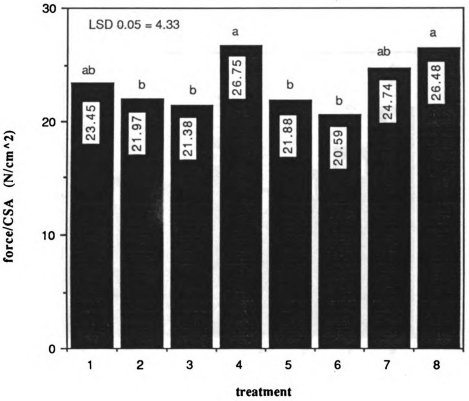


Figure 43. Mean values of the breaking force/CSA for carrot sticks with different dipping treatments in MA storage at 0-1°C, 97-98%RH over 21 and 60 days; treatments include: 1) citric /ascorbic acids, 0.01%; 2) $CaCl_2$, 0.002%; 3) glucose, 0.7%; 4) lecithin, 0.02%; 5) Mixture of 1 to 4; 6) sodium metaphosphate, 0.1%; 7) no dip control; 8) fresh-cut control; means followed by like letters are not significantly different ($p < 0.05$)

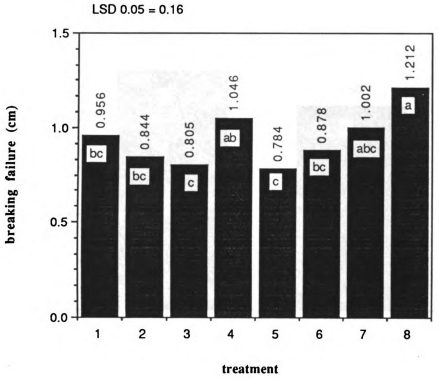


Figure 44. Mean values of the breaking failure for carrot sticks with different dipping treatments in MA storage at 0-1°C, 97-98%RH over 21 and 60 days; treatments include: 1) citric/ascorbic acids, 0.01%; 2) $CaCl_2$, 0.002%; 3) glucose, 0.7%; 4) lecithin, 0.02%; 5) Mixture of 1 to 4; 6) sodium metaphosphate, 0.1%; 7) no dip control; 8) fresh-cut control; means followed by like letters are not significantly different ($p < 0.05$)

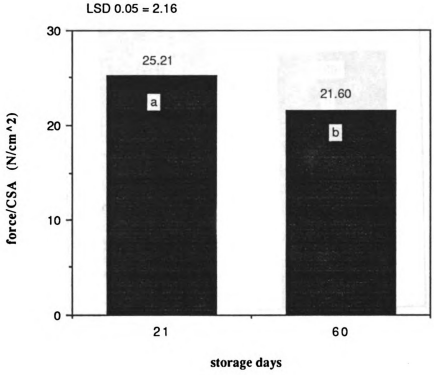


Figure 45. Mean values of the breaking force/CSA for carrot sticks on 21 and 60 days of MA storage at 0-1°C, 97-98%RH over all treatments; means followed by like letters are not significantly different ($p < 0.05$)

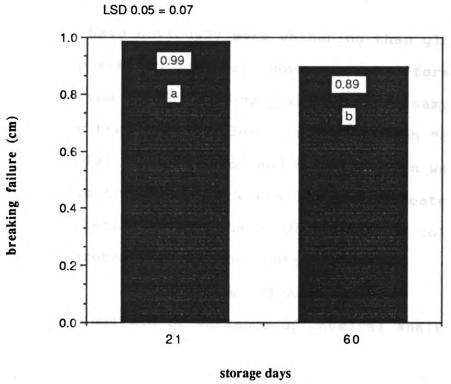


Figure 46. Mean values of the breaking failure for carrot sticks on 21 and 60 days of MA storage at 0-1°C, 97-98%RH over all treatments; means followed by like letters are not significantly different ($p < 0.05$)

and contributed to the physical textural differences among the treated samples.

The subjective visual and aroma evaluation was done prior to sensory evaluation. The no dip control sticks were found to have obviously more whitening than glucose, mixture and Na-mp treated samples. However, some "fermented" aroma was observed in glucose and mixture dipped samples; while the other treatment samples retained a fresh "earthy" aroma. No microbial proliferation and deterioration was observed in any of the treatments. Generally, Na-mp treated sticks were found to better retain the original surface color and the "fresh" aroma than did the control samples.

Chemical Analyses

The analysis of variance of chemical analyses (sucrose, reducing sugars, total phenolic compounds and moisture content) and the mean values for sugar analyses are presented in Tables 25 and 26. The mean values and LSD mean separations for total phenolic compounds and moisture content are presented in Table 27.

Significant differences were found among dipping treatments for all chemical analyses. The overall treatment differences for sugar analyses are presented in Figures 47 and 48. Na-mp dipped samples were found to have the highest levels of sucrose (14.37 mg/g db.) and the lowest levels of reducing sugars (1.15 mg/g). These results showed that Na-mp dipped carrot sticks retained the highest sucrose/

Table 25. ANALYSIS OF VARIANCE FOR CHEMICAL ANALYSES OF DIPPING PRE-TREATED CARROT STICKS HELD UNDER MA STORAGE AT 0-1°C, 97-98%RH FOR UP TO 21 DAYS

source of variance	df	sucrose	reducing sugars	total phenolics	moisture
			MEAN SQUARES[1]		
Main Effects					
treatment[2]	7	6.52**	1.39**	0.11**	6.09**
storage period	1	0.001	13.74**	0.01	---
Two Way					
treatment x stroage period	7	3.89**	1.45**	0.10**	---
Error	48	1.11	0.45	0.02	0.84
%CV		8.28	32.99	3.89	1.03

1. n = 4; * = significant at $p \leq 0.05$, ** = significant at $p \leq 0.01$
2. treatments include: 1) citric/ascorbic acids, 0.01%; 2) $CaCl_2$, 0.002%; 3) glucose, 0.7%; 4) lecithin, 0.02%; 5) Mixture of 1 to 4; 6) sodium metaphosphate, 0.1%; 7) no dip control; 8) fresh-cut control

TABLE 26 MEAN VALUES[1] OF SUGAR ANALYSIS[2] OF DIPPING TREATED CARROT STICKS (CARO-BEST) HELD UNDER MA STORAGE OF 0-1°C, 97-98%RH FOR 0 AND 21 DAYS

	storage days at 0-1°C			
	0 day		21 days	
treatment[3]	sucrose	reducing sugars	sucrose	reducing sugars
citric/ascrobic acids (0.01%)	14.18±0.48	1.01±0.50	12.15±1.72	2.89±0.38
calcium chloride (0.002%)	11.94±1.75	1.93±1.21	13.46±1.04	1.57±0.41
glucose (0.7%)	12.31±0.76	1.87±0.73	10.91±0.71	3.03±0.70
lecithin (0.02%)	12.21±0.42	1.31±0.30	11.90±0.31	2.92±0.39
Mixture	11.46±0.89	1.40±0.77	12.92±0.83	2.95±0.72
sodium meta-phosphate (0.1%)	13.88±1.57	1.27±0.58	14.87±0.69	1.04±0.54
control (no dipping)	12.91±1.08	1.03±0.47	12.63±1.09	2.36±0.44
Mean separation $LSD_{0.05}$	1.51	0.88	1.51	0.88

1. n = 4, Least significant difference ($LSD_{0.05}$) mean separation, significant at $p \leq 0.05$.
2. All units are presented as mg/g dry bases (db.)
3. Details of treatment are presented in Table 3.

TABLE 27 MEAN VALUES[1] OF TOTAL PHENOLIC COMPOUND AND MOISTURE CONTENT OF DIFFERENT DIPPING PRETREATED CARROT STICKS (CARO-BEST) HELD UNDER MA STORAGE AT 0-1°C, 97-98%RH FOR 21 DAYS

treatment[2]	storage days at 0-1°C		Moisture content
	0	21	
	Total phenolics (mg/g db.)		(%)
citric/ascorbic acids (0.01%)	3.20±0.01	3.20±0.01	89.93±0.85
calcium chloride (0.002%)	3.06±0.06	3.04±0.03	89.42±1.06
glucose (0.7%)	3.06±0.04	3.10±0.02	90.58±1.24
lecithin (0.02%)	3.36±0.09	3.22±0.03	87.85±0.50
Mixture	3.11±0.03	3.12±0.05	90.11±0.45
sodium metaphosphate (0.1%)	2.77±0.22	3.10±0.03	89.07±0.55
control (no dipping)	3.23±0.36	2.82±0.08	87.01±0.55
fresh-cut control	-	-	86.93±1.41
Mean separation $LSD_{0.05}$	0.17	0.17	1.51

1. n = 3, Least significant difference (LSD) mean separation, significant at $p \leq 0.05$.
2. Details of treatment are presented in Table 3.

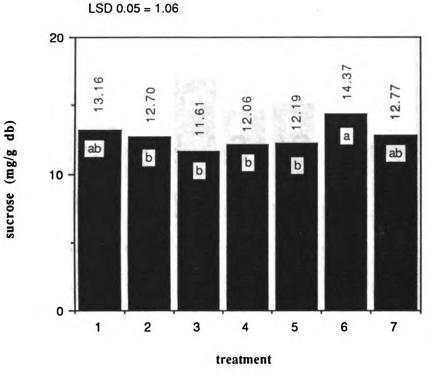


Figure 47. Mean values of the sucrose amount for carrot sticks with different dipping treatments in MA storage at 0-1°C, 97-98%RH for 21 days; treatments include: 1) citric/ascorbic acids, 0.01%; 2) $CaCl_2$, 0.002%; 3) glucose, 0.7%; 4) lecithin, 0.02%; 5) Mixture of 1 to 4; 6) sodium metaphosphate, 0.1%; 7) no dip control; means followed by like letters are not significantly different ($p < 0.05$)

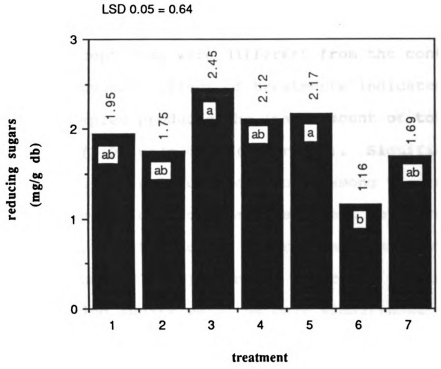


Figure 48. Mean values of the reducing sugars for carrot sticks with different dipping treatments in MA storage at 0-1°C, 97-98%RH for 21 days; treatments include: 1) citric/ascorbic acids, 0.01%; 2) $CaCl_2$, 0.002%; 3) glucose, 0.7%; 4) lecithin, 0.02%; 5) Mixture of 1 to 4; 6) sodium metaphosphate, 0.1%; 7) no dip control; means followed by like letters are not significantly different ($p < 0.05$)

reducing sugars ratio, therefore it is likely to have the sweetest taste according to the study of Phan et al. (1973).

No significant differences for total phenolic content were found among all dip treatments at the beginning of storage except they were different from the control (Table 27). The overall effect of treatments indicated that Na-mp treated samples produced the least amount of total phenolic compounds (2.94 mg/g db.) (Figure 49). Significant differences for moisture were found among treatments (Figure 50). Fresh-cut controls had the lowest moisture content (86.93%) , and the no dip control was also found to have less moisture (87.01%) than the other dip treatments.

Reducing sugars were the only significant differences found among storage days. Increase of reducing sugars was observed during 21 days of MA storage (Figure 51). There were no differences for total phenolic compounds among storage periods, which indicated that peel treatment was effective in preventing phenolic compound formation for fresh market carrots.

Sensory Evaluation

The analysis of variance and mean values for three major sensory profiles (Tactile, Masticatory and Flavor) are presented in Table 28 and Table 29. And the QDA diagrams for sensory evaluation are presented in Figure 52. The mean values of "overall preference" is presented in Figure 53.

There were no significant differences found in any of

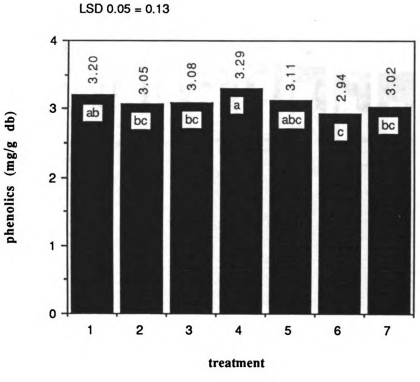


Figure 49. Mean values of the total phenolic compounds for carrot sticks with different dipping treatments in MA storage at 0-1°C, 97-98%RH for 21 days; treatments include: 1) citric/ascorbic acids, 0.01%; 2) $CaCl_2$, 0.002%; 3) glucose, 0.7%; 4) lecithin, 0.02%; 5) Mixture of 1 to 4; 6) sodium metaphosphate, 0.1%; 7) no dip control; means followed by like letters are not significantly different ($p < 0.05$)

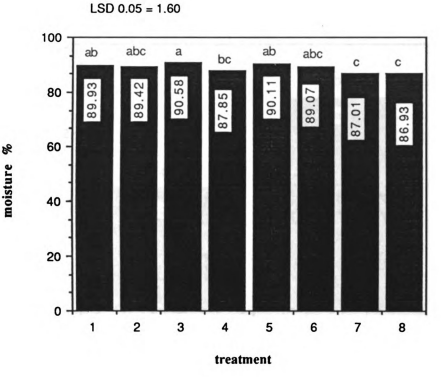


Figure 50. Mean values of the moisture content for carrot sticks with different dipping treatments in MA storage at 0-1°C, 97-98%RH; treatments include: 1) citric/ascorbic acids, 0.01%; 2) $CaCl_2$, 0.002%; 3) glucose, 0.7%; 4) lecithin, 0.02%; 5) Mixture of 1 to 4; 6) sodium metaphosphate, 0.1%; 7) no dip control; 8) fresh-cut control; means followed by like letters are not significantly different ($p < 0.05$)

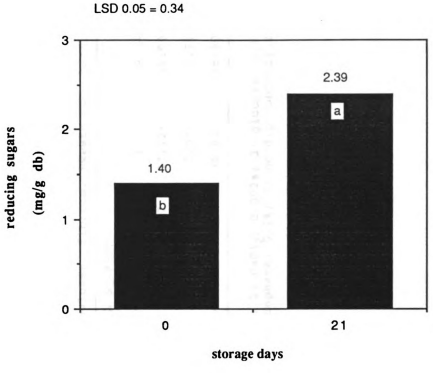


Figure 51. Mean values of the reducing sugars for carrot sticks on 21 and 60 days of MA storage at 0-1°C, 97-98%RH over all treatments; means followed by like letters are not significantly different ($p < 0.05$)

Table 28. ANALYSIS OF VARIANCE FOR SENSORY EVALUATION OF DIPPING PRE-TREATED CARROT STICKS (CARO-BEST) HELD UNDER MA STORAGE AT 0-1°C, 97-98%RH FOR 21 DAYS WITH DIFFERENT FOOD GRADE CHEMICALS (AT ROOM TEMPERATURE)

		Sensory Parameters							
		Tactile		Masticatory			Flavor		Overall
	df	firmness	juiciness	crispness	chewiness	fibrous.	sweetness	harshness	preference
		MEAN SQUARES[1]							
Main Effects									
treatment[2]	7	1.64	4.44	1.23	7.46	6.60	2.37	5.72	1.98
panelist	3	5.47	12.08	11.68*	2.72	4.92	11.12*	22.92*	1.45
Error	21	3.20	5.87	3.03	3.25	3.95	2.63	3.75	2.68
%CV		23.32	37.74	23.44	29.45	43.34	36.43	45.90	29.70

1. n = 4, * = significant at $p < 0.05$
2. treatments include: 1) citric/ascorbic acids, 0.01%; 2) $CaCl_2$, 0.002%; 3) glucose, 0.7%; 4) lecithin, 0.02%; 5) Mixture of 1 to 4; 6) sodium metaphosphate, 0.1%; 7) no dip control; 8) fresh-cut control

TABLE 29 MEANS[1] OF SENSORY EVALUATION[2] OF PRETREATED CARROT STICKS HELD UNDER MA STORAGE AT 0-1°C, 97-98%RH FOR 21 DAYS WITH DIFFERENT DIPPING SOLUTIONS AND UNSEALED FRESH-CUT CONTROL

	Tactile		Masticatory			Flavor	
treatment[3]	firmness	juiciness	crispness	chewiness	fibrousness	sweetness	harshness
citric/ascorbic acids	8.79±1.12	6.39±2.75	7.53±1.89	7.48±2.06	5.01±1.39	3.54±1.84	5.05±2.67
$CaCl_2$	7.08±1.31	6.96±1.44	7.78±1.28	5.09±1.64	2.35±1.25	4.08±0.74	3.25±3.03
glucose	8.06±1.20	5.94±3.16	6.85±2.23	6.80±2.56	5.40±1.94	5.03±3.12	3.66±3.79
lecithin	8.19±1.58	5.11±3.15	7.65±2.04	7.61±2.28	5.45±3.25	5.58±0.70	3.31±3.05
Mixture	7.43±2.84	6.31±2.65	6.71±3.16	3.98±1.62	3.93±2.97	3.73±2.23	2.41±0.85
Na meta-PO_4	7.06±1.95	6.46±2.44	6.83±2.09	4.85±1.55	3.61±1.28	5.38±1.76	5.16±0.81
control	7.75±2.17	5.58±3.19	8.05±0.98	7.23±1.13	6.48±1.07	4.09±2.38	5.64±1.58
unsealed[4] control	7.03±2.09	8.61±0.76	8.04±1.80	5.98±0.74	4.48±1.78	4.19±1.27	5.26±1.91
Mean separation							
$LSD_{0.05}$	2.60	3.53	2.54	2.63	2.89	2.36	2.83

1. n = 4, Least significant difference (LSD) mean separation, significant at $p \leq 0.05$.
2. scale for all parameters: 0 = least; 10 = most.
3. Details of treatment are presented in Table 3.
4. whole carrots stored in package without seal and cut immediately before sensory.

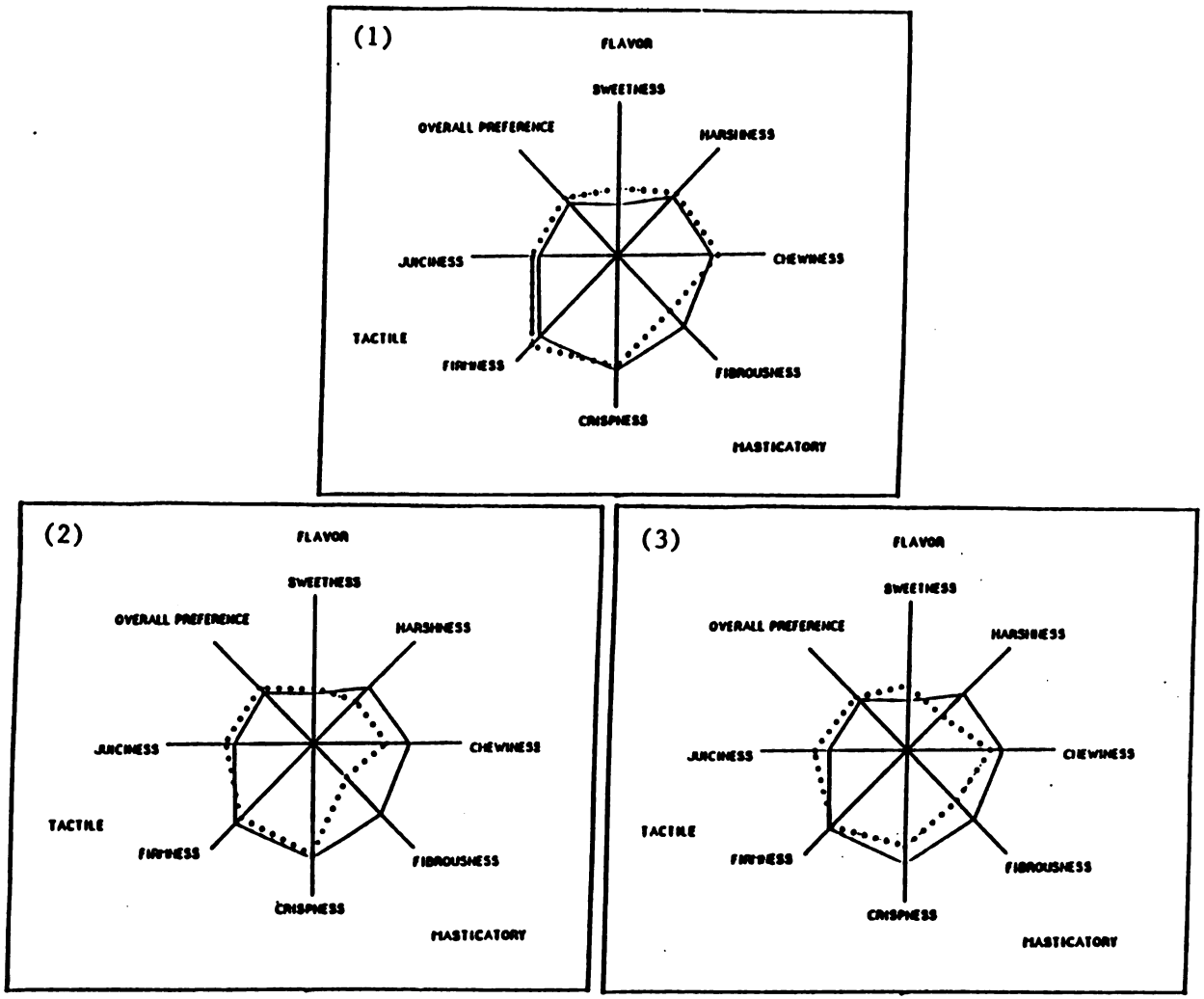


Figure 52. The Quantitative Descriptive Analysis (QDA) diagram of sensory evaluation for DIPPING treated carrot sticks under MA storage at 0-1°C, 97-98%RH for 3 weeks: ——— no dip (control), ... treated samples; (1) citric/ascorbic acids, (2) $CaCl_2$, (3) glucose, (4) lecithin, (5) Mixture of 1 to 4, (6) Na-metaphosphate, (7) fresh-cut control

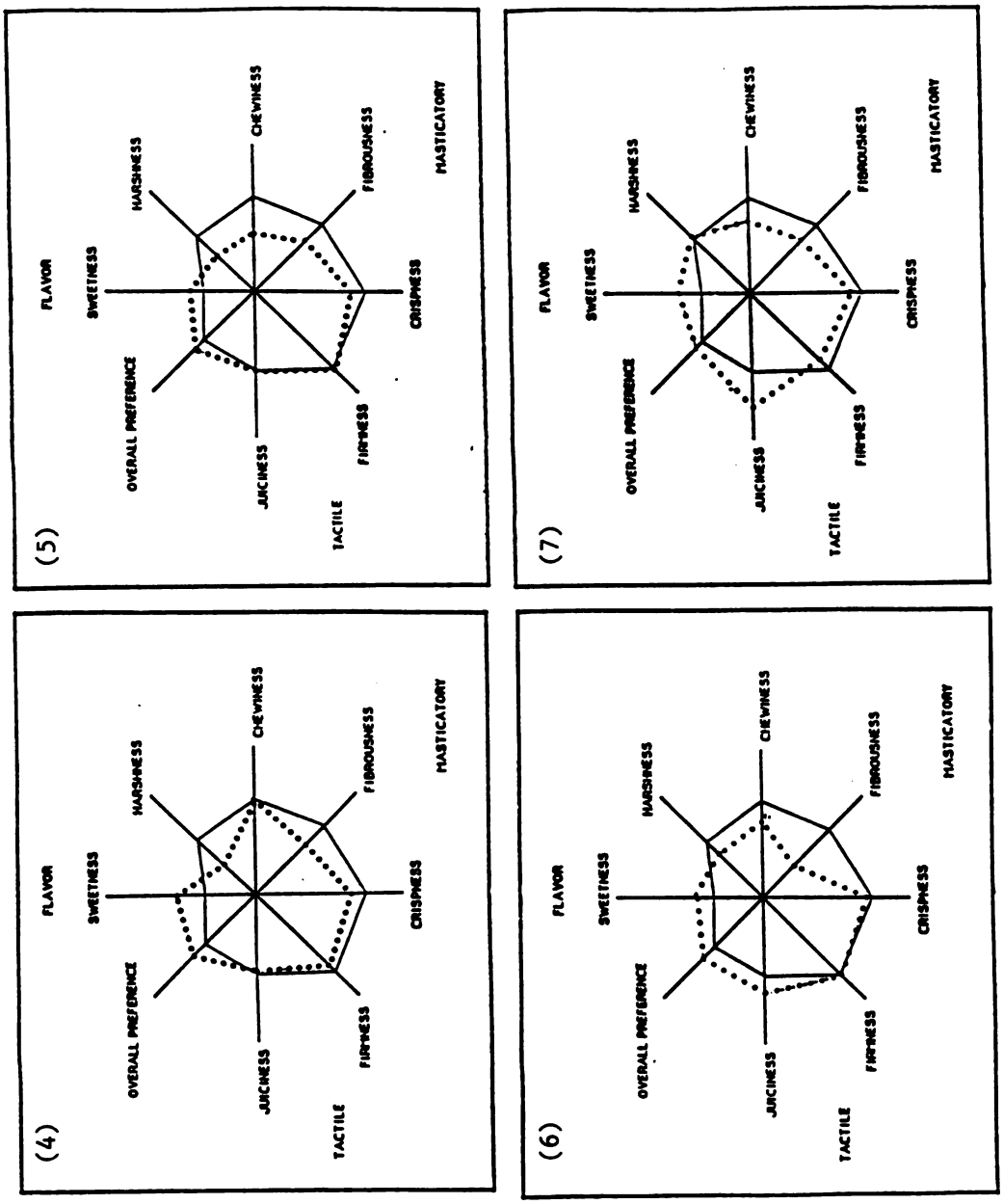


Figure 52. (Con't.)

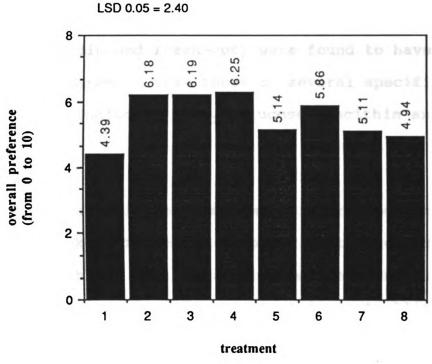


Figure 53. Mean values of "overall preference" in the sensory evaluation of different dipping treatments (1-8); scale = 0 to 10; treatments include: 1) citric/ascorbic acids, 0.01%; 2) $CaCl_2$, 0.002%; 3) glucose, 0.7%; 4) lecithin, 0.02%; 5) Mixture of 1 to 4; 6) sodium metaphosphate, 0.1%; 7) no dip control; 8) fresh-cut control

the sensory characters among dipping treatments, however, it was observed that significant differences were detected within the panelists (replicates) for "crispness", "sweetness" and "harshness" measures. Although there were no significant differences among treatments, both control samples (no dip and fresh-cut) were found to have lower sensory preferences than those of several specific treatments, including $CaCl_2$, glucose, lecithin and Na-mp.

Conclusions

The data indicated that lecithin treated samples had similar breaking force/CSA compared to the no dip controls and the fresh-cut controls. Dipping treatments were detected to have significant effect in controlling the surface "whitening" of carrot sticks. Higher sucrose/ reducing sugars ratio and lower total phenolic content were observed in Na-mp dipped samples, which indicated desirable quality characters were associated with this treatment. Reducing sugars increased during 21 days storage period. Carrot sticks obtained from the glucose and the mixture treatments were found to generate "fermented" aroma during long term storage; while samples obtained from Na-mp treatment retained the "fresh", "earthy" aroma as well as the surface original color. Ho.3 therefore was rejected according to these observations.

SUMMARY AND CONCLUSION

The data obtained in the controlled CO_2 storage study indicated carrot cultivars, peeling treatments and CO_2 concentration had no effect on the texture quality of breaking resistance (force/CSA). It was found that peel treated carrot sticks became more fragile after 28 days of cold storage. CARO-BEST was found to contain more sucrose and less reducing sugars than the other cultivars. Also most of the phenolic compounds were found in carrot peel. High CO_2 environment reduced sucrose degradation and provided limited inhibition of total phenolic content development. Generally, "surface whitening" was found to be the primary limiting quality factor within all storage treatments.

In the MAP study, peeled carrots were found to have lower respiration rate at selected days of storage. Fresh-cut carrot sticks became more rubbery than packaged pre-cut samples because of moisture loss. CARO-BEST had softer texture but was found more sweet than the other two cultivars studied. A high degree of association was found between sensory evaluation measures and objective quality analyses, which indicated some of the sensory parameters are more capable to represent the quality of carrots. No significant "surface whitening" was observed in packaged sticks of either treatment.

Peeled carrot sticks from CARO-BEST was selected for dipping treatments because they showed superior quality potential in previous studies. Some dipping pretreated samples, such as glucose, mixture and Na-mp, were found to have less "surface whitening" than no dip controls, however, a "fermented aroma" was also found to be associated with the glucose and mixture dipped sticks. Na-mp treated carrot sticks had superior physical and chemical quality results, although it was not clearly showed in the sensory evaluation. Generally, dipping treatment improved control of the surface "whitening" and some quality characters of MAP storaged carrot sticks.

Further work needs to be conducted at reducing the time and cost of product preparation in order to retain the best quality. It would be beneficial to further investigate the pathway of carbohydrate and phenolic acid metabolism during post-harvest stage in order to generate optimum condition of storage and to extend the shelf life of carrot sticks.

APPENDIX I

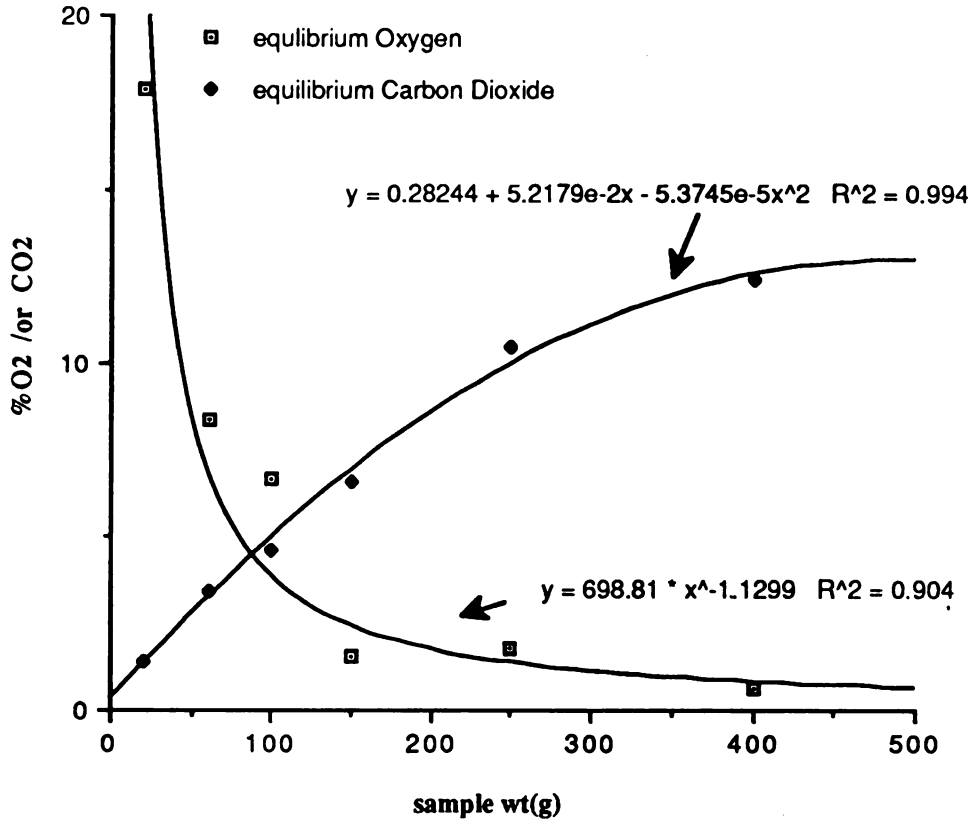


Figure 54. The Respiration curves of CO_2 and O_2 of preliminary test of carrot sticks storaged at 0°C, 98%RH for 15 days: equilibrium O_2 /or CO_2 vs. sample weight per plastic bag (20cm x 20cm)

APPENDIX II

Table 30 Mean values of physical TPA (compression force (N)) analysis of carrot cultivars

Region	Michigan			California		
Location	Kalamazoo	Cedar Spring	Grant	Cuyama	Bakersfield	El Centro
Harvest date	8/90	8/90	10/90	10/90	3/91	4/91
Cultivar/line						
APACHE	331.6	490.5	392.6	189.8	140.9	---
BLT#1	---[1]	---	---	166.2	191.3	196.3
BLT#2	---	426.6	416.0	199.0	176.2	182.0
BLT#3	---	449.5	458.7	180.5	168.0	200.0
CARO-BEST	394.3	502.3	441.1	207.2	159.5	210.2
CAROBRITE	444.8	426.6	423.4	---	---	---
CARO-CHOICE	454.1	404.2	449.6	187.4	194.0	201.7
CARO-GOLD	406.8	400.5	425.2	---	---	---
CARO-PAK	377.9	490.5	454.5	260.9	185.8	216.4
CARO-PRIDE	399.1	379.0	409.5	226.1	158.7	195.1
CELLOBUNCH	354.3	372.1	360.0	180.5	167.2	187.4
CHANCELLOR	381.3	455.9	376.6	220.7	127.7	---
DOMINATOR	---	---	---	173.9	219.1	184.7
FANCIPAK	---	---	---	215.7	167.2	194.4
FLAME	---	---	---	154.2	195.9	---
GOLDMINE	---	---	---	184.0	178.1	---
LONG IMP-58	---	---	---	209.1	233.5	188.9
PARAMOUNT	442.1	421.5	422.3	---	---	---
SIX PAK	439.4	478.2	463.8	221.1	197.8	185.8
SIX PAK 2	---	---	---	192.1	187.8	---
SIX PENCE	---	---	---	208.3	197.5	197.5
TX GOLDSPIKE	---	---	---	224.9	193.2	---
XPH 3485	383.9	482.9	450.4	---	---	---
XPH 3504	373.9	454.5	409.0	---	---	---
XPH 3507	463.6	476.0	357.0	---	---	---
XPH 3624	516.2	445.0	373.2	---	---	---
XPH 3649	---	---	---	216.8	185.8	---
XPH 3706	---	---	---	197.1	179.3	177.7
XPH 3708	426.2	372.2	396.7	213.7	137.8	221.5

1. "---" cultivar/line sample was not available for study
2. Least Significant Difference (LSD) mean separation: $LSD_{0.05}$ for 3 locations in Michigan = 120.56 $LSD_{0.05}$ for 3 locations in California = 43.79

Table 31 Mean values of physical breaking (force/CSA (N/cm^2)) analysis of carrot cultivars

Region	Michigan			California		
Location	Kalamazoo	Cedar Spring	Grant	Cuyama	Bakersfield	El Centro
Harvest date	8/90	8/90	10/90	10/90	3/91	4/91
Cultivar/line						
APACHE	76.83	---[1]	36.83	31.78	22.65	---
BLT#1	---	---	---	30.48	19.52	28.43
BLT#2	---	---	26.65	27.85	17.58	30.54
BLT#3	---	---	32.89	25.93	22.14	27.83
CARO-BEST	73.89	---	38.21	27.59	16.72	26.18
CAROBRITE	72.29	---	27.18	---	---	---
CARO-CHOICE	70.03	34.08	40.86	34.20	18.33	25.59
CARO-GOLD	65.98	---	33.73	---	---	---
CARO-PAK	62.12	---	29.96	26.67	23.07	19.20
CARO-PRIDE	55.46	---	22.49	31.72	22.77	30.29
CELLOBUNCH	67.55	---	42.09	34.74	23.68	26.29
CHANCELLOR	42.97	34.62	32.61	41.66	21.87	---
DOMINATOR	---	---	---	35.92	38.43	31.50
FANCIPAK	---	---	---	44.19	28.64	30.79
FLAME	---	---	---	30.43	25.05	---
GOLDMINE	---	---	---	33.80	21.29	---
LONG IMP-58	---	---	---	29.77	29.54	31.74
PARAMOUNT	60.11	39.72	43.28	---	---	---
SIX PAK	64.97	34.83	32.97	32.92	21.31	24.01
SIX PAK 2	---	---	---	30.27	30.54	---
SIX PENCE	---	---	---	32.37	21.05	27.46
TX GOLDSPIKE	---	---	---	29.29	25.64	---
XPH 3485	72.36	---	24.60	---	---	---
XPH 3504	75.74	33.25	28.34	---	---	---
XPH 3507	81.95	---	33.29	---	---	---
XPH 3624	42.89	37.83	32.43	---	---	---
XPH 3649	---	---	---	27.47	28.21	---
XPH 3706	---	---	---	29.44	29.12	21.57
XPH 3708	68.49	---	32.95	35.34	17.11	27.73

1. "---" cultivar/line sample was not available for study

2. Least Significant Difference (LSD) mean separation: $LSD_{0.05}$ for 3 locations in Michigan isn't available because of too many missing data. $LSD_{0.05}$ for 3 locations in California = 8.79

Table 32 Mean values of total soluble solids (°Brix) analysis of carrot cultivars/breeding lines

Region	Michigan			California		
Location	Kalamazoo	Cedar Spring	Grant	Cuyama	Bakersfield	El Centro
Harvest date	8/90	8/90	10/90	10/90	3/91	4/91
Cultivar/line						
APACHE	8.0	9.5	9.9	9.2	7.6	---
BLT#1	---[1]	---	---	9.0	8.2	9.7
BLT#2	---	7.8	12.0	10.1	7.6	9.2
BLT#3	---	7.6	11.2	9.7	8.4	8.0
CARO-BEST	5.8	9.3	9.5	11.8	7.5	10.1
CAROBRITE	7.8	9.2	12.5	---	---	---
CARO-CHOICE	8.6	7.6	10.2	9.0	8.0	9.0
CARO-GOLD	5.2	9.1	9.2	---	---	---
CARO-PAK	5.6	8.8	7.6	10.2	9.9	9.4
CARO-PRIDE	6.3	9.0	10.8	10.5	8.7	8.1
CELLOBUNCH	6.0	8.6	10.0	10.7	8.8	8.5
CHANCELLOR	6.6	9.6	9.7	9.9	7.7	---
DOMINATOR	---	---	---	10.2	9.5	8.3
FANCIPAK	---	---	---	10.1	8.6	9.7
FLAME	---	---	---	10.0	8.3	---
GOLDMINE	---	---	---	10.5	9.0	---
LONG IMP-58	---	---	---	10.0	8.1	8.5
PARAMOUNT	8.0	8.2	7.9	---	---	---
SIX PAK	5.7	8.3	11.8	10.7	9.1	8.6
SIX PAK 2	---	---	---	11.2	9.4	---
SIX PENCE	---	---	---	11.3	8.1	9.2
TX GOLDSPIKE	---	---	---	10.0	9.9	---
XPH 3485	4.9	10.2	10.4	---	---	---
XPH 3504	7.0	8.5	11.2	---	---	---
XPH 3507	7.7	8.2	11.0	---	---	---
XPH 3624	6.8	7.5	8.9	---	---	---
XPH 3649	---	---	---	11.0	8.5	---
XPH 3706	---	---	---	10.6	10.0	9.9
XPH 3708	4.6	7.0	10.9	11.5	10.4	9.0

1. "---" cultivar/line sample was not available for study
2. Least Significant Difference (LSD) mean separation: $LSD_{0.05}$ for 3 locations in Michigan = 1.15
   $LSD_{0.05}$ for 3 locations in California = 1.09

Table 33 Mean values of total phenolic compound (mg/g db.) analysis of carrot cultivars/breeding lines

Region	Michigan			California		
Location	Kalamazoo	Cedar Spring	Grant	Cuyama	Bakersfield	El Centro
Harvest date	8/90	8/90	10/90	10/90	3/91	4/91
Cultivar/line						
APACHE	2.89	1.60	3.04	3.03	3.87	---
BLT#1	---[1]	---	---	3.40	3.72	2.95
BLT#2	---	2.30	3.90	2.95	3.06	1.94
BLT#3	---	1.54	3.05	2.77	5.21	1.30
CARO-BEST	2.88	2.58	3.59	2.29	2.62	2.07
CAROBRITE	3.00	1.59	3.19	---	---	---
CARO-CHOICE	3.00	2.36	4.39	3.97	2.57	2.10
CARO-GOLD	2.35	3.06	2.68	---	---	---
CARO-PAK	3.00	2.33	3.23	3.19	4.23	3.37
CARO-PRIDE	1.90	1.91	4.44	5.36	2.95	1.91
CELLOBUNCH	1.94	1.32	2.96	2.69	3.95	2.31
CHANCELLOR	1.45	1.73	3.51	3.08	3.92	---
DOMINATOR	---	---	---	2.54	3.75	2.80
FANCIPAK	---	---	---	2.52	2.94	1.48
FLAME	---	---	---	3.02	2.86	--
GOLDMINE	---	---	---	3.16	2.80	---
LONG IMP-58	---	---	---	4.53	2.72	2.20
PARAMOUNT	3.10	1.81	3.88	---	---	---
SIX PAK	2.26	1.73	3.05	3.87	5.89	3.18
SIX PAK 2	---	---	---	5.12	3.35	---
SIX PENCE	---	---	---	2.74	2.99	2.24
TX GOLDSPIKE	---	---	---	2.90	2.39	---
XPH 3485	2.65	2.34	4.03	---	---	---
XPH 3504	3.12	2.09	3.07	---	---	---
XPH 3507	2.40	1.85	3.51	---	---	---
XPH 3624	1.87	1.91	3.44	---	---	---
XPH 3649	---	---	---	2.72	3.95	---
XPH 3706	---	---	---	2.62	3.83	2.57
XPH 3708	2.27	3.08	2.71	2.59	1.79	2.94

1. "---" cultivar/line sample was not available for study
2. Least Significant Difference (LSD) mean separation: $LSD_{0.05}$ for 3 locations in Michigan = 0.73
   $LSD_{0.05}$ for 3 locations in California = 1.82

Table 34 Mean values of selected physical and chemical analyses of Michigan and California carrot cultivars/breeding lines

	TPA (Neuton)		Breaking force/CSA		°Brix		Total Phenolics	
Region	Michigan	California	Michigan	California	Michigan	California	Michigan	California
Cultivar/line	(N)		(N/cm^2)		(%)		(mg/g db.)	
APACHE	404.9	165.4	54.60	27.21	9.13	8.40	2.56	3.45
BLT#1	---[1]	184.6	---	26.14	---	8.97	---	3.36
BLT#2	421.3	185.7	26.65	25.32	9.90	8.97	3.10	2.65
BLT#3	454.1	182.8	32.89	25.30	9.40	8.70	2.29	3.09
CARO-BEST	445.9	192.3	54.06	23.49	8.20	9.80	3.00	2.32
CARO-BRITE	431.6	---	49.74	---	9.83	---	2.65	---
CARO-CHOICE	435.9	194.4	48.33	26.04	8.80	8.67	3.22	2.88
CARO-GOLD	410.8	---	49.85	---	7.83	---	2.65	---
CARO-PAK	440.9	221.0	47.83	22.98	7.33	9.83	2.87	3.60
CARO-PRIDE	395.9	193.3	38.98	28.26	8.70	9.10	2.63	3.41
CELLOBUNCH	362.1	178.4	54.82	28.24	8.20	9.33	2.05	2.99
CHANCELLOR	404.6	174.2	36.73	31.76	8.63	8.80	2.12	3.50
DOMINATOR	---	192.6	---	35.28	---	9.33	---	3.03
FANCIPAK	---	192.4	---	34.54	---	9.47	---	2.31
FLAME	---	175.0	---	27.74	---	9.15	---	2.94
GOLDMINE	---	181.1	---	27.54	---	9.75	---	2.98
LONG IMP-58	---	210.5	---	30.35	---	8.87	---	3.15
PARAMOUNT	428.6	---	47.71	---	8.03	---	2.95	---
SIX PAK	460.5	201.6	42.78	26.08	8.60	9.47	2.33	4.31
SIX PAK 2	---	189.9	---	30.41	---	10.30	---	4.23
SIX PENCE	---	201.1	---	26.96	---	9.53	---	2.66
TX GOLDSPIKE	---	209.1	---	27.47	---	9.95	---	2.64
XPH 3485	439.1	---	34.16	---	8.50	---	2.96	---
XPH 3504	412.5	---	45.78	---	8.90	---	2.81	---
XPH 3507	432.2	---	41.40	---	8.97	---	2.56	---
XPH 3624	444.8	---	36.92	---	7.73	---	2.33	---
XPH 3649	---	201.3	---	27.84	---	9.75	---	3.33
XPH 3706	---	184.7	---	26.71	---	10.17	---	3.01
XPH 3708	398.4	191.0	48.75	26.73	7.50	10.30	2.63	2.44
Mean separation								
$LSD_{0.05}$		72.81		29.22		1.85		1.66

1. "---" cultivar/line sample was not available for study

Reference

Abdel-Rahman, M. and F. M. R. Isenberg 1974. Effects of growth regulators and controlled atmosphere on stored carrots. J. Agri. Sci. 82:245-249.

Alabran, D. M. and A. F. Mabrouk 1973. Carrot flavor: Sugars and free nitrogenous compounds in fresh carrots. J. Agri. Food Chem. 21(2):205-208.

Amerine, M. A., R. M. Pangborn, and E. B. Roessler. 1965. Physical and chemical tests related to sensory properties of foods. Chap. 11 in "Principles of sensory evaluation of food". Academic Press. N. Y. pp.505.

Apeland, J. and H. Hoftun 1971. Physiological effects of oxygen on carrots in storage. Acta Hort. 20:108-114.

Baumann, H. 1974. Preservation of carrot quality under various storage conditions. Acta Hort. 38:327-337.

Bessey, P. M. 1957. Studies on the occurrence, measurement, and control of bitterness in carrots. Ph.D. Thesis. Michigan State University. pp.13.

Bolin, H. R. and C. C. Huxsoll. 1991. Control of minimally processed carrot (*Daucus carota*) surface discoloration caused by abrassion peeling. J. Food Sci. 56(2):416-418.

Bourne, M. C. 1975. Is rheology enough for food texture measurements. J. Texture Studies. 6:259-262.

Bourne, M. C. 1977. Limitations of rheology in food texture measurements. J. Texture Studies. 8:219-227.

Bourne, M. C. 1968. Texture profile of ripening pears. J. Food Sci. 33:223-226.

Breene, W. M. 1975. Application of texture profile analysis to instrumental food texture evaluation. J. Texture Studies 6:53-80.

Bruemmer, J. H. 1988. Quality changes of carrot sticks in storage. Proc. Fla. State Hort. Soc. 101:207-210.

Bruemmer, J. H. 1987. Stability of prepared carrot sticks in storage. Proc. Fla. State Hort. Soc. 100:36-38.

Buttery, R. G., R. M. Seifert, D. G. Guadagni, D. R. Black and L. C. Ling 1968. Characterization of some volatile constituents of carrots. J. Amer. Food Chem. 16:1009-1015.

Carlin, F., C. Nguyen-The, G. Hilbert and Y. Chambroy 1990. Modified atmosphere packaging of fresh, "Ready-to-Use" grated carrots in polymeric films. J. Food Sci. 55(4):1033-1037.

Carlton, B. C., C. E. Peterson, and N. E. Tolbert. 1961. Effects of ethylene and oxygen on production of a bitter compound by carrot roots. Plant Physiology 36:550-552.

Carlton, B. C. and C. E. Peterson 1963. Breeding carrots for sugar and dry matter content. J. Amer. Soc. Hort. Sci. 82:332-340.

Chiang, J. C., B. Singh, and D. K. Salunkhe. 1971. Effects of water quality on canned carrots, sweet cherries and apricots. J. Amer. Soc. Hort. Sci. 96(3):357-359.

Conrad, E. C. and J. K. Palmer 1976. Rapid analysis of carbohydrates by High-Pressure Liquid Chromatography. Food Tech. 30:84-92.

Coxon, D. T., R. F. Curtis, K. R. Price, and G. Levett. 1973. Abnormal metabolites produced by *Daucus carota* roots stored under conditions of stress. Phytochemistry 12:1881-1885.

Delcour, J. A., C. J. A. Vinkx, S. Vanhamel, and G. G. A. G. Block. 1989. Combined monitoring of UV absorbance and fluorescence intensity as a diagnostic criterion in reversed-phase high-performance liquid chromatographic separations of natural phenolic acids. J. Chromatography 467:149-157.

Dudek, J. A., E. R. Elkins, jr., H. B. Chin and R. E. Hagen 1982. Investigations to determine nutrient content of selected fruits and vegetables - raw, processed and prepared. Final report. National Food Processors Assoc., Washington D. C. pp.199-204.

Goldstein, J. L. and T. Swain. 1963. Changes in tannins in ripening fruits. Phytochemistry 2:371-383.

Hansen, H. and G. Rampf 1974. Storage of carrots ('Nantaise): The influence of the storage atmosphere on flavor, decay and content of sucrose, glucose and fructose. Acta Hort. 38:321-326.

Hard, M. M., M. V. Zaebringer, F. Bowman, and A. C. Mackey. 1977. Predicting texture of fresh fruits and vegetables by chemical and physical methods. Washington Agricultural Experiment Station. Bulletin# 836.

Hardenburg, R. E., M. Lieberman, and A. Schomer. 1953. Pre-packaging carrots in different types of consumer bags. Proc. Am. Soc. Hort. Sci. 61:404.

Heil, J. R. and M. J. McCarthy 1989. Influence of acidification on texture of canned carrots. J. Food Sci. 54(4):1092-1093.

Howard, P. L., and D. E. Heinz. 1970. Texture of carrots. J. Texture Studies 1:185-195.

Hultin, H. O. and M. Milner (editor) 1978. Biochemical and functional changes in cereals: maturation, storage and germination. in "Postharvest biology and biotechnology". Food & Nutrition Press, Inc., Westport, CN. pp.14.

Jaworski, J. G., J. Kuc', and E. B. Williams. 1973. Effect of ethrel and *Ceratocystis fimbriata* on the accumulation of chlorogenic acid and 6-methoxy mellein in carrot root. Phytopathology 63:408-413.

Juliot, K. N., R. C. Lindsay, and S. C. Ridley. 1989. Directly-acidified carrot slices for ingredients in refrigerated vegetable salads. J. Food Sci. 54(1):90-95.

Kader, A. A. 1986. Biochemical and physiological basis for effects of controlled and modified atmospheres on fruits and vegetables. Food Tech. 40(May):99-104.

Kaminski, E., E. Wasowicz, R. Zawirska and M. Wower 1986. The effect of drying and storage of dried carrots on sensory characteristics and volatile constituents. Die Nahrung 30(8):819-828.

Kapsalis, J. G., R. A. Segars, and J. G. Krizik. 1972. An instrument for measuring rheological properties by bending-application to food materials of plant origin. J. Texture Studies 3:31-50.

Kostaropoulos, A. E. 1981. The introduction of an empirical expression in the texture studies of the vegetables. Lebensmittel-Wissenschaft und-Technologie. 14(2):97-99.

Kramer, A. and B. A. Twigg. 1974. Chap. 8. Flavor in "Quality control for the food industry". Vol.I AVI pub. Co. Inc., Westport, CN. pp.106-119.

Kramer, A. 1972. Texture measurement - definition, measurement, relation to other attributes of food quality. Food Tech. 26:34.

Kramer, A. 1964. Definition of texture and its measurements in vegetable products. Food Tech. 18:46.

Krzysztof, K., F. Sosulski and L. Hogge 1982. Free, esterified, and insoluble-bound phenolic acids. I. Extraction and purification prodcedure. J. Agri. Food Chem. 30:330-334.

Lafuente, M. T., M. Cantwell, S. F. Yang, and V. Rubatsky. 1989. Isocoumarin content of carrots as influenced by ethylene concentration, storage temperature and stress conditions. Acta Hort. 258:523-534.

Lapedes, D. N. (editor) 1977. Science and Technology in "Encyclopedia of food, agriculture & nutrition". McGraw-Hill Inc., New York. 4th ed. pp.170.

Leveille, G. A., C. L. Bedford, C. W. Krout and Y. C. Lee 1974. Nutrient composition of carrots, tomatoes and red tart cherries. Federation Proc. 33(11):2264-2266.

Mackey, A. C., M. M. Hard, and M. V. Zaehringer. 1973. Measuring textural characteristics of fresh fruit and vegetables - apples, carrots and cantaloupes. Technical Bulletin #123. Agricultural Experiment Station, Oregan State University.

Martens, M., B. Fjeldsenden, and H. Russwurm jr. 1979. Evaluation of sensory and chemical quality criteria of carrots and swedes. Acta Hort. 93:21-25.

Martens, M., B. Fjeldsenden, H. Russwurm jr., and H. Martens. 1982. Relationship between sensory and chemical quality criteria for carrots studied by multivariate data analysis. Chap.4.2 in Quality criteria for vegetables. pp. 233-245.

Massey, L. M. jr. and E. E. Woodams. 1973. Effect of Ca on the texture profile of irradiated carrots, beets and potatoes. J. Texture Studies 4:242-247.

Mclellan, M. R. 1981. The study of aroma characteristics of raw carrots with the use of factor analysis. Ph.D. Thesis. Michigan State University.

O'Beirne, D. 1987. Modified atmosphere packaging (MAP)- New technology for food products. Farm and Food Res. pp.7-8.

Phan, C. T. 1974. Use of plastic films in the storage of carrots. Acta Hort. 38:345-349.

Phan, C. T., H. Hsu, and S. K. Sarker. 1973. Physical and chemical changes occurring in the carrot root during storage. Can. J. Plant Sci. 53:635-641.

Reeleder, R. D., G. S. V. Raghavan, S. Monette, and Y. Gariepy. 1989. Use of Modified atmospheres to control storage rot of carrot caused by *Sclerotinia sclerotiorum*. International J. Refrigeration 12(3):159-163.

Rumpf, G. and H. Hansen. 1973. (Abstract) Gas chromatographic determination of the soluble substances of carrots, stored in controlled atmospheres. Gartenbauwissenschaft 38(20):281-285.

Saltveit, M. E. jr. and T. Strike. 1989. A rapid method for accurately measuring oxygen concentrations in milliliter gas samples. HortScience 24(1):145-147.

Salunkhe, D. K., and B. B. Desai. 1984. chapter 8. Root Vegetables. Postharvest Biotechnology of vegetables. CRC Press Inc., Boca Raton, FL. pp. 90-103.

Sarkar, S. K. and C. T. Phan. 1974. Effect of ethylene on the qualitative and quantitative composition of the phenol content of carrot roots. Physiol. Plant 30:72-76.

Sarkar, S. K. and C. T. Phan. 1979. Naturally-occurring and ethylene-induced phenolic compounds in the carrot root. J. Food Protection 42(6):526-534.

Scheerens, J. C. and G. L. Hosfield 1976. The feasibility of improving eating quality of table carrots by selecting for total soluble solids. J. Amer. Soc. Hort. Sci. 101(6):705-709.

Segerlind, L. T., B. A. Snobar, and D. R. Heldman. 1977. Compression and relaxation properties of carrots. J. Texture Studies 7:451-456.

Senter, S. D., J. A. Robertson, and F. I. Meredith. 1989. Phenolic compounds of the mesocarp of Cresthaven peaches during storage and ripening. J. Food Sci. 54(5):1259-1260, 1268.

Shattuck, V. I., R. Yada and E. C. Lougheed 1988. Ethylene-induced bitterness in stored parsnips. HortScience 23(5):912.

Shewfelt, R. L. 1986. Postharvest treatment for extending the shelf-life of fruits and vegetables. Food Tech. 40:70-80.

Simon, P. W., C. E. Peterson, and R. C. Lindsay. 1980a. Genetic and environmental influences on carrot flavor. J. Amer. Soc. Hort. Sci. 105(3):416-420.

Simon, P. W., C. E. Peterson and R. C. Lindsay 1980b. Correlations between sensory and objective parameters of carrot flavor. J. Agri. Food Chem. 28:559-562.

Simon, P. W., R. C. Lindsay and C. E. Peterson 1980c. Analysis of carrot volatiles collected on porous polymer traps. J. Agri. Food Chem. 28:549-552.

Sondheimer, E., W. F. Phillips, and J. D. Atkin. 1955. Bitter flavor in carrots. I. A tentative spectrophotometric method for the estimation of bitterness. Food Research 20:659-665.

Sondheimer, E. 1957. Bitter flavor in carrots. III. The isolation of a compound with spectral characteristics similar to hydrocarbon extracts of bitter carrots. Food Research 22:296-299.

Stoll, K. 1974. Storage of vegetables in modified atmospheres. Acta Hort. 38:13-20.

Stommel, J. R. and P. W. Simon. 1989. Phenotypic recurrent selection and heritability estimates for total dissolved solids and sugar type in carrot. J. Amer. Soc. Hort. Sci. 114(4):695-699.

Stone, H., J. Sidel, S. Oliver, A. Woolsey and R. C. Singleton 1974. Sensory evaluation by Quantitative Descriptive Analysis. Food Tech. 28:24-34.

Szczesniak, A. S. 1963. Classification of textural characteristics. J. Food Sci. 28:385-389.

Szczesniak, A. S., P. R. Humbaugh, and H. W. Block. 1970. Behavior of different foods in the standard shear compression cell of the shear press and the effect of sample weight on peak area and maximum force. J. Texture Studies 1:356-377.

Van den Berg, L. and C. P. Lentz 1973. High humidity storage of carrots, parsnips, rutabagas, and cabbage. J. Amer. Soc. Hort. Sci. 98(2):129-132.

Von Elbe, J. H., W. E. Artz and C. E. Johnson 1977. Quality of canned potatoes, carrots, and beets after long-term fresh product storage. J. Food Protection 40(11):765-768.

Wasserman, B. P., L. L. Eiberger and K. J. McCarthy 1986. Biotechnological approaches for controlled cell wall glucan biosynthesis in fruits and vegetables. Food Tech. 40:90-98.

Weichmann, J. 1973b. (Abstract) Influence of different oxygen contents on respiration of carrots (*Daucus carota* L.). Gartenbauwissenschaft 38:253-262.

Weichmann, J. and E. Ammerseder 1974. Influence of Controlled Atmosphere (CA) storage conditions on carbohydrate changes in carrot. Acta Hort. 38:329-344.

Weichmann, J. 1973a. (Abstract) Influence of different CO2 contents on respiration of carrots (*Daucus carota* L.). Gartenbauwissenschaft 38:243-252.

Wills, R. H. H., T. H. Lee, D. Graham, W. B. McGlasson and E. G. Hall 1981. Postharvest - An introduction to the physiology and handling of fruit and vegetables. AVI Publishing Co. Inc., Westport, CN. pp.32.

Wilson, J. G. 1989. Quality evaluation of dry beans after soaking, processing, and extended canned storage. Master's Thesis. Michigan State University. pp.29.