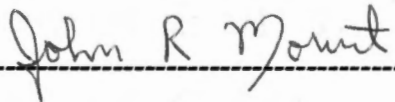


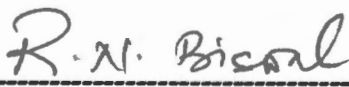
To the Graduate Council:

I am submitting herewith a thesis written by Kamran Nadeem entitled "Quality Attributes of Fresh Carrots under Modified Atmospheres." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Food Technology and Science.

A handwritten signature in cursive script, reading "John R Mount", written over a horizontal dashed line.

John R. Mount, Major Professor

We have read this thesis
and recommend its acceptance:

A handwritten signature in cursive script, reading "R. N. Biscail", written over a horizontal dashed line.A handwritten signature in cursive script, reading "Genevieve Chresten", written over a horizontal dashed line.

Accepted for the Council:

A handwritten signature in cursive script, reading "Lew Minktel", written over a horizontal dashed line.

Associate Vice Chancellor
and Dean of The Graduate School

**QUALITY ATTRIBUTES OF FRESH CARROTS STORED
UNDER MODIFIED ATMOSPHERES**

**A THESIS
PRESENTED FOR THE
MASTER OF SCIENCE
DEGREE
THE UNIVERSITY OF TENNESSEE, KNOXVILLE**

**KAMRAN NADEEM
AUGUST, 1992**

Ag-VetMed

THESIS
92
.N233

In the name of ALLAH, the most beneficent, the most merciful

DEDICATION

This thesis is dedicated to my beloved parents, Mr. Shaikh Shafiuddin and Mrs. Shehnaz Shafi whose love, prayers and emotional support have induced a never ending thirst for knowledge inside me.

ACKNOWLEDGMENT

I would like to heartily thank Mr. Ziauddin Shaikh and Mr. Zafar Mahmood Shaikh, M/S Ahmed Food Industries (Pvt.) Ltd., Karachi, Pakistan., for their emotional and financial support for my graduate studies which were impossible without it. My sincere appreciation is also expressed to:

Dr. John R. Mount, major professor, for advising this study with spirit, and expertise and for his support in the completion of my thesis.

Dr. Genevie Christen for her guidance and assistance as a committee member and her tremendous help in writing.

Dr. R.N. Biswal for his expert advice and assistance as a committee member.

Ms. Anne Ruth Hill for her friendship and enormous help during my research.

Daniel Phifer for his amity and assistance in performing the Electron Microscopy.

Polly Ann Payne for her benevolence and help in the preparatory research work.

Christopher Sean Purdy, Corey Isbel, Elizabeth Ann King , John Mitchum and Lee Barnard for their great friendship and support.

To my sisters Humera Nasir, Ghazala Zia, and Uzma Shafi for their love and courageous letters from home.

ABSTRACT

Physical and chemical changes in peeled and non-peeled carrots stored at 7°C for up to 28 days under modified CO₂ and O₂ levels were determined. U.S. No. 1 carrots were packaged in four films with varying permeabilities from highly permeable to a barrier film. Peeled carrots consumed less O₂ and produced more CO₂ than non-peeled carrots during the 28 day storage period. Peeling affected the texture of carrots with peeled carrots being more flexible. ✓ Peeling reduced the microbial load on the surface of carrots, but did not affect the moisture content. Peeled carrots had higher Hunter L, 'a' and 'b' values. Carrots stored in barrier film produced CO₂ levels above 40% within 7 days and an O₂ level less than 5%. The other films maintained CO₂ levels of 3 to 5% and O₂ levels of 11 to 20%. The moisture content of the carrots was maintained during the storage period within all the films. The sucrose, glucose and fructose levels were not significantly affected by peeling or storage conditions in the permeable films.

TABLE OF CONTENTS

CHAPTER		PAGE
I	INTRODUCTION.....	1
II	REVIEW OF LITERATURE.....	2
	QUALITY OF CARROTS.....	2
	STORAGE OF CARROTS.....	9
III	MATERIALS AND METHODS.....	17
	EXPERIMENTAL MATERIALS.....	17
	EXPERIMENTAL PROCEDURES.....	19
IV	RESULTS AND DISCUSSION.....	25
	POST PACKAGE RESPIRATION.....	25
	MOISTURE CONTENT.....	30
	TEXTURE.....	33
	COLOR.....	36
	SUGAR CONTENT.....	42
	MICROBIAL COUNT.....	47
	pH.....	50
V	SUMMARY.....	51
VI	CONCLUSIONS.....	53
	REFERENCES.....	55

TABLE OF CONTENTS

CHAPTER	PAGE
APPENDIXES.....	62
A. RAW DATA.....	63
B. ELECTRON MICROSCOPY.....	73
VITA.....	79

LIST OF TABLES

TABLE		PAGE
1	Proximate composition of fresh carrots.....	3
2	Relative permeabilities of four films to CO ₂ and O ₂ for 24 hours storage at 7°C.....	18
3	Analysis of variance of CO ₂ and O ₂ percentages of atmospheres within bags of carrots stored at 7°C.....	26
4	Mean CO ₂ and O ₂ percentages of atmospheres within bags of carrots stored at 7°C.....	27
5	Mean CO ₂ and O ₂ percentages of atmospheres within bags from 4 films for carrots 7°C for 28 days.....	29
6	Analysis of variance of moisture content of carrots stored at 7°C in plastic bags.....	31
7	Mean moisture percentages of carrots stored at 7°C in plastic bags.....	32
8	Analysis of variance of Instron measurement for the texture evaluation of carrots and number of broken carrots stored at 7°C in plastic bags.....	34
9	Mean Instron measurements (joules) for the texture evaluation of carrots and mean number of broken carrots stored at 7°C in plastic bags.....	35
10	Mean Instron measurements (joules) for 3 replications for the carrots stored at 7°C in plastic bags for 28 days.....	37

LIST OF TABLES

TABLE		PAGE
11	Analysis of variance of Hunter L, 'a', 'b', and 'a'/'b' values of carrots stored at 7°C in plastic bags.....	38
12	Mean Hunter L, 'a', 'b', and 'a'/'b' values of carrots stored at 7°C in plastic bags.....	39
13	Mean Hunter L, 'a', 'b', and 'a'/'b' values for 2 replications of carrots stored at 7°C in plastic bags.....	41
14	Analysis of variance of sucrose, glucose, and fructose contents of carrots stored at 7°C in plastic bags.....	43
15	Mean sucrose, glucose, and fructose contents of carrots stored at 7°C in plastic bags.....	44
16	Mean sucrose, glucose, and fructose contents in 4 films for carrots stored at 7°C.....	45
17	Analysis of log CFU/g and surface pH of carrots stored at 7°C in plastic bags.....	48
18	Mean log CFU/g and surface pH of carrots stored at 7°C in plastic bags.....	49

CHAPTER I

INTRODUCTION

Carrots (*Daucus carota* L.) belong to the Umbelliferae family which also includes celery, parsnips and parsley. The carrot was used primarily for medicinal purposes, and was not consumed as a plant source for food until the early twentieth century. Historically, the purple rooted carrot was domesticated in Afghanistan and spread to the eastern Mediterranean in the tenth to twelfth centuries and then cultivated in western Europe in the fourteenth and fifteenth centuries. Carrot roots of various sizes, colors, and shapes were developed by the sixteenth century (McCollum, 1975).

The U.S. consumer is consuming more produce and readily consumable foods which include fresh, frozen, refrigerated or minimally processed products. Carrots are one of the major crops produced in the U.S. The total crop production of carrots has increased from 19.3 million cwt in 1976 to 29.2 million cwt in 1990. The value of fresh market production of carrots was \$408 million in 1990 (USDA, 1991). Carrots are consumed in many forms such as whole, peeled, diced, shredded, and sliced. It is important therefore to know how to best handle these products.

The objective of this experiment was to determine physical and chemical changes in peeled and non-peeled carrots stored at 7°C (45°F) under modified atmospheres. Atmospheres were established by the respiration of the carrots held in four different types of polymeric bags.

CHAPTER II

REVIEW OF LITERATURE

QUALITY OF CARROTS

Fresh carrots can be evaluated for quality using U.S. Department of Agriculture grade standards. The grade standard, "U.S. No.1", consists of carrots of similar varietal characteristics with roots which are firm, fairly clean, fairly well colored, fairly smooth, well formed, and free from soft rot and damage caused by freezing, growth cracks, sunburn, pithiness, woodiness, internal discoloration, oil spray, dry rot, other disease insects or mechanical or other means. Here, "firm" is defined as a carrot that is not soft, flabby or shriveled. Unless otherwise specified, the diameter of each carrot shall not be less than three-fourths inch (CFR, 1992).

Composition of carrots

The major constituent of carrot (*Daucus carota* L.) is water (Table 1). Carrots contain approximately 88% water which is similar to most root type vegetable products (USDA, 1984). The actual water content in fresh produce is dependent upon how much water was available to the tissue at the time of harvest (Wills et al., 1989). The water content of carrots will vary with temperature fluctuations during the day, therefore, it is desirable to harvest the produce at the time when the maximum water content is present which is early in the morning.

Carbohydrates are present in produce as low molecular weight sugars or high molecular weight polymers such as starch or dietary fiber (Wills et al.,

Table 1: Proximate composition of fresh carrots^a

Component	Proximate composition %
Water	87.79
Carbohydrate	10.14
Fiber ^b	1.04
Pectin ^c	1.00
Protein	1.03
Lipid	0.19
Ash	0.87

^aUSDA, 1984. Agriculture Handbook No. 8-11 pg 121.

Composition of Foods: Vegetables and vegetable products. U.S. Government Printing Office, Washington DC. 20402.

^binsoluble dietary fiber considered part of carbohydrate material.

^cconsidered part of insoluble dietary fiber.

1989). Carrots contain 10% carbohydrate (Table 1) which includes primarily sugars. The sugar content of carrots ranges from 3 to 8% and usually consists of sucrose with lesser amounts of glucose and fructose (Bajaj et al., 1980; Pattee, 1985; Simon and Peterson, 1979). Fresh carrots are reported to have 4.24% sucrose, 0.85% D-glucose, and 0.85% D-fructose (Fennema, 1985). The amount and type of free sugar content in carrots is affected by genetic variation (Simon et al., 1982). The total soluble-solids level, which is mainly comprised of sugars, ranges from 5 to 13% in carrot juice (Carlton and Peterson, 1963). Dietary fiber, that portion of carbohydrate that passes undigestible through the intestinal system, includes pectic systems, hemicellulose, cellulose, and lignin. It is primarily pectin in carrots (USDA, 1984).

The carrot has fairly low protein and lipid contents (Table 1). The protein content of carrot is mostly functional (enzymes), whereas, the lipid content is cohered with the protective cuticle layer on the surface of the produce and is part of the cell membranes (Wills et al., 1989).

Carrots contain malic acid as the major organic acid, which is stored in vacuoles as excess after being used in the operation of the TCA cycle and other metabolic pathways (Wills et al., 1989). Commercially canned carrots have an average pH of 5.2 (Gould and Gould, 1988), whereas, small whole frozen carrots have a pH of 6.0 (United Foods, 1992).

The carrot is an excellent source of vitamin A and a good source of vitamins B₁, C, and B₂ (McCollum, 1975). Vitamin A is required by the body to maintain structure of the eye and its deficiency could lead to blindness. The active Vitamin A, retinal, is not present in produce, however, carotenoids are present in significant amounts. Some carotenoids, such as, β -

carotene can be converted to retinal by humans (Wills et al., 1989). Carrots contain 16.9 mg of β -carotene or 2,813 Retinal Equivalents per 100 g (USDA, 1984).

Texture of carrots

The texture of fruit and vegetable tissue fundamentally originates from the cell wall and middle lamella (Bourne, 1989). Water content of plant tissue has an important role in the texture of fruits and vegetables (Paul and Palmer, 1972). Water is adsorbed by the macromolecules in the cell wall and in the cytoplasm and its inclusions. Most of the volume inside the cell is an aqueous solution of salts and sugars that does not give structural potency to the tissue (Bourne, 1989). Water is present in high amount in vacuoles where the cell sap comprised of soluble constituents is surrounded by a thin protoplasmic layer. This living tissue acts as a selectively permeable layer and regulates the water content of the cell. The amount of water in the vacuole varies and is dependent upon the amount of water available to the plant tissue from its environment (Paul and Palmer, 1972). The physiological processes generate osmotic or hydrostatic pressure (turgor pressure) within the living cell which provides "rigidity", "turgidity" and crispiness to fresh produce (Bourne, 1989; Paul and Palmer, 1972). When a cell has access to water due to osmosis, the inflated vacuole presses the cytoplasm against the cell wall. As a result, the aqueous contents distend the cell, which is confined by the elastic wall. At this point, the internally directed pressure of the stretched cell wall is equal to the oppositely directed outward pressure (turgor pressure). Turgor pressure (crispness) of produce can be maintained by storing them in a water vapor saturated atmosphere (Paul and Palmer, 1972).

Processing of fresh produce by heating or freezing may destroy cellular structure and reduce the turgor pressure (Bourne, 1989). Most vegetables, as they mature, become less juicy, less tender, and more fibrous. This is due to the thickening of cell walls and accumulation of lignin, appreciably in vascular tissue. Lignification promotes the woody structure in a vegetable tissue which is unpalatable. The stringiness of the core of carrots is due to the presence of high amounts of lignin (Paul and Palmer, 1972).

Consumers desire firm, crisp, and juicy texture in raw vegetables (Bourne, 1982). Firmness of fruits and vegetables is a basic textural property. Howard and Heinz (1970) studied the texture of carrots and compared the sensory test with an instrument operated test. The texture of carrots was judged by trained sensory panelists, on a 9-point scale, by evaluating the compressibility and flexibility of carrots. Compressibility was determined by pressing the middle portion of the carrot with the fingers and evaluating the resistance. Flexibility was evaluated by gently bending the carrot at the middle by hand. Textural parameters of compression and shear also were evaluated with the Instron Universal Testing Machine (Model TM) with a load cell CT (Load range 0-200 pounds). The compression test measured the distance the carrot compressed under a given force and the shear test measured the work required to slice each carrot. Howard and Heinz (1970) reported the compression measurement correlated highly, but the shear measurement poorly, with sensory hardness judged by compressing and bending. They concluded it was useful to measure the coefficient compression to predict textural quality of carrots.

Color of carrots

Carotenoids, widely distributed in nature, are tetraterpenoids. Their basic structure may be viewed as joining together eight isoprene (C_5H_8) units in head to tail linkages to form aliphatic-alicyclic structures. The name "carotenoid," is derived from the major color pigments of the carrot (DeMan, 1980; Emodi, 1978). In foods, carotenoids impart yellow to red color and if complexed with proteins, they impart green and blue colors (Lampila et al., 1984). When β -carotene is ingested by the animal body it is converted to vitamin A.

The carotenoid content in a plant varies from leaf to leaf and also varies among plants (Bauernfeind, 1973). It is also affected by growth conditions. Bauernfeind (1978) stated that the factors which influence carotenoid production in fruits and vegetables include oxygen, light and temperature.

Microbiology of fresh carrots

Vegetables and fruits as received from orchards, vineyards and growing fields carry a varied number of microflora (Splittstoesser and Mundt, 1984). The normal resident microorganisms present on green plants normally survive on the minute amounts of carbohydrate, protein, and inorganic salts which are dissolved in the water on the surface of the substrate (Thaysen and Galloway, 1930). Many factors can contribute to the amount of contamination of produce including: soil, water, dust, and other natural sources; the extent of the contact during harvest with soiled surfaces of harvesters and containers; and properties of the fruit or vegetable such as protective skin against surface damage and subsequent growth of saprophytic microorganisms (Splittstoesser and Mundt, 1984). Brackett (1987) reported several factors that influence the

microflora of fruits and vegetables. These include source and form of product and its storage conditions (temperature, humidity, atmosphere, packaging, etc.). Vegetables that are in contact with soil such as carrots, beets, potatoes, and cucumbers are reported to have an aerobic plate count of approximately 10^7 per gram (Vaughn, 1951). A soil contaminated fruit or vegetable carries microflora primarily comprising of sporeformers, coryneforms and other soil type microorganisms. These microorganisms compete with each other for substrate.

The high acid and sugar contents of fruit favors yeast and mold growth, whereas, the high carbohydrate content and more neutral pH of many vegetables permit the growth of lactic acid bacteria. Vegetables which are low in sugar content favor the growth of both hyaline and yellow pigmented aerobic and gram-negative microorganisms (Splittstoesser and Mundt, 1984). Mold counts of fresh vegetables have rarely been found to exceed 10^5 per gram (Webb and Mundt, 1978). Peels on fresh, whole fruits and vegetables protect against the microbial invasion, however, cuts on fruits and vegetables release internal juices which serve as a nutrient to microorganisms and promote faster growth (Brackett, 1987).

In the United States, the presence of pathogenic microorganisms, which include enteric pathogens, on raw fruits and vegetables has not been a problem of concern (Splittstoesser and Mundt, 1984). The microbiology of fresh fruits and vegetables has usually been reported to have little correlation to the safety and quality. Therefore, routine microbial examination of most fruits and vegetables is not recommended (Splittstoesser and Mundt, 1984).

STORAGE OF CARROTS

Respiration

Respiration is the oxidative breakdown of more complex materials normally present in plant cells, which include carbohydrates (starch and sugars) and organic acids, into simpler molecules such as CO₂ and H₂O. Respiration can be aerobic (in the presence of oxygen) or anaerobic (absence of oxygen). As a result of this breakdown, energy is released and simpler molecules are formed (Wills et al., 1982). The energy enables the plant to maintain cellular constitution, transport metabolites around the cellular tissue, and sustain permeability.

Most of the energy required by fruits and vegetables is supplied by aerobic respiration. The normal substrate for respiration is glucose. The overall reaction on complete oxidation of glucose is:



The complete utilization of glucose includes two main pathways:

- i) Glucose $\longrightarrow$ Pyruvate; by the Embden-Meyerhof-Parnas (EMP) pathway, located in the cytoplasm;
- ii) Pyruvate $\longrightarrow$ CO₂; by the TCA cycle, the enzymes of which are located in mitochondria.

The total chemical energy liberated during the oxidation of 1 mole of glucose is approximately 1.6 megajoules. Starch, a glucose polymer, is usually the main carbohydrate, and it must be degraded first to glucose by amylases and maltases. In produce with high sucrose content, the enzyme invertase

hydrolyzes sucrose to glucose and fructose. In many plant tissues interconversion of sucrose and starch can also take place (Wills et al., 1989).

During the process of anaerobic respiration (fermentation) glucose is converted to pyruvate, by EMP pathway, which is then metabolized into either lactic acid or acetaldehyde and ethanol. The extinction point, (which depends upon oxygen concentration), at which anaerobic respiration takes place differs between tissues and is influenced by factors which include species, cultivar, maturity, and temperature. The energy per mole produced as a result of anaerobic respiration is much less than that produced by aerobic respiration (Wills et al., 1989).

Vegetables, bulbs, roots and tubers are storage organs that contain food reserves utilized upon the plant's resumed growth. However, these reserves are often held to be consumed during propagation. Upon harvest, the metabolic rate of these plants is low and under appropriate storage conditions dormancy can be prolonged (Wills et al., 1982).

Carotenoid content during storage

Several factors affect the stability of carotenoids. Emodi (1978) and Stefanovich and Karel (1982) reported prevent degradation of carotenoids can be prevented by storing products should be stored under vacuum or an inert gas. Arya and coworkers (1979) reported that the stability of β -carotene was enhanced by methyl stearate and oleate esters, but that methyl linoleate acted as a prooxidant after the initial stages of slow oxidation. The stability of β -carotene is also increased by increasing nitrogen levels in the atmosphere (Baloch et al., 1977).

Carotenoids, due to their highly unsaturated chemical structure, are sensitive to light and oxidation (Emodi, 1978 ; Stefanovich and Karel, 1982). Because of this instability the carotenoid content of plants, vegetables and fruits tends to decrease rapidly during processing and storage (Bauernfeind, 1978).

Microbiology of stored carrots

Upon storage and processing of fruits and vegetables the microflora changes. Market or storage diseases in fruits and vegetables are generally identified and named after their appearance which include brown, cottony, and stemmed rots. Molds are generally more responsible for spoilage than bacteria. More than 20 genera of molds have been found to cause spoilage include *Alternaria*, *Botrytis*, *Penicillium*, and *Phytophthora*. The bacterium, *Erwinia carotovora*, has been reported to be the major cause of bacterial soft rot in many vegetables (Splittstoesser and Mundt, 1984). Temperature has the greatest influence on microbial growth. Lower temperatures usually slow down bacterial and fungal growth. However, colder temperature also can serve as a selective factor for psychrotrophic microbes like *Pseudomonas*, which are more likely to be associated with refrigerated spoilage (Kraft and Rey, 1979). Humidity affects microbial growth. Low humidity does not favor the growth of bacteria on the surface of fruits and vegetables, but may select for fungal growth (Brackett, 1987; Van den Berg and Lentz, 1966). However, in this environment, the product dehydrates and shrinks which not only lowers the product quality, but also makes it more susceptible to microbial invasion. High humidity results in providing favorable conditions for microbial growth (Ben-Yehoshua et al., 1983).

Modified atmosphere storage

Modified atmosphere storage of produce, achieved by reducing oxygen and increasing carbon dioxide concentration, has been reported to enhance the shelf life (Brecht, 1980; Kramer et al., 1980). However, this method changes the general microflora resulting in the growth of gram positive bacteria, particularly lactic acid bacteria (Sinell, 1980).

The technology of controlled atmosphere and modified atmosphere packaging (CAP/MAP) has been successfully applied in European market for more than 25 years (Lioutas, 1988). CAP is an expensive technology as compared to MAP where the gaseous environment inside the package is intentionally altered and is maintained throughout the shelf life of the product. Whereas, in MAP, the gaseous environment surrounding the product changes during storage based upon film permeability and gas production or consumption by the food product (Brody, 1989). In addition, CAP/MAP technology which was once described as a "quiet revolution", has gained massive popularity in the U.S. in recent years (Lioutas, 1988). Lioutas (1988) lists several reasons why this technology has not been as widespread in U.S. markets as in European markets. These reasons include: 1) the relatively smaller geographical distribution systems in Europe; 2) more frequent purchase by European consumer; 3) higher awareness/acceptance for refrigerated foods by European consumer; 4) higher food prices in Europe (which is feasible for CAP/MAP approach); 5) total system/quality approach for the CAP/MAP technology; and 6) a retail driven European market vs. a consumer driven U.S. market. Factors which may contribute to the success of CAP/MAP in the U.S. in the future include geographic distances, efficiency of

distribution systems and desire for extended shelf life of highly perishable foods (Lioutas, 1988).

CAP/MAP is a multidisciplinary technology to maintain the fresh quality of a product. If viewed as a "total quality control packaging" technology instead of simply a packaging step integrated with some special gas, it will exhibit its fullest potential. (Brody, 1989; Lioutas, 1988).

Successful storage of fresh produce requires a reduced rate of ripening, or a delay in the onset of ripening, and prevention of decay so that "freshness" is maintained at a high level of acceptability to the consumer (Irving, 1984). Such storage is achieved through altering the environment of the produce immediately after harvesting by lowering the temperature, by applying chemicals, by changing the composition of the atmosphere, or by a combination of these treatments (Irving, 1984).

Respiration rate is an excellent indicator of metabolic activity of the tissue and is a useful guide to the potential storage life of produce (Wills et al., 1982). Wills and coworkers (1982) reported that respiration rates of fruits or vegetables (measured as either O₂ consumed or CO₂ evolved during the course of its development, maturation, ripening and senescent periods) have characteristic patterns.

The tolerance of fruits and vegetables to reduced O₂ and elevated CO₂ can be significant when determining the appropriate modified atmosphere for a commodity and when determining adequate aeration rates. Kader and Morris (1977) reviewed published and unpublished data and subsequently tabulated the tolerances of some fruits and vegetables (Fig. 1). They emphasized that these are not recommended modified atmosphere conditions, but rather levels of CO₂ above which and O₂ below which

physiological damage could occur. Also, in using this information, they emphasized that the limits and tolerances can vary as a function of temperature, duration, added supplemental gases, physiological age, tissue involved, and atmospheric combinations other than air plus elevated CO₂ or reduced O₂ plus no added CO₂ (Irving, 1984).

Very few published research articles are available on studying the effects of CAP/MAP on carrots (Carlin et al., 1990 a, b; Marcellin, 1974; Phan, 1974). Carrots packed in sealed polyethylene (PE) bags (stored at 1⁰C) maintained fresh appearance, retained total sugars, and reduced phenolic compounds for up to 15 months (Phan, 1974). Rooting and sprouting of carrots was controlled and shelf life was increased under a controlled atmosphere of 17% CO₂ and 3% O₂ (achieved in 3 days) inside sealed PE bags fitted with silicone rubber windows and stored at 1-2⁰C (Marcellin, 1974). Packaging of fresh, "ready-to-use", grated carrots with films of high permeability (about 22,000 cc/m², day, atm at 25⁰C) allowed better preservation, with considerable reduction in all factors related to fermentation. In packages with high permeability films stored at 10⁰C, the atmospheres at equilibrium contained about 20% CO₂ and 5% O₂ (Carlin et al., 1990a). These films, however, caused reduction in sucrose content, a major factor in the taste of carrots (Rumpf and Hansen, 1973).

Zagory and Kader (1988) suggested that the appropriate temperatures for storage of fruits and vegetables in flexible plastic films need to be determined. Also, little information is available on respiration rates as affected by different combinations of O₂ and CO₂ concentrations. Furthermore, additional techniques are needed to make MAP a practical alternative to the economically less feasible CAP technology. King and Bolin

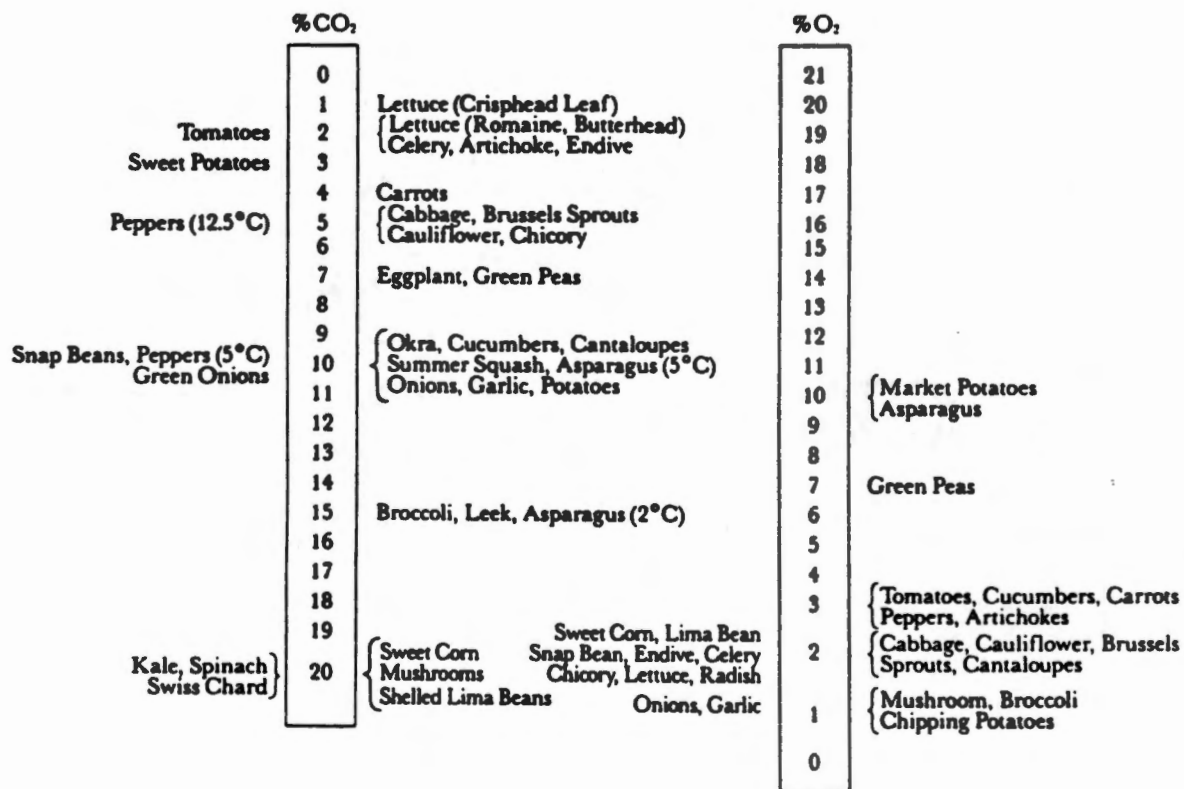


Fig 1. Relative tolerances of vegetables to elevated CO₂ and reduced O₂ levels at recommended storage temperatures (Irving, 1984).

(1989) indicated the challenge for the future is the extension and expansion of current knowledge to include peeled, cut, and otherwise partially processed fruits and vegetables.

CHAPTER III

MATERIALS AND METHODS

EXPERIMENTAL MATERIALS

Florida grown, U.S. No.1 carrots were purchased from a local wholesale market in Knoxville, Tennessee, during April and May, 1992. Four packaging films were obtained from three different commercial sources. Films 1, 2, and 3 were polyethylene (PE) and film 4 was polyvinylidene (PVDC). The CO₂ and O₂ permeability of these films were determined at the storage temperature, 7°C. For this purpose a vacuum was pulled in bags made from each of the four films (Table 2) and then an equal amount of gas (50% CO₂ and 50% N₂) was injected inside the bags through a syringe. Within half an hour of this injection a 3 cc sample of gas was collected from each bag and injected into a gas chromatograph to analyze for percent CO₂ and O₂. After 24 hr of storage at 7°C, a sample of gas from each bag was analyzed as described above. Film 1 was the most permeable since it had holes in the film (similar to bags carrots are packaged in commercially). Film 2 and 3 were similar in that they both allowed O₂ to equilibrate with the outside atmosphere almost completely within 24 hr. Film 4 would be considered a barrier film allowing no significant change in atmosphere after 24 hr. Chemicals, equipments and instruments used for analyses are given with the procedure. Carrots were purchased at different times for the three replications and handled according to the experimental procedures.

Table 2: Relative permeabilities of four films to CO₂ and O₂ for 24 hours storage at 7°C

Variable	CO ₂ %		O ₂ %	
	0 hr ^a	24 hr	0 hr ^a	24 hr
Films ^b				
1	2.77	0.24	19.55	21.05
2	21.58	0.70	8.67	20.97
3	23.76	2.61	7.49	19.77
4	52.36	51.65	1.78	1.69

^aAtmosphere sampled 30 min after mixture of 50% CO₂ and 50% N₂ was injected into each bag.

^bFilms designated with identifying number based upon 1= most permeable and 4= least permeable

EXPERIMENTAL PROCEDURES

Carrot preparation

Carrots were sorted and 120 carrots were selected based upon uniformity of size, lack of physical damage and freedom from discoloration. These carrots were washed and free surface moisture was removed by air drying and wiping off the moisture. One half of the carrots were hand peeled using a vegetable peeler.

Carrot packaging and storage

Peeled and non-peeled carrots were randomly packaged (three per bag) in four different plastic film bags. The bags were heat sealed with no adjustment of the atmosphere. The packaged carrots were stored in the dark at 7°C (45°F) for 0, 7, 14, 21, or 28 days.

Sample analyses

Sample bags of carrots were taken after 0 (fresh), 7, 14, 21, and 28 days of storage for analyses. The details of analyses are as follows:

i). Respiration

The sample bags initially were analyzed for O₂ and CO₂ content. A strip of adhesive resealing plastic tape was placed onto the packaging film surface to allow for leakproof sampling of the headspace gas. A sample of the headspace gases (3 cc) was obtained by the inserting a syringe needle (22 gauge) through the tape into the package and drawing a 3 cc sample. The sample was immediately injected into a gas chromatograph (GC) for analysis.

The O₂ and CO₂ concentrations were determined by using a 1.8-m, 0.625-mm i.d. stainless steel CTR1 column (Alltech Associates, Deerfield, IL) attached to a Hewlett Packard Model 5890A gas chromatograph equipped with a thermal conductivity detector (TCD). The 1-mL gas injection valve was flushed with 3 cc of the package head space gases prior to injection. The analyses were performed using a helium carrier gas flow rate of 50-mL/min at a column temperature of 70°C and TCD temperature of 90°C. The concentrations of O₂ and CO₂ were determined as percentage volume of package headspace gases.

ii). Textural analysis

The flexibility of carrots was determined with the Instron universal testing machine (Model 1132, Instron Corporation, Canton, MA). Each carrot was longitudinally sliced into halves and placed on the Instron plate. The Instron blade (installed with 50 kg load cell) was allowed to apply pressure 2 cm from the tip end of each half of two carrots from each sample bag. Force was applied to each carrot to either break or bend the carrot to a maximum of 90° angle (Fig. 2). The total force was determined and the four values for each treatment were averaged and the average value was used for statistical analyses.

iii). Sugar analysis

Carrots from each treatment were shredded (Presto SaladShooter model 02910, National Presto Industries, Inc., Eau Claire, WI). Approximately 200 g of shredded carrots was placed in a barrier bag and the bag was sealed.

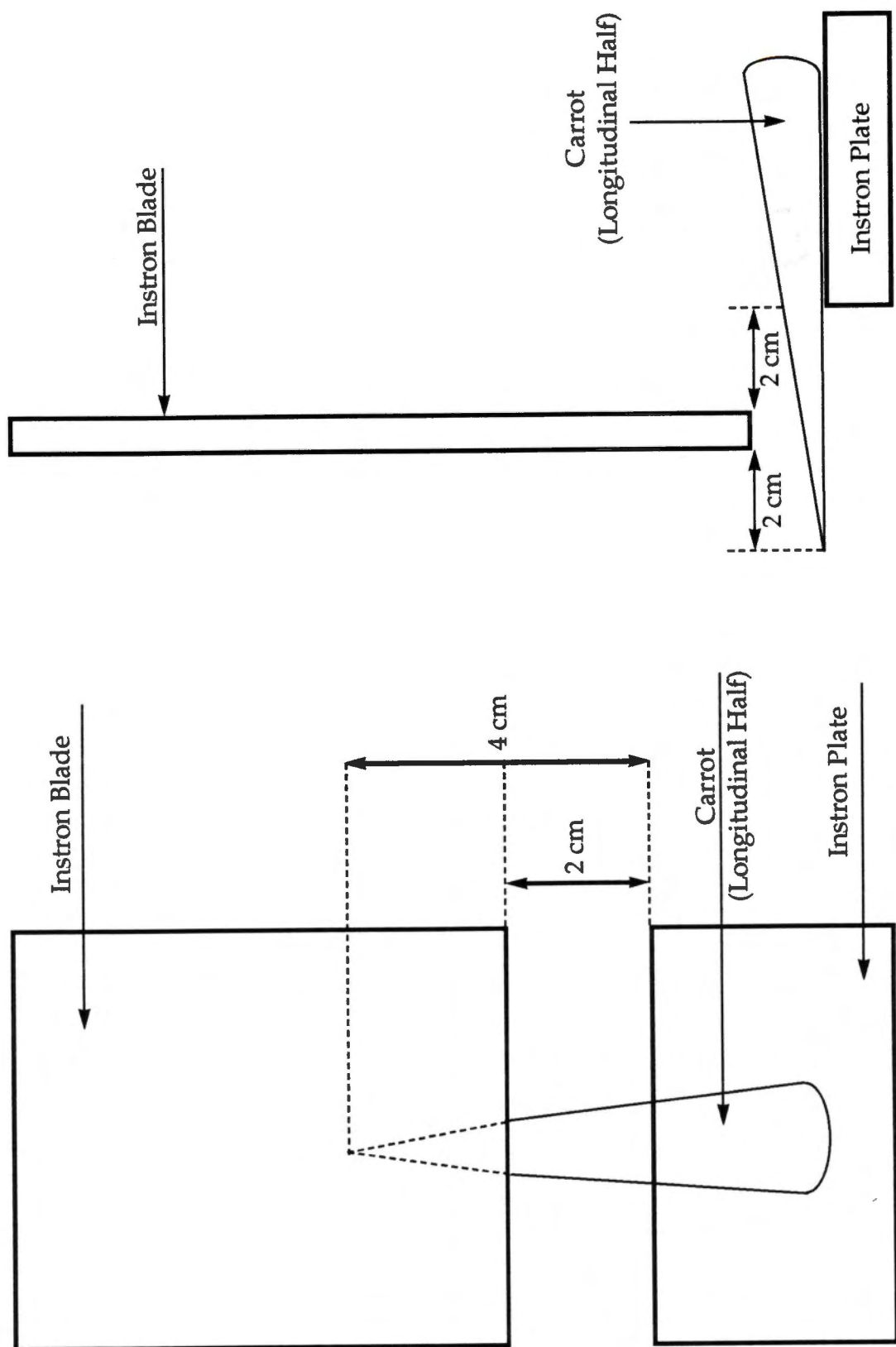


Fig 2. Front & side view of an Instron blade acting on a carrot.

The bags were placed in a freezer at -30°C and held until the end of the storage for analyses of sugar content.

Sugars were determined using a high performance liquid chromatograph (HPLC). The procedure of this analysis was adapted from Zhu and coworkers (1992). The shredded carrot from each treatment (200 g) was homogenized in an Osterizer blender. Ten grams of the homogenate was weighed into a 50 mL stainless steel centrifuge tube to which 7 mL of ethanol/water (80/20 v/v) was added. The tube containing the mixture was heated in boiling water for 5 min and centrifuged (10 min at $48,200\times g$). The precipitate was washed three times with 11 mL of the ethanol-water mixture, heated in boiling water for 5 min and centrifuged following each wash. The supernatants were combined, brought to 50 mL with the ethanol-water mixture, centrifuged, and filtered through a $0.45\ \mu\text{m}$ Acrodisc filter. The filtrate was held at 0°C until being analyzed for sugar content by HPLC procedures.

The HPLC system which was employed for this analysis consisted of a Waters Associates' model 6000A solvent delivery system, model U6K injector and R-401 differential refractometer (Waters Association., Milford, MA), a Baxter Carbohydrate Analysis column, CA AM5, (4.6 mm id x 25 cm length), (Baxter Health Care Corporation, Muskegon, MI) and a Shimadzu Corporation Chromatopac C-R6A two channel data process recorder (Shimadzu corp., Kyoto, Japan). The mobile phase was a mixture of HPLC grade acetonitrile/water (80/20, v/v) previously filtered through a $0.45\ \mu\text{m}$ Acrodisc filter. The mobile phase was degassed prior to use, and the flow rate of the solvent was maintained as 2.0 mL per min.

Standard solutions of the sugars (5%) were prepared and filtered through a 0.45 μm Acrodisc filter and injected into the HPLC to determine standard curves for sucrose, fructose and glucose. A 20 μL portion of each sample extract was injected (in duplicate) to determine the content of sugars. The amount of each sugar was reported as mg sugar per 100 g carrots.

iv). Moisture analysis

Moisture of shredded carrots from each treatment was determined according to A.O.A.C method No. 930.04. (AOAC, 1990). For the analysis, a 2.0 g sample was dried under vacuum, at 70°C, for 24 hr.

v). Color Analysis

The color of shredded carrots from each treatment was evaluated by measuring the L, 'a', and 'b' values with the Hunter Tristimulus colorimeter (model D25D2-M, Hunterlab, Reston, VA). The Hunter Tristimulus colorimeter was standardized with an orange tile (L=59.2, a=33.5, b=34.4) (Hunterlab, 1980). The 'a'/'b' ratios were also calculated.

vi). pH analysis

The pH of the carrot's external surface, from each treatment, was determined using a surface pH electrode attached to a Fisher Acumet pH meter (Model 600, Fisher Scientific Company, Nocrass, GA 30091).

vii). Microbial analysis

The microbiological load of the carrot's external surface was analyzed by standard plate count (aerobic plate count) (Busta et al., 1984). A randomly

chosen carrot from each treatment was transferred from its package into a stomacher bag using sterilized tweezers. The weight of the carrot was recorded along with the weight of the stomacher bag which was later subtracted from the calculation. Peptone water (250 mL) was added to the carrot in the stomacher bag. The carrot's surface was gently massaged by hand from outside the package for 2 min. The peptone water from this bag was then diluted four times with peptone water (99 mL each). Each dilution (0.1 mL) was plated on on Standard Methods Agar (SMA, Difco) (Draughon, 1992). The colony forming units (CFU) per gram on the surface of the carrot was calculated based upon the following formula.

$$\text{CFU/g} = \frac{250 \text{ mL Peptone water}}{\text{weight of carrot (g)}} \times \text{Colony count} \times \text{Dilution}$$

viii). Statistical analyses

The design of the experiment was a factorial (2 peeling treatments x 4 films x 5 storage periods x 2 or 3 replications). Analysis of variance was performed to determine differences in populations at a $p=0.05$ significance level (SAS, 1987). The interactions among the independent factors were determined and if not significant placed into the error term. Means within each of the factors were separated using Student-Neumann Kuel analysis. Three replications were completed for respiration (CO_2 % and O_2 %), texture, and sugars (sucrose, glucose, and fructose content), and two replications for pH, color (L, 'a', 'b', and 'a'/'b') and microbial count.

CHAPTER IV

RESULTS AND DISCUSSION

POST PACKAGE RESPIRATION

Peeling treatment, film type and days of storage were found to have a significant effect ($P < 0.05$) on CO_2 and O_2 percentages within bags of carrots stored at 7°C (Table 3). The film $\times$ days interaction was the only interaction that had a significant effect on CO_2 and none of the interactions had significant effect on O_2 (Table 3). The mean percent CO_2 in the bags of carrots was significantly higher for the non-peeled carrots (17.6%) than for the peeled carrots (9.4%) while the mean percent O_2 was significantly lower for non-peeled versus peeled carrots (14.3% to 16.1%) (Table 4). Respiration was occurring during both treatments since the atmosphere had changed from the initial air atmosphere containing 21% O_2 and $< 0.1\%$ CO_2 . There was also physical evidence of respiration since the bags expanded during storage indicating gas production. The results indicated that the respiration of the peeled carrots decreased during the 28 day storage period since less CO_2 was produced and less O_2 was consumed. The process of peeling may have cut down the number of actively respiring tissue cells on the surface of carrots.

Film 4, the highest barrier film, allowed for significantly higher CO_2 accumulation (44.3%) inside the bag of carrots and significantly lower O_2 accumulation (8.0%) than the other films. These bags expanded the most during storage. The more permeable films, 1 and 2, had significantly higher O_2 percentages (20.3% and 19.3%) than film 3 (13.3%), but these three films did not vary significantly in percent CO_2 (2.2% to 4.0%). The high amount of CO_2

Table 3: Analysis of variance of CO₂ and O₂ percentages of atmospheres
within bags of carrots stored at 7°C

Source	DF	CO ₂ Sums of squares	CO ₂ Pr>F	O ₂ Sums of squares	O ₂ Pr>F
Peel	1	18.127	0.0360	0.924	0.0061
Film	3	207.613	0.0001	17.165	0.0001
Days	4	50.002	0.0188	3.180	0.0001
Film x Days	12	116.711	0.0091	2.106	0.1392
Error	82	327.017		9.566	

Table 4: Mean CO₂ and O₂ percentages of atmospheres within bags
of carrots stored at 7°C

Variable	CO ₂ %	O ₂ %
Peeling.....		
Non-peeled	17.57 ^a	14.30 ^b
Peeled	9.43 ^b	16.07 ^a
Films.....		
1	3.31 ^b	20.34 ^a
2	2.22 ^b	19.29 ^a
3	3.96 ^b	13.31 ^b
4	44.28 ^a	7.97 ^c
Days.....		
0	2.02 ^b	19.97 ^a
7	13.63 ^{ab}	13.63 ^b
14	12.17 ^{ab}	14.91 ^b
21	24.53 ^a	14.19 ^b
28	7.41 ^{ab}	16.44 ^b

a-c Means within variables and columns followed by unlike letters
are different (P < 0.05)

accumulation in the barrier film bag was expected since the gas permeability of this film is very low. The lower O₂ content also was expected since respiration of the carrots would require the utilization of O₂ and the O₂ could not be replaced through the film.

The accumulation of CO₂ and loss of O₂ during storage was influenced by the type of film (Table 3). The CO₂ and O₂ percentages did not vary significantly in films 1 and 2 during the 28 day storage period (Table 5). Therefore, these two films were permeable to CO₂ and O₂ at a rate that was equal or greater than the respiration rate of the carrots stored in these films. The CO₂ could move out of the bag and O₂ could move into the bag through the films. The CO₂ percentage was significantly higher for films 3 and 4 on day 21 than on day 0 with film 3 containing 4.9% compared to 3.1% CO₂ and film 4 containing 85.4% compared to 3.4% (Table 5). The CO₂ accumulation at day 21 was significantly higher than at day 14 for film 3, 4.9% compared to 3.2%. On none of the other days were CO₂ percentages significantly different from those at either day 0 or day 21 for films 3 and 4. The O₂ percentage in film 4 significantly decreased between day 0 and 7 from 18.5% to 4.2%, but did not significantly change during the remainder of storage (Table 5). The O₂ percentage was not significantly different in film 3 although it averaged 11.2% on day 21 compared to 19.1% on day 0. Irving (1984) reported a recommended maximum level of 4 to 5% CO₂ and a minimum of 3 to 4% O₂ as a relative tolerance for respiration to occur. In this study, the CO₂ percentages reached an average of 42.2% by day 7 for film 4. Respiration by carrots changes from oxidative to fermentative if there is not enough O₂ or there is too much CO₂ surrounding the product (Irving, 1984). A fermentation aroma was detected for both peeled and non-peeled carrots packaged in film 4 after 21 days of

Table 5: Mean CO₂ and O₂ percentages of atmospheres within bags from 4 films for carrots stored at 7°C for 28 days

Films	1	2	3	4
Days.....				
	CO ₂ %			
0	0.73 ^a	0.82 ^a	3.14 ^b	3.37 ^b
7	6.71 ^a	1.77 ^a	3.89 ^{ab}	42.16 ^{ab}
14	3.38 ^a	1.28 ^a	3.18 ^b	40.85 ^{ab}
21	2.68 ^a	5.12 ^a	4.86 ^a	85.44 ^a
28	0.93 ^a	1.19 ^a	4.16 ^{ab}	22.29 ^{ab}
	O ₂ %			
0	21.48 ^a	20.88 ^a	19.05 ^a	18.47 ^a
7	18.95 ^a	17.98 ^a	13.42 ^a	4.18 ^b
14	20.38 ^a	19.52 ^a	12.69 ^a	7.07 ^b
21	20.50 ^a	18.99 ^a	11.20 ^a	6.08 ^b
28	21.34 ^a	20.14 ^a	14.03 ^a	11.05 ^b
a-bMeans within variables and columns followed by unlike letters are different (P < 0.05)				

storage. These results indicate that film 4 traps an excessive amount of CO₂ and does not allow for replacement of an adequate amount of O₂ for this film to be used for extended storage of fresh carrots.

MOISTURE CONTENT

The type of film and the storage period significantly affected ($P < 0.05$) the moisture content of carrots stored at 7°C (Table 6). The moisture content of carrots was not significantly affected by the peeling treatment (Table 6 and 7). Carrots packaged in films 1, 2, or 3 were found to have significantly lower moisture contents than film 4, 88.3% or 88.2% compared to 89.0%, respectively (Table 7). This was most likely due to the higher barrier properties of film 4 which would allow less evaporation of moisture from the bag compared to the other three films. There were visible color changes on the surface of carrots in bags from film 1 and 2 by 14 days of storage which indicated possible surface dehydration which were not apparent from film 3 and 4.

The average initial moisture content of carrots (87.7% on day 0) was found to be significantly lower than the moisture content of those held in storage for 7 to 28 days (88.6%) (Table 7). This was not expected since carrots typically lose moisture during storage. The relative humidity present inside the refrigeration chamber was very high causing moisture to collect on the surface of the bags. This may have contributed to the prevention of moisture loss during storage. Also, one of the respiration products is water and the films may have trapped more moisture than the carrots lost with a resulting increase in relative humidity inside the bags. The highest moisture percentage was 90% in carrots stored in film 4 for 21 days of which was also

**Table 6: Analysis of variance of moisture content of carrots
stored at 7°C in plastic bags**

Source	DF	Moisture	Moisture
		Sums of squares	Pr>F
Peel	1	0.967	0.2068
Film	3	7.708	0.0076
Days	4	10.065	0.0041
Error	69	41.084	

Table 7: Mean moisture percentages of carrots stored at
7°C in plastic bags

Variable	Moisture %
Peeling.....	
Non-peeled	88.57 ^a
Peeled	88.31 ^a
Films.....	
1	88.29 ^b
2	88.24 ^b
3	88.22 ^b
4	89.01 ^a
Days.....	
0	87.65 ^b
7	88.66 ^a
14	88.47 ^a
21	88.59 ^a
28	88.70 ^a

a-b Means within variables followed by unlike letters are
different (P < 0.05)

when highest CO₂ content occurred. Therefore, respiration and moisture percentage may be related. The total weight of the carrots in the bags was not monitored and it might have decreased due to conversion of sugar to CO₂ and water during storage.

TEXTURE

Peeling, days of storage and replication significantly affected ($P < 0.05$) the Instron evaluation of texture of carrots and the number of carrots which broke during evaluation while the type of film used had no significant affect (Table 8). Non-peeled carrot halves required less work, 0.031 joules, to bend or break than peeled carrot halves, 0.038 joules (Table 9). Also, more of the non-peeled carrots broke during testing, 35%, compared to the peeled carrots, 15% (Table 9). The reason more work was required to bend or break the peeled carrots may be related to the fewer peeled carrots that broke. Therefore, force had to be applied over a longer period for the carrots to bend to 90°. The higher number of non-peeled carrots that broke may be related to the outer cellular layer of carrots. This would need to be investigated further to determine the exact cause.

The work required to bend or break the carrots increased during storage with day 0 requiring 0.022 joules, day 7 requiring 0.033 joules and day 21 requiring 0.044 joules (Table 9). The increased work indicated the carrots may have become tougher during storage which agrees with the results of Howard and Heinz (1970). Only 6% of the carrots broke on day 0, while 23% of the carrots broke on day 7 and 42% of the carrots broke on day 21. The carrots also increased in moisture content by day 7 which would be expected to increase the crispiness of carrots (Bourne, 1989).

Table 8: Analysis of variance of Instron measurement for the texture evaluation of carrots and number of broken carrots stored at 7°C in plastic bags

Source	DF	Instron	Instron	<u>No. of broken carrots</u>	
		Sums of squares	Pr>F	Sums of squares	Pr>F
Peel	1	0.001	0.0058	20.008	0.0001
Film	3	0.001	0.1278	3.358	0.2717
Days	4	0.005	0.0001	24.700	0.0001
Rep	2	0.003	0.0001	14.467	0.0004
Days x Rep	8	0.004	0.0041		
Error	101	0.015			
Error	109			92.458	

Table 9: Mean Instron measurements (joules) for the texture evaluation of carrots and mean number of broken carrots stored at 7°C in plastic bags

Variable	Instron (joules)	Mean number of broken carrots ^a
Peeling.....		
Non-peeled	0.031 ^c	1.40 ^b
Peeled	0.038 ^b	0.58 ^c
Films.....		
1	0.035 ^b	1.20 ^b
2	0.034 ^b	1.00 ^b
3	0.030 ^b	0.73 ^b
4	0.038 ^b	1.03 ^b
Days.....		
0	0.022 ^d	0.25 ^d
7	0.033 ^c	0.92 ^c
14	0.036 ^{bc}	1.00 ^c
21	0.044 ^b	1.67 ^b
28	0.037 ^{bc}	1.12 ^{bc}
Rep.....		
1	0.037 ^b	1.42 ^b
2	0.039 ^b	0.97 ^c
3	0.027 ^c	0.57 ^c

^a The mean number of carrot halves out of 4 half carrots that broke during Instron testing for each bag of carrots

^{b-d} Means within variables and columns followed by unlike letters are different (P < 0.05)

Carrots from replication 1 and 2 required more work, 0.037-0.039 joules, to bend or break than those from replication 3, 0.027 joules, and more carrots broke in replication 1, an average of 35%, than replication 2 and 3, an average of 20% (Table 9). The three replications also were affected differently during the days of storage (Table 8). Replication 1 increased significantly in the average work required to break or bend the carrots by day 7, while replication 2 did not increase until day 21 and replication 3 did not increase significantly by day 28 (Table 10). The work required to bend or break the carrots from replication 2 and 3, on day 0, was higher than that for the carrots from replication 1 (Table 10). It was also visually apparent that the carrots from replication 2 and 3 had been in storage for a longer period than the carrots from replication 1. Therefore, it is important that a processor have a consistent quality of fresh carrots to package in order for the processor to provide a consistent product to their customers.

COLOR

Peeling and storage were found to have a significant affect ($P < 0.05$) on the Hunter values of L, 'a', and 'b' (Table 11). Replication significantly affected the values of L and 'b'. The interactions of peel x film, film x days and days x rep significantly affected only the value of L whereas, the interactions of peel x days, peel x rep, and days x rep significantly affected the Hunter values of both 'a' and 'b'. The 'a'/'b' value was affected by days of storage and replication only.

The peeled carrots were lighter ($L=47.5$) than the non-peeled carrots ($L=43.8$), more red ('a'=32.2 compared to 28.2) and more yellow ('b'=27.2 compared to 24.4) (Table 12). The 'a'/'b' value indicated the red/yellow ratio

Table 10: Mean Instron measurements (joules) for 3 replications for the carrots stored at 7°C in plastic bags for 28 days

Variable	Replication		
	1	2	3
Days.....			
0	0.012 ^b	0.028 ^b	0.026 ^a
7	0.035 ^a	0.039 ^{ab}	0.025 ^a
14	0.048 ^a	0.037 ^{ab}	0.024 ^a
21	0.049 ^a	0.052 ^a	0.030 ^a
28	0.040 ^a	0.039 ^{ab}	0.032 ^a

^{a-b}Means within variables and columns followed by unlike letters are different (P < 0.05)

Table 11: Analysis of variance of Hunter L, 'a', 'b', and 'a'/'b' values of carrots stored at 7°C in plastic bags

Source	DF	SS ^a	L	'a'	'a'	'b'	'b'	'a'/'b'	'a'/'b'
Peel	1	269.38	0.0001	315.22	0.0001	155.68	0.0001	0.020	0.0691
Film	3	1.41	0.7927	13.32	0.3597	1.177	0.6958	0.018	0.3742
Days	4	24.40	0.0036	184.69	0.0001	67.68	0.0001	0.074	0.0179
Rep	1	16.20	0.0011	0.20	0.8253	48.67	0.0001	0.094	0.0001
Peel x Film	3	11.78	0.0449						
Film x Days	12	37.00	0.0219						
Days x Rep	4	16.22	0.0278						
Peel x Days	4			85.94	0.0010	24.80	0.0001		
Peel x Rep	1			41.18	0.0023	7.69	0.0032		
Days x Rep	4			59.76	0.0096	16.49	0.0014		
Error	51	445.96							
Error	61			248.27		49.62			
Error	70							0.403	

^a Sums of squares

Table 12: Mean Hunter L, 'a', 'b', and 'a'/'b' values of carrots stored at 7°C in plastic bags

Variable	L	'a'	'b'	'a'/'b'
Peeling.....				
Non-peeled	43.8 ^b	28.2 ^b	24.4 ^b	1.15 ^a
Peeled	47.5 ^a	32.2 ^a	27.2 ^a	1.18 ^a
Films.....				
1	45.5 ^a	29.7 ^a	25.7 ^a	1.15 ^a
2	45.6 ^a	30.1 ^a	25.7 ^a	1.17 ^a
3	45.6 ^a	30.9 ^a	25.8 ^a	1.19 ^a
4	45.9 ^a	30.0 ^a	26.0 ^a	1.16 ^a
Rep.....				
1	46.1 ^b	30.25 ^a	25.0 ^b	1.20 ^a
2	45.2 ^a	30.15 ^a	26.6 ^a	1.13 ^b

a-cMeans within variables and columns followed by unlike letters are different (P < 0.05)

was similar for both treatments. The differences were visually apparent where peeled carrots appeared to be brighter and more red than non-peeled carrots.

The lightness increased by day 7 from $L=44.6$ to $L=47.2$ for carrots from replication 2, but did not change during storage of carrots from replication 1 (Table 13). However, 'a' values increased by day 7 for replication 1, but not for replication 2. The 'b' value increased by day 7 for both replications. These differences between replications resulted in 'a'/'b' value increasing in replication 1 by day 14, but not significantly changing in replication 2 (Table 13). The color in carrots is due to chlorophyll and carotenoids pigments. As the carrots mature the chlorophyll is reduced and the carotenoids become the visible color pigment. Chlorophyll is sensitive to degradation by acid, particularly carboxylic acids that are present in fruits and vegetables (Aronoff, 1953). The chlorophyll content may have been reduced during respiration in the first 7 days which resulted in higher L, 'a' and 'b' values. Carotenoids are found in high concentration in many varieties of carrots and are more abundant in the phloem than in the central core. The major carotenoids are β -carotene and α -carotene (Paul and Palmer, 1972). The carotenoid pigments are highly unsaturated molecules and therefore are susceptible to oxidation when exposed to air. This oxidation of the carotenoid pigments results in the loss of color (Paul and Palmer, 1972). During this study, carotenoids might have oxidized during storage and this may have resulted in the lower but not significantly less L and 'b' values at day 28 as compared to day 7.

The color of carrots is greatly affected by growing conditions and initial storage conditions. It was not unexpected for the two replications to vary in color. The first lot of carrots were lighter and less yellow than the second lot

Table 13 : Mean Hunter L, 'a', 'b', and 'a'/'b' values for 2 replications of carrots stored at 7°C in plastic bags

Variable	L	'a'	'b'	'a'/'b'
Days.....				
Replication 1				
0	45.5 ^a	25.5 ^b	22.4 ^b	1.12 ^b
7	45.5 ^a	31.4 ^a	26.1 ^a	1.20 ^{ab}
14	45.4 ^a	31.8 ^a	25.7 ^a	1.24 ^a
21	45.4 ^a	31.2 ^a	25.9 ^a	1.20 ^{ab}
28	44.2 ^a	31.3 ^a	25.0 ^a	1.25 ^a
Replication 2				
0	44.6 ^b	28.8 ^a	25.7 ^b	1.12 ^a
7	47.2 ^a	30.8 ^a	27.2 ^a	1.13 ^a
14	46.7 ^a	30.6 ^a	27.0 ^a	1.13 ^a
21	46.4 ^{ab}	29.8 ^a	26.7 ^{ab}	1.12 ^a
28	45.6 ^{ab}	30.7 ^a	26.2 ^{ab}	1.17 ^a

a-b Means within variables and columns followed by unlike letters are different (P < 0.05)

(Table 12). The 'a'/'b' ratio differed significantly since the carrots from replication 1 were less yellow, but similar in redness to replication 2.

SUGAR CONTENT

Peeling and days of storage did not significantly affect ($P < 0.05$) the sucrose, glucose and fructose content of carrots (Table 14). Film type had a significant affect on the sucrose and glucose contents, whereas, replication had a significant affect only on the glucose content of carrots (Table 14). Film x days interaction significantly affected the sucrose content of carrots (Table 14). Sucrose, glucose and fructose contents of carrots were not significantly different ($P < 0.05$) for peeled and non-peeled carrots (Table 15). The carrots packaged in film 4 were significantly higher in sucrose content than carrots packaged in film 2. These carrots also had higher glucose content than carrots packaged in film 3 (Table 15). The fructose content was not affected by the type of film. The sucrose content of carrots packaged in film 4 was found to be significantly higher on day 7 and 21 than on day 0 and 28. Storage did not significantly affected the sucrose content in the other three films. Glucose content was not significantly affected by any of the films. Fructose content decreased by day 7 in film 1 and did not significantly vary in the other films (Table 16).

The glucose content in carrots from replication 2 was significantly higher than carrots from replication 1 (Table 15). Sucrose and fructose contents did not vary significantly between replications. During storage, there may be conversion of polysaccharides to simple sugars and sucrose to reducing sugars (Hasselbring, 1927; Phan et al., 1973; Werner, 1941). Denny

Table 14: Analysis of variance of sucrose, glucose and fructose contents of carrots stored at 7°C in plastic bags

Source	DF	Sucrose SS ^a	Sucrose Pr>F	Glucose SS	Glucose Pr>F	Fructose SS	Fructose Pr>F
Peel	1	1007	0.7133	7814	0.7137	1804	0.5508
Film	3	6637	0.0385	1652	0.0443	2973	0.1277
Days	4	3740	0.2945	7876	0.2559	1123	0.0762
Rep	1	1425	0.1705	2506	0.0414	177.0	0.9851
Peel X Film	3	8905	0.1171	4041	0.5540	2531	0.6800
Film X Days	12	2548	0.0039	5572	0.4880	2140	0.9458
Error	55	4063		3160		2754	

^a Sums of squares

Table 15: Mean sucrose, glucose, and fructose content of carrots stored at 7°C
in plastic bags

Variable	Sucrose (g/100g)	Glucose (g/100g)	Fructose (g/100g)
Peeling.....			
Non-peeled	1.12 ^a	1.29 ^a	1.06 ^a
Peeled	1.05 ^a	1.36 ^a	1.15 ^a
Films.....			
1	0.99 ^{ab}	1.27 ^{ab}	0.92 ^a
2	0.74 ^b	1.28 ^{ab}	1.39 ^a
3	1.08 ^{ab}	1.03 ^b	0.93 ^a
4	1.54 ^a	1.72 ^a	1.18 ^a
Rep.....			
1	0.95 ^a	1.15 ^b	1.10 ^a
2	1.22 ^a	1.50 ^a	1.10 ^a

^{a-b} Means within variables and columns followed by unlike letters are different (P<0.05)

Table 16: Mean sucrose, glucose, and fructose contents in 4 films for carrots stored at 7°C

Films	1	2	3	4
Days.....				
	Sucrose (g/100g)			
0	0.37 ^a	0.44 ^a	1.78 ^a	0.37 ^b
7	0.42 ^a	1.02 ^a	0.42 ^a	2.77 ^a
14	1.04 ^a	0.54 ^a	1.16 ^a	1.62 ^{ab}
21	1.77 ^a	0.48 ^a	1.06 ^a	2.33 ^a
28	1.35 ^a	1.22 ^a	0.96 ^a	0.59 ^b
	Glucose (g/100g)			
0	1.47 ^a	1.13 ^a	1.13 ^a	1.43 ^a
7	1.49 ^a	1.48 ^a	0.65 ^a	1.16 ^a
14	1.69 ^a	1.79 ^a	0.93 ^a	2.45 ^a
21	0.96 ^a	0.95 ^a	1.31 ^a	1.53 ^a
28	0.73 ^a	1.04 ^a	1.14 ^a	2.03 ^a

(contd)

Table 16: (contd)

Films	1	2	3	4
Days.....				
	Fructose (g/100g)			
0	1.39 ^a	1.40 ^a	1.43 ^a	1.27 ^a
7	0.83 ^b	1.52 ^a	0.62 ^a	1.29 ^a
14	0.83 ^b	1.13 ^a	0.64 ^a	0.64 ^a
21	0.83 ^b	1.69 ^a	1.24 ^a	1.75 ^a
28	0.72 ^b	1.18 ^a	0.74 ^a	0.92 ^a
a-c Means within variables and columns followed by unlike letters are different (P < 0.05)				

and coworkers (1944) reported that the addition of as little as 2.5% CO₂ to the storage atmosphere retarded the conversion of sugars. The differences in respiration in the carrots stored in the four films in this study and the differences in the carrots from the replications may have resulted in the variation in sugar contents of carrots for the different treatments.

MICROBIAL COUNT

Peeling was found to have a significant effect ($P < 0.05$) on the microbial count of carrots as did the days of storage and replication (Table 17). Peeled carrots were found to have a significantly lower log microbial count than non-peeled carrots (Table 18) and although there was significant peel $\times$ replication interaction, both replications were reduced in a similar manner. This was expected since removal of the outer layer of the carrot should also remove surface microorganisms.

Storage of carrots was found to significantly increase the microbial counts of both peeled and non-peeled carrots. There was a significant increase from day 0, 2.8 log CFU/g, to day 7, 3.9 log CFU/g. The microbial count did not significantly increase after day 7, but did reach 4.6 log CFU/g on day 28. The standard plate count may not have indicated the growth of lactic acid bacteria or other facultative anaerobes.

The two replications of the carrots used had different microbial loads at day 0, but the peeling treatment not only reduced the microbial load, but also made it more uniform for both replications. This was indicated by the significant peel $\times$ rep interaction (Table 17).

Table 17: Analysis of log CFU and surface pH of carrots stored at 7°C in plastic bags

Source	DF	Log CFU/g Sums of squares	Log CFU/g Pr>F	pH Sums of squares	pH Pr>F
Peel	1	36.263	0.0001	0.001	0.9198
Film	3	0.351	0.8866	0.126	0.1062
Days	4	27.744	0.0001	1.084	0.0001
Rep	1	5.640	0.0020	0.091	0.0361
Peel x Rep	1	7.9607	0.0003		
Days x Rep	1			0.986	0.0001
Error	67	36.655			
Error	43			0.837	

Table 18: Mean log CFU/g and surface pH of carrots stored at 7°C in plastic bags

Variable	Microbial count Log CFU/g		pH
Peeling.....			
	<u>Rep 1</u>	<u>Rep 2</u>	
Non-peeled	4.1 ^a	5.3 ^a	6.32 ^a
Peeled	3.4 ^b	3.2 ^b	6.47 ^a
Films.....			
1	3.9 ^a		6.43 ^a
2	3.9 ^a		6.41 ^a
3	4.0 ^a		6.39 ^a
4	4.1 ^a		6.36 ^a
Days.....			
		<u>Rep 1</u>	<u>Rep 2</u>
0	2.8 ^b	6.20 ^b	6.25 ^c
7	3.9 ^a	6.38 ^b	6.25 ^c
14	4.1 ^a	6.32 ^b	6.46 ^b
21	4.5 ^a	6.70 ^a	6.54 ^b
28	4.6 ^a	6.22 ^b	6.67 ^a

a-bMeans within variables and columns followed by unlike letters are different (P < 0.05)

pH

Storage and replication had a significant effect ($P < 0.05$) on the pH of carrots (Table 17). Peeled carrots were not significantly different in pH as compared to non-peeled carrots (Table 18). Films were found not to affect the pH of carrots significantly (Table 18). The surface pH of stored carrots was found to be significantly different from day 0 (6.2) to day 21 (6.7) for replication 1 and from day 0 (6.2) to day 14 (6.5) for replication 2 (Table 18). The pH significantly increased to 6.7 for carrots from replication 2 on day 28. The pH for carrots was significantly lower on day 28 for replication 1 (Table 18). This significant decrease could be due to the production of lactic acid as some carrots might have been going through the process of fermentation as it is mentioned earlier that fermentation aroma was noticed for some carrots. The increase in pH during storage may have been due to the growth of spoilage microorganisms.

CHAPTER V

SUMMARY

U.S. No. 1 carrots were purchased from a local wholesale market in Knoxville, TN. The carrots were washed and half of the carrots were peeled. The carrots were then packaged in bags made from 4 different films. Three polyethylene films were highly permeable for CO₂ and O₂ and one polyvinylidene chloride film which was impermeable to the gases. The carrots were stored at 7°C and bags were removed each 7 days for analysis.

The atmosphere inside the bags was analyzed for CO₂ and O₂ contents. The carrots were then evaluated for surface microbial count and pH. The longitudinally split carrots were evaluated for texture by determining the work required to bend the carrots to a 90° or break them, and recording the number of carrots that broke during testing. The color (Hunter L, 'a', 'b' and 'a'/'b' values), sugar content (sucrose, glucose, and fructose) and moisture content of the carrots were also measured.

Peeling had the following effects on the carrots. The bags with peeled carrots contained significantly less CO₂, 9.4%, and more O₂, 16.1%, than non-peeled carrots, 17.6% CO₂ and 14.3% O₂, during the 28 day storage period. Peeled carrots required more work, 0.38 joules, to bend the carrots than non-peeled carrots, 0.31 joules, and fewer of the peeled carrots broke during testing, 15%, compared to the non-peeled carrots, 35%. The Hunter L, 'a' and 'b' values were significantly higher for the peeled carrots, 47.5, 32.2 and 27.2 respectively, than for the non-peeled carrots, 43.8, 28.2 and 24.4, respectively. The microbial count was significantly lower for the peeled carrots, 3.3 log

CFU/g, than for the non-peeled carrots, 4.7 log CFU/g. Peeling did not significantly affect the moisture content, sucrose, glucose or fructose contents, or the pH of the carrots.

Film 4, the barrier film, contained significantly more CO₂, 44.3%, and less O₂, 0.8%, than the other three films, 2.2-4.0%. Film 3 contained less O₂, 13.3%, than films 1 and 2, 19.3-20.3%. Carrots packaged within film 4 had a significantly higher moisture content, 89.0%, than films 1, 2 or 3, 88.2-88.3%. The carrots packaged in film 4 also contained more sucrose, 1.5%, than film 2, 0.7%, and more glucose, 1.7%, than film 3, 1.0%. The film that the carrots were stored in did not significantly affect the texture, color, microbial count or pH of the carrots.

The CO₂ level significantly increased during storage in films 3 and 4 with the highest percentages occurring on day 21, 4.9% and 85.4%, respectively. The O₂ level significantly decreased in film 4 during the storage with the lowest percentage occurring by day 7, 88.7%. The work required to bend or to break the carrots increased during storage with day 0 requiring 0.022 joules, day 7 requiring 0.033 joules and day 21 requiring 0.044 joules. Only 6% of the carrots broke on day 0, while 23% of the carrots broke on day 7 and 42% of the carrots broke on day 21. The carrots from replication 1 significantly increased in 'a' and 'b' values by day 7 and 'a'/'b' value by day 14, and the carrots from replication 2 increased in L and 'b' values by day 7. The glucose content varied in film 4 during the storage and the fructose content decrease in film 1 from 1.4% on day 0 to 0.8% by day 7. The glucose content was not significantly affected by storage time. The microbial count significantly increased by day 7 to 3.9 log CFU/g from 2.8 log CFU/g on day 0. The pH increased from 6.2 to 6.7 during storage.

The three replications of carrots varied. Carrots from replication 1 and 2 required more work, 0.037-0.039 joules, to bend or break than the carrots from replication 3, 0.027 joules, and more carrots broke in replication 1, 1.4 out of 4, than replication 2 and 3, 0.6-1.0 out of 4. Carrots in replication 1 were significantly lighter and less yellow than those from replication 2. The 'a'/'b' value was also significantly higher for replication 1, 1.2, than replication 2, 1.1. Carrots from replication 1 were significantly lower in glucose content, 1.2%, than those from replication 2, 1.5%. Replication did not significantly affect CO₂ and O₂ percentages in the bags or the percent moisture, microbial count or pH of the carrots.

CHAPTER VI

CONCLUSIONS

Peeling carrots reduced CO₂ production and O₂ consumption in the bags, made the carrots lighter, more red and more yellow, and reduced the initial microbial load. Peeling made the carrots less likely to break when being bent and therefore, those carrots required more work to bend the carrots.

Carrots packaged in films 2 and 3 did not significantly vary from carrots packaged in film 1 and these films could therefore be used to replace films that have holes punched into them for high permeability rates. These films are more attractive in appearance and may reduce the moisture loss from the surface of carrots compared to carrots stored in the high permeability bags. These three films maintained the CO₂ levels below maximum acceptable levels and O₂ percentages above minimum acceptable levels.

Film 4, the barrier film, was not a desirable film to use for the storage of carrots because of the increased CO₂ level in the atmosphere, increased fermentation aroma, increased moisture content of the carrots, and increased slime on the surface of the carrots.

The major physical and chemical changes in carrots occurred by day 7 of storage at 7°C. These changes are greatly affected by the initial quality of the carrots used for storage.

REFERENCES

REFERENCES

- AOAC. 1990. *Official Methods of Analysis of the Association of Official Chemists*. 15th ed. Vol. II. AOAC, Inc., Arlington, VA.
- Aronoff, S. 1953. The chemistry of chlorophyll. *Adv. in Food Res.* 4 : 133.
- Arya, S.S., Natesan, V., Parihar, D.B. and Vijayraghava. 1979. Stability of beta-carotene in isolated systems. *J. Food Technol.* 14 : 571.
- Bajaj, K.L., Kaur, G., and Sukhija, B.C. 1980. Chemical composition and some plant characteristics in relation to quality of some promising cultivars of carrot (*Daucus carota* L.). *Plant Foods Hum.Nutr.* 30 : 97.
- Baloch, A.D., Buckle., K.A. and Edwards, R. 1977. Stability of beta-carotene in model systems containing sulphite. *J. Food Technol.* 12 : 309.
- Bauernfeind, J.C. 1973. Direct and indirect coloring with carotenoid food colors. *IFT World Directory and Guide* 26 : 96.
- Bauernfeind, J.C. 1978. Carotenoids : A class of natural pigments in food. In *Encyclopedia of Food Science*, Peterson, M.S. and Johnson, A.H. eds. AVI Publishing Company, Inc., Westport, CT.
- Ben-Yehoshua, S. Shapiro, B., Even-Chen, Z. and Lurie, S. 1983. Mode of action of plastic film extending the life of lemon and bell pepper fruits by alleviation of water stress. *Plant Physiol.* 73 : 87.
- Bourne, M.C. 1982. *Food Texture and Viscosity, Concept Measurement*. Academic Press, NY.
- Bourne, M.C. 1989. Applications of chemical kinetic theory to the rate of thermal softening of vegetable tissue. In *Quality Factors of Fruits and Vegetables*. Jen, J.J., (Ed). American Chemical Society, Washington, DC.
- Brackett, R.E. 1987. Microbiological consequences of minimally processed fruits and vegetables. *J. Food Qual.* 10(3) : 195.

- Brecht, P.E. 1980. Use of controlled atmospheres to retard deterioration of produce. *Food Technol.* 45(3) : 30.
- Brody, A.L. 1989. *Controlled/Modified Atmosphere/Vacuum Packaging of Foods*. Food and Nutrition Press, Inc., Trumbull, CT.
- Busta, F.F., Peterson, E.H., Adams, D.M., and Johnson, M.G. 1984. Colony Count Methods. In APHA. 1984. *Compendium of Methods for the Microbiological Examination of Foods*. 2nd ed., M.L. Speck, editor. Washington, D.C.: American Public Health Association.
- Carlin, F., Nguyen-the, F., Hilbert, G., and Chambroy, Y. 1990a. Modified atmosphere packaging of fresh, "ready-to-use" grated carrots in polymeric films. *J. Food Sci.* 55 : 1033.
- Carlin, F., Nguyen-the, F., Chambroy, Y., and Reich, M. 1990b. Effects of controlled atmospheres on microbial spoilage, electrolyte leakage and sugar content of fresh, "ready-to-use" grated carrots. *Int. J. Food Sci. Technol.* 25 : 110.
- Carlton, B.C. and Peterson, C.E. 1963. Breeding carrots for sugar and dry matter content. *Proc. Am. Soc. Hortic. Sci.* 82 : 332.
- CFR. 1992. *Code of Federal Regulations*, Title 7, section 52. Office of the Federal Register, National Archives and Records Service, General Service Administration, Washington DC.
- DeMan, J.M. 1980. *Principles of Food Chemistry*. AVI Publishing Company, Inc., Westport, CT.
- Denny, F.E., Thornton, N.C., and Schroeder, E.M. 1944. The effect of carbon dioxide upon the changes in the sugar content of certain vegetables in cold storage. *Contrib. Boyce Thompson Inst.* 13 : 295
- Draughon, F.A. 1992. Personal communication. The University of Tennessee, Knoxville.
- Emodi, A. 1978. Carotenoids, properties and applications. *Food Technol.* 5 : 38.

- Fennema, O. R. (edt). 1985. *Food Chemistry*. Marcel Dekker, Inc. NY.
- Gould, W.A. and Gould, R.W. 1988. *Total Quality Assurance for the Food Industries*. CTI Publications, Inc., Baltimore, MD.
- Hasselbring, E. 1927. Carbohydrate transformation in carrots during storage. *Plant physiol.* 2 : 225
- Howard, P.L. and Heinz, D.E. 1970. Texture of carrots. *J. Texture Studies* 1.
- Hunterlab. 1980. *Instructional Manual*. Hunter Association Laboratories, Inc., Reston, VA.
- Irving, A.R. 1984. Transport of fresh horticultural produce under modified atmosphere. *CSIRO-Food Research* 44 : 2.
- Kader, A.A. and Morris, L.L. 1977. Relative tolerances of fruits and vegetables to elevated CO₂ and reduced O₂ levels. In *Controlled Atmospheres for the Storage and Transport of Horticultural Crops*, ed. D.H. Dewey, pp 260-5 (Department of Horticulture., Michigan State Univ. East Lansing, MI).
- King, Jr., A.D. and Bolin, H.R. 1989. Physiological and microbiological storage stability of minimally processed fruits and vegetables. *Food Technol.* 43(2) : 132.
- Kraft, A.A. and Rey, C.R. 1979. Psychrotrophic bacteria in foods : An update. *Food Technology* 33(1) : 66.
- Kramer, A., Solomos, T., Wheaton, F., Puri, A., Sirivichaya, S., Lotem, Y., Fowke, M. and Ehrman, L. 1980. A gas-exchange process for extending shelf life of raw foods. *Food Technol.* 34(7) : 65.
- Lampila, L.E., Wallen, S.E. and Bullerman, L.B. 1984. Beta-carotene: A brief history, biogenesis and functions in food. *Dairy and Food Sanitation.* 3 : 90.

- Lioutas, T.S. 1988. Challenges of controlled and modified atmosphere packaging. *Food Technol.* 42(9) : 78.
- Marcellin, P. 1974. Preservation of vegetables under controlled atmosphere in polyethylene bags with a silicone elastomer window. *Acta Hort.* 38 : 33.
- McCollum, W. 1975. *Producing Vegetable Crops. 2nd ed.* The Interstate Printers and Publishers, Inc. Danville, IL.
- Pattee, H.E. 1985. *Evaluation of Quality of Fruits and Vegetables.* AVI Publishing Company, Inc., Westport, CT.
- Phan, C.T., Hsu, S., and Sarkar, S.K. 1973. Physical and chemical changes occurring in the carrot root during storage. *Can. J. Plant Sci.* 53 : 635
- Phan, C.T. 1974. Use of plastic films in the storage of carrots. *Acta Hort.* 38 : 345.
- Paul, P.C. and Palmer, H.E. 1972. *Food Theory and Applications.* John Wiley and Sons, Inc., NY.
- Rumpf, G. and Hansen, H. 1973. Gas chromatographische Bestimmung löslicher Inhaltstoffe in "Controlled Atmosphere"-gelagerten Möhren. *Gartenbauwissenschaft* 38 : 281 in Carlin, F., Nguyen-the, F., Hilbert, G., and Chambroy, Y. 1990. Modified atmosphere packaging of fresh, "ready-to-use" grated carrots in polymeric films. *J. Food Science.* 55 : 1033.
- SAS. 1987. *System for Elementary Statistical Analysis.* SAS Institute Inc., Cary, NC.
- Simon, P.W. and Peterson, C.E. 1979. Genetic and environmental components of carrot culinary and nutritive value. *Acta Hort.* 93 : 271.
- Simon, P.W. and Peterson, C.E., and Lindsay, R.C. 1982. Genotype, soil and climate effects on sensory and objective components of carrot flavor. *J. Amer. Soc. Hort. Sci.* 107 : 644.

Sinell, H.J. 1980. *Packaging*. Academic Press, NY.

Splittstoesser, D.F. and Mundt, J.O. 1984. Fruits and vegetables. In APHA. 1984. *Compendium of Methods for the microbiological Examination of Foods*. 2nd ed., Speck, M.L., editor. Washington, DC.: American Public Health Association.

Stefanovich, A.F. and Karel, M. 1982. Kinetics of β -carotene degradation at temperatures typical of air drying of foods. *Food Proc. and Preservation* 6 : 227.

Thaysen, A.C. and Galloway, W.W. 1930. In Splittstoesser, D.F. and Mundt, J.O. 1984. Fruits and vegetables. In APHA. 1984. *Compendium of Methods For the microbiological Examination of Foods*. 2nd ed., Speck, M.L., editor. Washington, DC.: American Public Health Association.

United Foods, Inc. 1992. Vegetable compositions. United Foods, Inc., Bells, TN.

USDA. 1984. Agriculture Handbook No. 8-11. pg 121. Composition of Foods: Vegetables and Vegetable Products. U.S. Government Printing Office, Washington D.C. 20402.

USDA. 1991. Agricultural Statistics. U.S. Government Printing Office, USDA, Washington, DC.

Van den Berg, L. and Lentz, C.P. 1966. Effect of temperature, relative humidity, and atmospheric composition on changes in quality of carrots during storage. *Food Technol.* 20(7) : 104.

Vaughn, R.H. 1951. In Splittstoesser, D.F. and Mundt, J.O. 1984. Fruits and vegetables. In APHA. 1984. *Compendium of Methods for the microbiological Examination of Foods*. 2nd ed., Speck, M.L., editor. Washington, DC.: American Public Health Association.

Webb, T.A. and Mundt, J.O. 1978. Molds on vegetables at the time of harvest. *Appl. Environ. Microbiol.* 35 : 655.

- Werner, H.O. 1941. Dry matter, sugar and carotene content of morphological portions of carrots through the growing season. J. Am. Soc. Hort. Sci. 38 : 267.
- Wills, R.B.H., Lee, T.H., Graham, D., McGlasson, W.B., and Hall, E.G. 1982. *Post harvest- An Introduction To The Physiology and Handling of Fruits and Vegetables*. AVI. Westport, CT.
- Wills, R.B.H., McGlasson, W.B., Graham, D., Lee, T.H. and Hall, E.G. (Ed.). 1989. *Postharvest*. Van Nostrand Reinhold, NY.
- Zagory, D. and Kader, A.A. 1988. Modified atmosphere packaging of fresh produce. Food Technol. 42(9) : 70.
- Zhu, S., Mount, J.R., and Collins, J.L. 1992. Sugar and soluble solids changes in refrigerated sweet corn (*Zea mays* L). J. Food Sci. 57 : 454.

APPENDIXES

APPENDIX A

Raw Data

Raw data for CO₂ and O₂ percentages of atmospheres within bags of carrots
stored at 7°C

OBS	PEEL	FILM	DAYS	REP	CO2PC	O2PC
5	P	1	7	1	0.1402	21.6288
6	P	2	7	1	2.2814	15.8661
7	P	3	7	1	4.0048	9.8603
8	P	4	7	1	46.4918	3.0904
9	P	1	14	1	0.0821	21.5867
10	P	2	14	1	0.7601	20.2825
11	P	3	14	1	1.9496	14.0991
12	P	4	14	1	9.8818	13.2421
13	P	1	21	1	0.1268	21.8499
14	P	2	21	1	0.5226	21.2439
15	P	3	21	1	4.1678	7.1619
16	P	4	21	1	13.4142	12.3304
18	P	2	28	1	1.3019	19.6061
19	P	3	28	1	2.7735	19.7581
20	P	4	28	1	20.2943	9.0574
25	P	1	7	2	0.0615	21.4691
26	P	2	7	2	0.5956	20.8842
27	P	3	7	2	3.2711	11.5238
28	P	4	7	2	51.4244	4.0987
29	P	1	14	2	0.6703	21.4577
30	P	2	14	2	0.8923	20.3798
31	P	3	14	2	3.6448	8.6789
32	P	4	14	2	11.4436	12.8087
33	P	1	21	2	0.4593	27.2243
34	P	2	21	2	2.0744	24.3288
35	P	3	21	2	4.2322	18.3781
36	P	4	21	2	80.0267	4.3234
37	P	1	28	2	0.1085	21.6455
38	P	2	28	2	1.0694	18.8526
39	P	3	28	2	3.8786	13.6474
40	P	4	28	2	15.8611	11.3606
41	P	1	0	3	0.3455	21.6152
42	P	2	0	3	0.2012	21.7513
43	P	3	0	3	3.0925	19.0637
44	P	4	0	3	2.8493	19.7097
45	P	1	7	3	0.9146	21.0407
46	P	2	7	3	1.1691	20.3428
47	P	3	7	3	2.9815	18.8485
48	P	4	7	3	25.6363	6.5017
49	P	1	14	3	0.1021	21.1228
50	P	2	14	3	1.6564	17.5490
51	P	3	14	3	4.3060	15.6212
52	P	4	14	3	56.3587	4.8096
53	P	1	21	3	1.1584	19.3505
54	P	2	21	3	2.2098	14.8464

Raw data for CO₂ and O₂ percentages of atmospheres within bags of carrots
stored at 7°C

OBS	PEEL	FILM	DAYS	REP	CO2PC	O2PC
55	P	3	21	3	5.3113	12.8937
56	P	4	21	3	73.133	2.1240
57	P	1	28	3	0.124	21.1769
58	P	2	28	3	1.231	19.5310
59	P	3	28	3	4.481	12.9942
60	P	4	28	3	5.836	17.1684
65	N	1	7	1	25.474	11.9448
66	N	2	7	1	2.319	16.2676
67	N	3	7	1	4.031	9.6937
68	N	4	7	1	31.737	3.8411
69	N	1	14	1	1.382	20.8021
70	N	2	14	1	0.701	20.8931
71	N	3	14	1	0.909	20.9677
72	N	4	14	1	39.543	5.4393
73	N	1	21	1	1.044	21.0028
74	N	2	21	1	1.394	19.8034
75	N	3	21	1	3.731	9.6225
76	N	4	21	1	48.291	5.4599
77	N	1	28	1	1.738	22.7151
78	N	2	28	1	1.727	21.8444
79	N	3	28	1	4.931	14.1824
80	N	4	28	1	17.990	10.7557
85	N	1	7	2	9.241	18.8107
86	N	2	7	2	1.215	20.0497
87	N	3	7	2	4.030	13.9376
88	N	4	7	2	37.683	4.2112
89	N	1	14	2	1.978	20.6500
90	N	2	14	2	0.443	21.4281
91	N	3	14	2	3.381	9.7552
92	N	4	14	2	61.684	3.5752
93	N	1	21	2	5.423	14.4860
94	N	2	21	2	18.061	24.2455
95	N	3	21	2	5.255	10.0017
96	N	4	21	2	228.882	9.3163
97	N	1	28	2	1.964	20.4676
98	N	2	28	2	0.455	21.2180
99	N	3	28	2	3.630	15.4035
100	N	4	28	2	61.343	4.9129
101	N	1	0	3	1.121	21.3544
102	N	2	0	3	1.448	20.0065
103	N	3	0	3	3.198	19.0364
104	N	4	0	3	3.890	17.2142
105	N	1	7	3	4.450	18.7832
106	N	2	7	3	3.042	14.4612
107	N	3	7	3	5.030	16.6474

Raw data for CO₂ and O₂ percentages of atmospheres within bags of carrots
stored at 7°C

OBS	PEEL	FILM	DAYS	REP	CO2PC	O2PC
108	N	4	7	3	59.985	3.3268
109	N	1	14	3	16.081	16.6411
110	N	2	14	3	3.220	16.5620
111	N	3	14	3	4.8734	7.0110
112	N	4	14	3	66.2087	2.5253
113	N	1	21	3	7.8582	19.0687
114	N	2	21	3	6.4776	9.4629
115	N	3	21	3	6.4843	9.1531
116	N	4	21	3	68.8857	2.9235
117	N	1	28	3	0.7033	20.7010
118	N	2	28	3	1.3337	19.7952
119	N	3	28	3	5.2866	8.2121
120	N	4	28	3	12.4223	13.0736

Raw data for moisture percentages of carrots stored at 7°C in plastic bags

OBS	PEEL	FILM	DAYS	Moisture %	
				Rep 1	Rep 2
1	N	1	0	88.50	88.27
3	N	1	7	88.25	88.34
5	N	1	14	88.60	88.63
7	N	1	21	88.99	88.68
9	N	1	28	87.18	88.34
11	N	2	0	87.50	.
13	N	2	7	88.43	88.39
15	N	2	14	87.81	88.07
17	N	2	21	88.11	88.47
19	N	2	28	88.48	87.78
21	N	3	0	88.27	88.50
23	N	3	7	88.62	88.44
25	N	3	14	88.78	89.25
27	N	3	21	86.99	88.12
29	N	3	28	89.43	87.67
31	N	4	0	.	87.50
33	N	4	7	88.93	89.25
35	N	4	14	88.07	89.47
37	N	4	21	90.48	90.27
39	N	4	28	88.83	91.81
41	P	1	0	87.88	86.37
43	P	1	7	89.19	87.97
45	P	1	14	88.31	87.73
47	P	1	21	88.39	88.87
49	P	1	28	88.19	89.18
51	P	2	0	88.27	86.77
53	P	2	7	88.87	88.84
55	P	2	14	89.41	88.05
57	P	2	21	87.43	87.34
59	P	2	28	90.43	88.14
61	P	3	0	86.37	87.88
63	P	3	7	88.09	88.82
65	P	3	14	88.49	88.02
67	P	3	21	88.32	87.93
69	P	3	28	88.48	88.01
71	P	4	0	86.77	88.27
73	P	4	7	89.33	88.81
75	P	4	14	88.69	88.22
77	P	4	21	89.89	89.20
79	P	4	28	89.20	88.09

Raw data for mean Instron measurements (joules) for the texture evaluation
of carrots and number of broken carrots stored at 7°C in plastic bags

PEEL	FILM	DAYS	REP 1		REP 2		REP 3	
			INSTRON (Joules)	BREAK #	INSTRON (Joules)	BREAK #	INSTRON (Joules)	BREAK #
N	1	0	0.015611	0	0.036578	0	0.033682	1
N	1	7	0.020182	4	0.045474	0	0.028153	2
N	1	14	0.055364	4	0.026025	2	0.022641	1
N	1	21	0.026444	4	0.038444	1	0.023408	2
N	1	28	0.047288	4	0.025083	0	0.026182	1
N	2	0	0.015611	0	0.036578	0	0.025292	1
N	2	7	0.019850	1	0.025135	3	0.030298	0
N	2	14	0.036299	3	0.024612	1	0.029391	1
N	2	21	0.052922	4	0.046625	1	0.024560	1
N	2	28	0.045195	2	0.033682	2	0.021682	1
N	3	0	0.015611	0	0.036578	0	0.008285	1
N	3	7	0.033386	2	0.029950	2	0.022763	0
N	3	14	0.026513	1	0.038130	1	0.019257	0
N	3	21	0.027089	2	0.028659	1	0.041759	1
N	3	28	0.023618	1	0.042997	1	0.018437	1
N	4	0	0.015611	0	0.036578	0	0.030421	1
N	4	7	0.026845	2	0.032583	2	0.014443	2
N	4	14	0.041096	2	0.042247	2	0.016100	1
N	4	21	0.054614	4	0.075389	3	0.024612	1
N	4	28	0.041898	2	0.040258	1	0.030735	0
P	1	0	0.009419	0	0.019833	0	0.034031	1
P	1	7	0.046119	1	0.059533	0	0.036822	0
P	1	14	0.028886	2	0.036404	0	0.020373	0
P	1	21	0.059411	3	0.059795	1	0.016902	0
P	1	28	0.034328	1	0.044951	1	0.069615	0
P	2	0	0.009419	0	0.019833	0	0.030403	0
P	2	7	0.042282	0	0.067836	0	0.018961	0
P	2	14	0.072022	1	0.037904	0	0.029618	0
P	2	21	0.053515	1	0.039003	3	0.031293	1
P	2	28	0.037590	0	0.051439	3	0.021054	0
P	3	0	0.009419	0	0.019833	0	0.029444	0
P	3	7	0.019711	0	0.022170	1	0.020600	0
P	3	14	0.053934	1	0.025955	0	0.030333	0
P	3	21	0.055643	2	0.040032	1	0.031781	0
P	3	28	0.054073	0	0.053620	3	0.032845	0
P	4	0	0.009419	0	0.019833	0	0.012402	1
P	4	7	0.069702	0	0.032165	0	0.030019	0
P	4	14	0.070679	1	0.062324	0	0.024926	0
P	4	21	0.063684	2	0.086046	0	0.045736	1
P	4	28	0.036438	0	0.018995	3	0.037468	0

Raw data of Hunter L, 'a', 'b', and 'a'/'b' values of carrots stored at 7°C in plastic bags

OBS	PEEL	FILM	DAYS	REP	L	'a'	'b'	'a'/'b'
1	P	1	0	1	47.8	32.3	26.1	1.23755
2	P	2	0	1	47.8	32.3	26.1	1.23755
3	P	3	0	1	47.8	32.3	26.1	1.23755
4	P	4	0	1	47.8	32.3	26.1	1.23755
5	P	1	7	1	47.2	31.4	27.3	1.15018
6	P	2	7	1	46.7	33.9	27.0	1.25556
7	P	3	7	1	46.2	34.6	26.9	1.28625
8	P	4	7	1	49.8	31.7	28.3	1.12014
9	P	1	14	1	46.1	34.2	26.4	1.29545
10	P	2	14	1	46.9	31.7	26.4	1.20076
11	P	3	14	1	47.7	33.7	27.1	1.24354
12	P	4	14	1	47.8	34.0	27.4	1.24088
13	P	1	21	1	46.0	33.5	26.5	1.26415
14	P	2	21	1	46.4	31.1	26.3	1.18251
15	P	3	21	1	47.1	36.4	27.2	1.33824
16	P	4	21	1	49.5	32.4	28.0	1.15714
17	P	1	28	1	46.1	35.0	26.6	1.31579
18	P	2	28	1	45.6	31.0	25.8	1.20155
19	P	3	28	1	47.0	31.4	26.9	1.16729
20	P	4	28	1	45.5	33.9	25.8	1.31395
21	P	1	0	2	46.3	30.1	27.0	1.11481
22	P	2	0	2	46.3	30.1	27.0	1.11481
23	P	3	0	2	46.3	30.1	27.0	1.11481
24	P	4	0	2	46.3	30.1	27.0	1.11481
25	P	1	7	2	50.6	30.6	29.1	1.05155
26	P	2	7	2	47.4	32.9	27.6	1.19203
27	P	3	7	2	47.7	36.1	28.0	1.28929
28	P	4	7	2	49.8	31.1	28.7	1.08362
29	P	1	14	2	47.2	31.9	27.2	1.17279
30	P	2	14	2	49.3	33.0	28.3	1.16608
31	P	3	14	2	48.6	33.0	28.4	1.16197
32	P	4	14	2	51.4	29.3	29.8	0.98322
33	P	1	21	2	46.4	27.2	26.3	1.03422
34	P	2	21	2	48.0	32.6	27.7	1.17690
35	P	3	21	2	46.3	35.0	27.2	1.28676
36	P	4	21	2	49.2	29.9	28.4	1.05282
37	P	1	28	2	50.1	29.9	28.4	1.05282
38	P	2	28	2	47.3	32.4	27.3	1.18681
39	P	3	28	2	46.3	29.5	26.1	1.13027
40	P	4	28	2	46.0	33.6	26.6	1.26316

Raw data of Hunter L, 'a', 'b', and 'a'/'b' values of carrots stored at 7°C in plastic bags

OBS	PEEL	FILM	DAYS	REP	L	'a'	'b'	'a'/'b'
61	N	1	0	1	43.2	18.8	18.7	1.00535
62	N	2	0	1	43.2	18.8	18.7	1.00535
63	N	3	0	1	43.2	18.8	18.7	1.00535
64	N	4	0	1	43.2	18.8	18.7	1.00535
65	N	1	7	1	44.6	27.9	25.5	1.09412
66	N	2	7	1	41.9	30.0	23.9	1.25523
67	N	3	7	1	43.1	29.7	24.1	1.23237
68	N	4	7	1	44.5	32.1	25.7	1.24903
69	N	1	14	1	43.2	29.6	24.4	1.21311
70	N	2	14	1	46.0	30.1	25.7	1.17121
71	N	3	14	1	42.8	29.9	23.9	1.25105
72	N	4	14	1	42.8	31.2	24.2	1.28926
73	N	1	21	1	44.1	29.0	25.0	1.16000
74	N	2	21	1	44.8	30.5	25.4	1.20079
75	N	3	21	1	42.0	26.5	23.6	1.12288
76	N	4	21	1	43.0	30.2	25.0	1.20800
77	N	1	28	1	40.8	28.9	22.7	1.27313
78	N	2	28	1	43.3	28.4	24.0	1.18333
79	N	3	28	1	45.0	33.0	25.0	1.32000
80	N	4	28	1	40.7	28.8	23.2	1.24138
81	N	1	0	2	43.0	27.6	24.5	1.12653
82	N	2	0	2	43.0	27.6	24.5	1.12653
83	N	3	0	2	43.0	27.6	24.5	1.12653
84	N	4	0	2	43.0	27.6	24.5	1.12653
85	N	1	7	2	44.8	28.9	25.5	1.13333
86	N	2	7	2	44.0	28.8	25.2	1.14286
87	N	3	7	2	48.4	27.6	27.5	1.00364
88	N	4	7	2	44.8	30.1	25.7	1.17121
89	N	1	14	2	43.7	26.9	24.9	1.08032
90	N	2	14	2	45.6	29.9	26.3	1.13688
91	N	3	14	2	43.7	32.1	25.4	1.26378
92	N	4	14	2	43.9	28.6	25.6	1.11719
93	N	1	21	2	43.9	30.5	25.4	1.20079
94	N	2	21	2	44.1	27.8	25.2	1.10317
95	N	3	21	2	46.8	29.1	26.9	1.08178
96	N	4	21	2	46.4	26.5	26.7	0.99251
97	N	1	28	2	44.9	30.7	25.9	1.18533
98	N	2	28	2	45.4	30.1	26.1	1.15326
99	N	3	28	2	43.1	30.8	25.0	1.23200
100	N	4	28	2	41.9	28.9	24.4	1.18443

Raw data for sucrose, glucose and fructose contents of carrots stored at 7°C in plastic bags

OBS	PEEL	FILM	DAYS	REP	SUCROSE mg/100 g	GLUCOSE mg/100 g	FRUCTOSE mg/100 g
1	N	1	0	1	333.67	1350.67	1282.67
2	N	1	0	2	333.67	1350.67	1282.67
3	N	1	7	1	340.67	587.33	888.33
4	N	1	7	2	422.67	3254.67	526.00
5	N	1	14	1	336.67	1618.00	964.33
6	N	1	14	2	438.00	2476.67	401.00
7	N	1	21	1	350.67	780.67	932.67
8	N	1	21	2	3281.00	1374.33	564.00
9	N	1	28	1	408.00	423.67	554.00
10	N	1	28	2	495.67	337.00	544.00
11	N	2	0	1	484.33	516.33	575.67
12	N	2	0	2	484.33	516.33	575.67
13	N	2	7	1	350.33	756.33	925.67
14	N	2	7	2	3060.00	3101.67	3201.00
15	N	2	14	1	418.33	1238.00	752.33
16	N	2	14	2	447.33	2758.33	368.33
17	N	2	21	1	347.00	796.67	926.33
18	N	2	21	2	511.00	782.33	3053.00
19	N	2	28	1	381.67	450.00	509.00
20	N	2	28	2	451.67	762.67	2051.00
21	N	3	0	1	2961.00	809.00	812.00
22	N	3	0	2	2961.00	809.00	812.00
23	N	3	7	1	340.67	536.00	788.67
24	N	3	7	2	451.00	425.33	454.33
25	N	3	14	1	396.00	1433.33	983.00
26	N	3	14	2	3318.33	1452.67	372.67
27	N	3	21	1	719.00	2532.67	2600.33
28	N	3	21	2	2651.67	569.67	634.00
29	N	3	28	1	2466.67	397.67	599.00
30	N	3	28	2	355.00	2280.67	379.00
31	N	4	0	1	333.67	1350.67	1282.67
32	N	4	0	2	333.67	1350.67	1282.67
33	N	4	7	1	2816.67	685.33	959.33
34	N	4	7	2	2160.00	980.33	2998.00
35	N	4	14	1	396.33	1596.00	890.67
36	N	4	14	2	2844.33	3048.00	386.00
37	N	4	21	1	1417.67	1103.67	1147.00
38	N	4	21	2	2753.00	842.33	1099.00
39	N	4	28	1	357.33	1363.00	1176.67
40	N	4	28	2	1204.33	2994.00	1735.33

Raw data for sucrose, glucose and fructose contents of carrots stored at 7°C in plastic bags

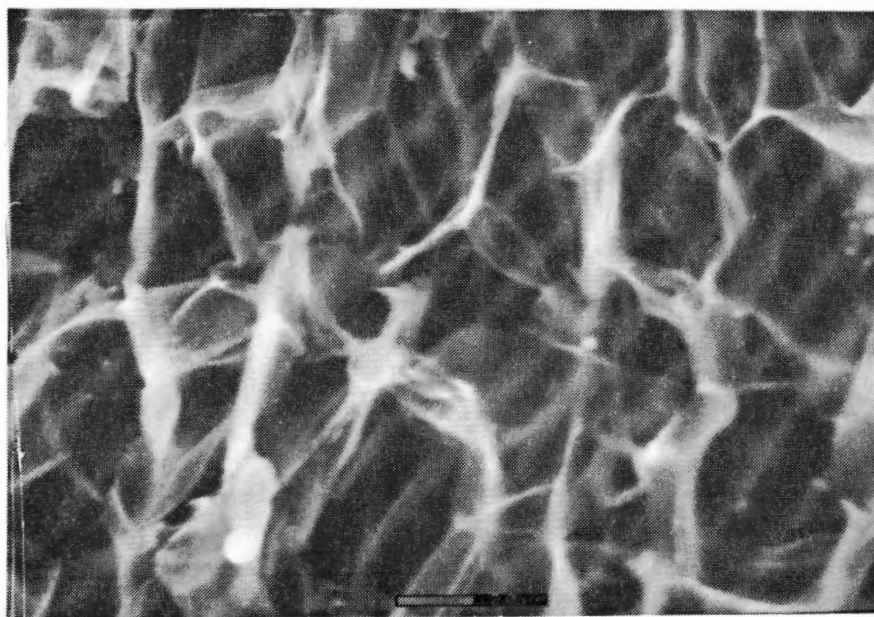
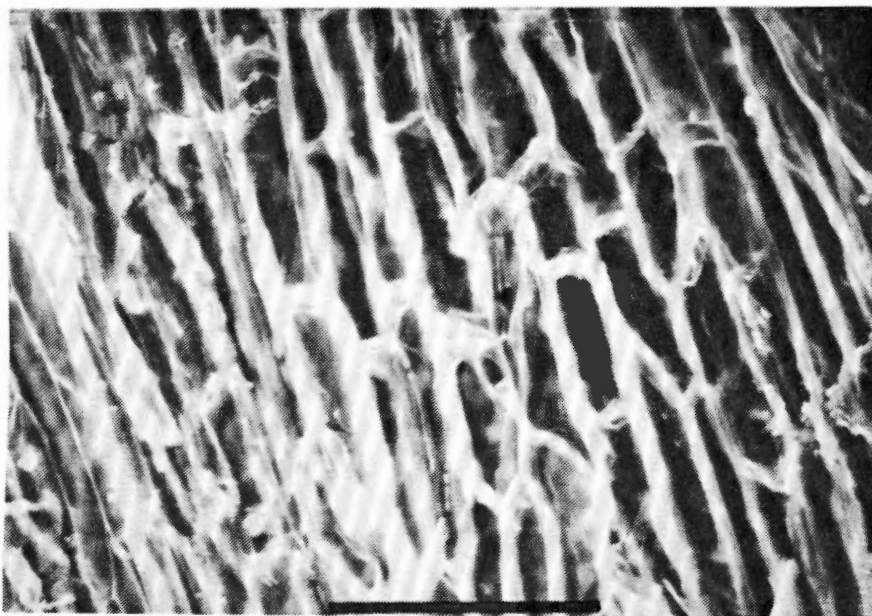
OBS	PEEL	FILM	DAYS	REP	SUCROSE mg/100 g	GLUCOSE mg/100 g	FRUCTOSE mg/100 g
41	P	1	0	1	406.33	1594.67	1499.00
42	P	1	0	2	406.33	1594.67	1499.00
43	P	1	7	1	504.00	1421.67	1038.00
44	P	1	7	2	442.33	698.00	859.33
45	P	1	14	1	2920.33	1979.33	1042.67
46	P	1	14	2	467.33	684.33	916.33
47	P	1	21	1	420.67	838.00	719.67
48	P	1	21	2	3016.00	867.00	1094.00
49	P	1	28	1	1791.67	563.67	671.67
50	P	1	28	2	2727.67	1595.67	1116.67
51	P	2	0	1	399.33	1750.67	2233.67
52	P	2	0	2	399.33	1750.67	2233.67
53	P	2	7	1	349.67	912.00	1035.33
54	P	2	7	2	342.00	1170.33	926.67
55	P	2	14	1	907.67	2418.00	2379.33
56	P	2	14	2	378.33	761.33	1029.67
57	P	2	21	1	638.00	1059.67	1293.33
58	P	2	21	2	421.67	1147.00	1510.67
59	P	2	28	1	1622.00	1774.00	1001.00
60	P	2	28	2	2433.00	1172.33	1170.00
61	P	3	0	1	594.00	1450.67	2587.00
62	P	3	0	2	594.00	1450.67	1499.00
63	P	3	7	1	495.00	372.67	617.67
64	P	3	7	2	392.00	1270.00	640.33
65	P	3	14	1	461.33	488.00	659.67
66	P	3	14	2	482.00	348.33	535.67
67	P	3	21	1	522.00	1750.33	1191.00
68	P	3	21	2	362.67	388.67	526.67
69	P	3	28	1	563.00	1291.33	1483.00
70	P	3	28	2	474.33	605.67	492.67
71	P	4	0	1	406.33	1594.00	1499.00
72	P	4	0	2	406.33	1421.67	1038.00
73	P	4	7	1	3066.00	761.33	846.67
74	P	4	7	2	3024.33	2231.67	355.33
75	P	4	14	1	2763.00	1996.00	942.33
76	P	4	14	2	498.00	3165.67	348.67
77	P	4	21	1	2942.67	977.67	1441.67
78	P	4	21	2	2224.33	3217.67	3311.67
79	P	4	28	1	427.33	644.67	378.00
80	P	4	28	2	383.00	3113.00	405.33

Raw data for log CFU/g and surface pH of carrots stored at 7°C in plastic bags

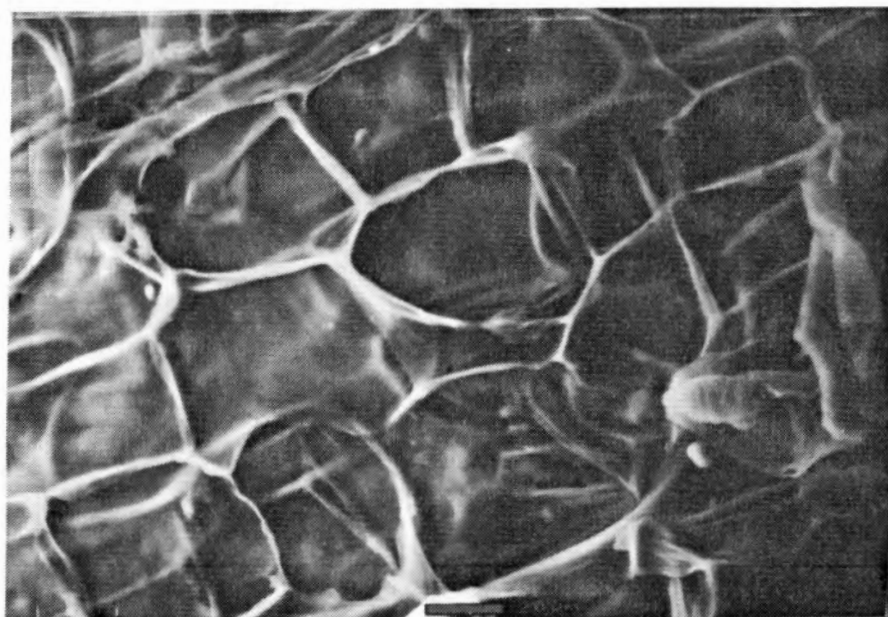
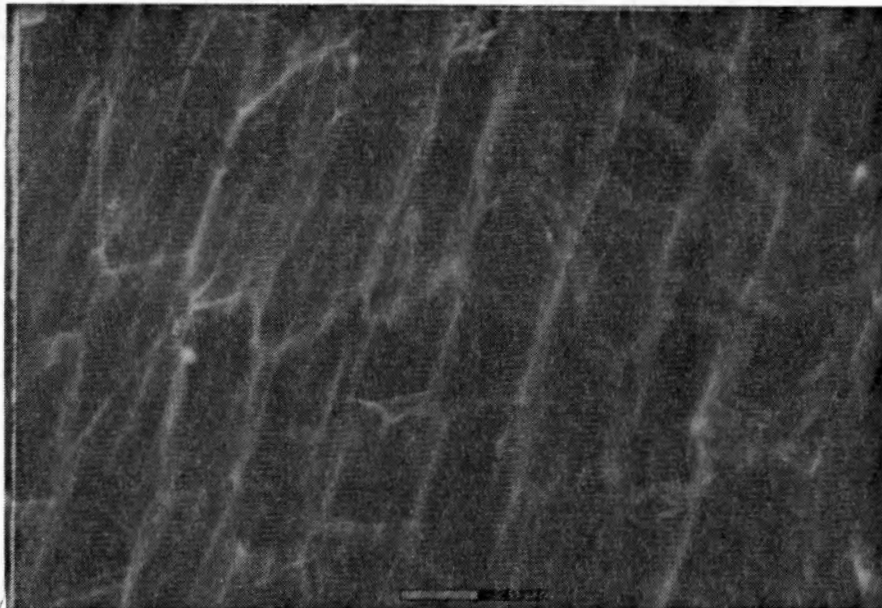
OBS	PEEL	FILM	DAYS	REP	LOG CFU/g	pH
41	P	1	0	1	2.47349	6.1
42	P	1	0	2	1.28936	6.4
43	P	1	7	1	3.01160	6.5
44	P	1	7	2	4.16041	6.5
45	P	1	14	1	2.32720	6.4
46	P	1	14	2	3.11877	6.6
47	P	1	21	1	4.17946	7.0
48	P	1	21	2	3.11480	6.6
49	P	1	28	1	3.58665	6.5
50	P	1	28	2	3.27353	6.8
51	P	2	0	1	2.43537	6.1
52	P	2	0	2	1.84167	6.4
53	P	2	7	1	3.01052	6.5
54	P	2	7	2	3.45384	6.3
55	P	2	14	1	1.77402	6.4
56	P	2	14	2	3.16484	6.6
57	P	2	21	1	4.55665	7.0
58	P	2	21	2	3.20653	6.5
59	P	2	28	1	4.20907	6.4
60	P	2	28	2	3.65852	6.7
61	P	3	0	1	1.28936	6.1
62	P	3	0	2	2.47349	6.4
63	P	3	7	1	3.61371	6.5
64	P	3	7	2	3.05470	6.2
65	P	3	14	1	4.63678	6.4
66	P	3	14	2	4.20434	6.5
67	P	3	21	1	3.69027	6.8
68	P	3	21	2	3.19513	6.7
69	P	3	28	1	4.61805	6.0
70	P	3	28	2	4.22283	6.7
71	P	4	0	1	1.84167	6.1
72	P	4	0	2	2.43537	6.4
73	P	4	7	1	4.24794	6.5
74	P	4	7	2	2.72106	6.3
75	P	4	14	1	3.75757	6.4
76	P	4	14	2	3.15067	6.5
77	P	4	21	1	3.67928	6.7
78	P	4	21	2	4.55227	6.8
79	P	4	28	1	4.09703	6.0
80	P	4	28	2	4.71834	6.8

APPENDIX B

Electron Microscopy

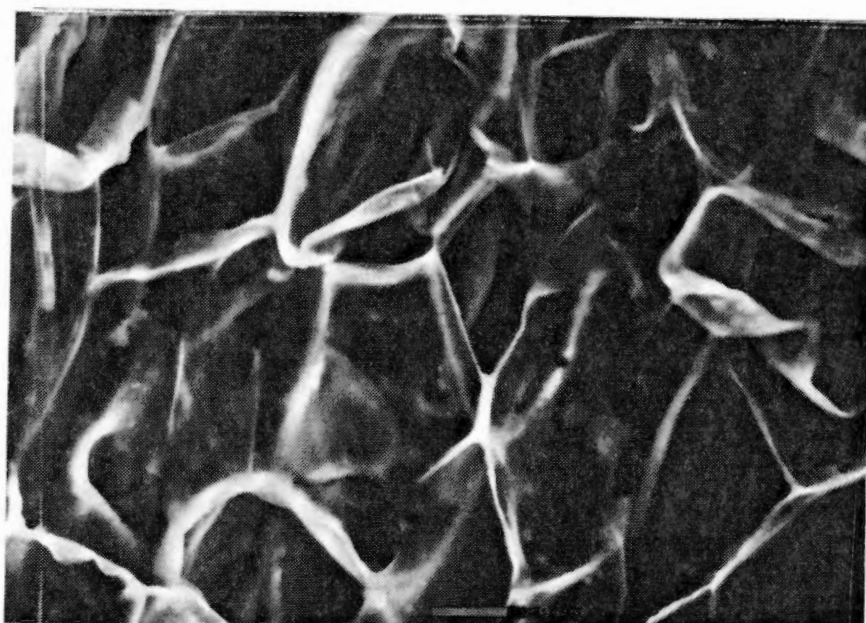
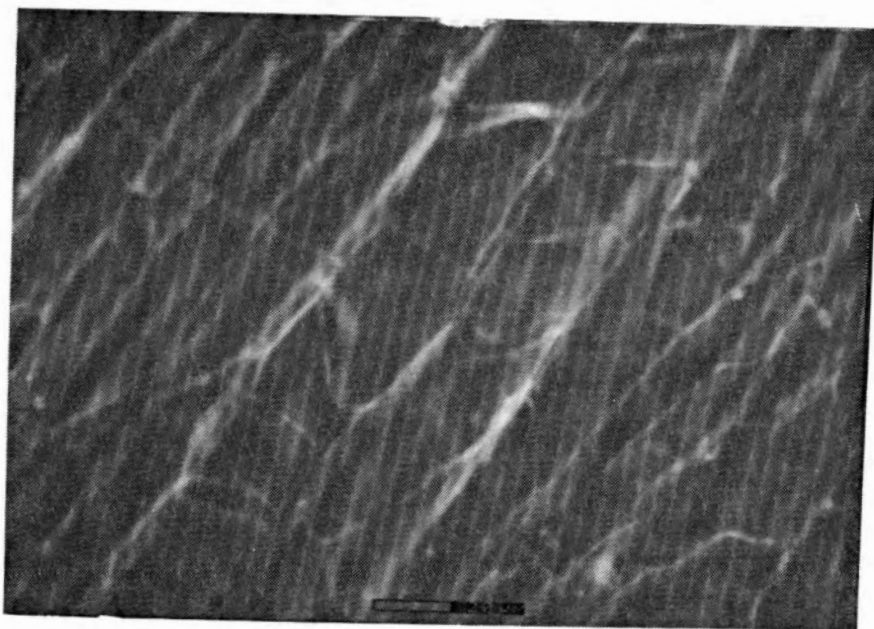


- A.** Electron microscopy scan^a of non-peeled carrot's surface stored at 7°C in film 1 for 28 days (above)
- B.** Electron microscopy scan^a of peeled carrot's surface stored at 7°C in film 1 for 28 days (below)



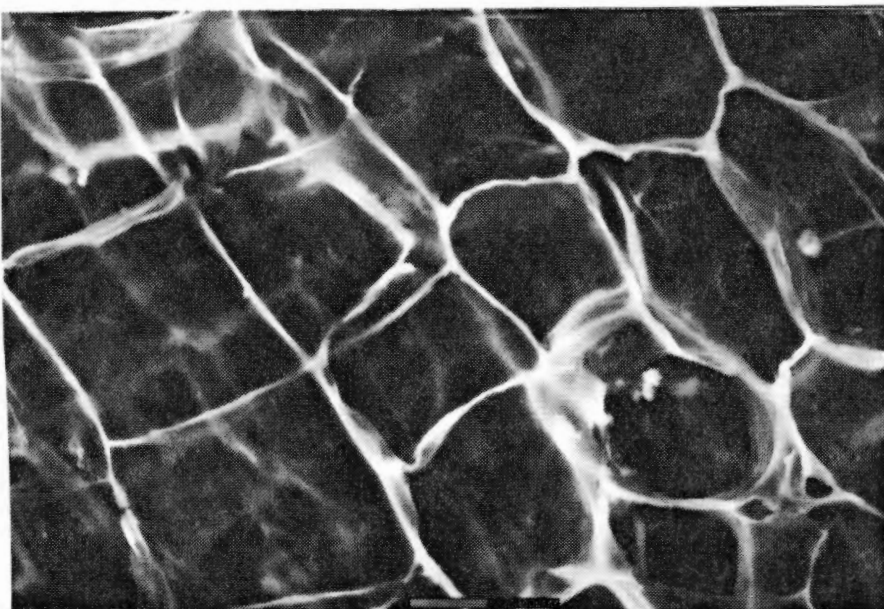
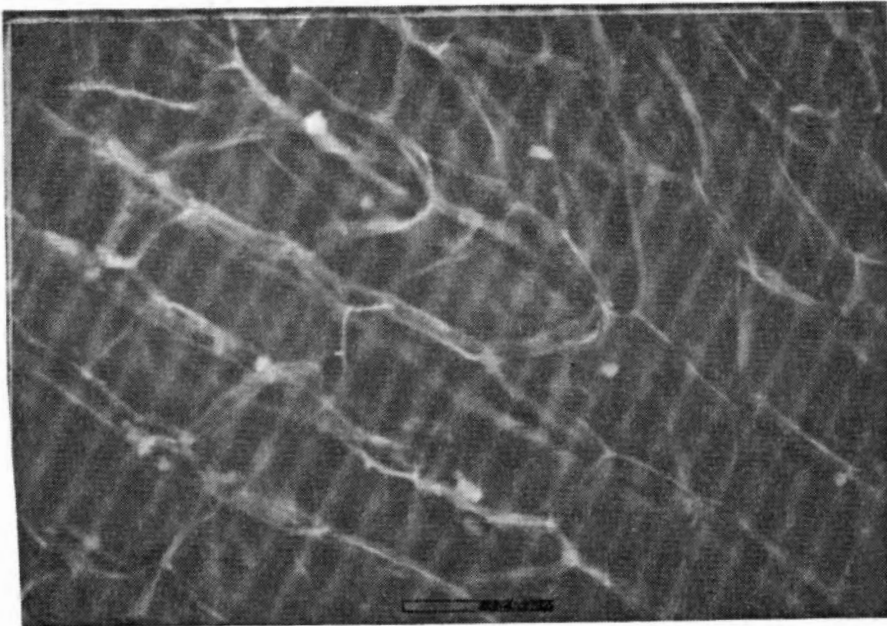
C. Electron microscopy scan^a of non-peeled carrot's surface stored at 7⁰C in film 2 for 28 days (above)

D. Electron microscopy scan^a of peeled carrot's surface stored at 7⁰C in film 2 for 28 days (below)



E. Electron microscopy scan^a of non-peeled carrot's surface stored at 7°C in film 3 for 28 days (above)

F. Electron microscopy scan^a of peeled carrot's surface stored at 7°C in film 3 for 28 days (below)



G. Electron microscopy scans of non-peeled carrot's surface stored at 7°C in film 4 for 28 days (above)

H. Electron microscopy scans of peeled carrot's surface stored at 7°C in film 4 for 28 days (below)

^aElectron microscopy scan

For this purpose a disc (1" x 1" size) was cut from the middle portion of one randomly selected carrot from the bag of each treatment. The disc was first immersed in liquid nitrogen and then placed into a freezer. Within 10 hr of this storage, all of the carrot discs were freeze-dried using a Labconco Freeze Corporation's lypholyzer. For scanning, a section of each carrot disc's outermost surface layer was removed with a blade and was directly scanned by using ESM 2.0 (Electron Scan, Wilmington, MA) with 500X magnification.

VITA

Kamran Nadeem was born in Karachi, Pakistan on November 22nd, 1967. He received his elementary education and matriculation certificate from Happy Home School, Karachi, Pakistan.

He achieved his senior high school diploma in pre-medicine from Adamjee Science College, Karachi, Pakistan, in 1986. He studied at the University of Karachi, Pakistan, in the department of chemistry for a period of one semester in the fall of 1986. In march of 1987, he came to the United States after accepting a full scholarship, for his undergraduate studies, from the Ahmed Food Industries (Pvt.) Ltd., Karachi, Pakistan. During the summer of 1989 the author worked as a practical trainee at Copenhagen Pektinfabrik, Lille Skensved, Denmark and H & R flavor GmbH, Holzminden, W. Germany. He graduated from the University of Tennessee, Knoxville, with a BS in Food Technology and Science in May 1990. The author went back to Pakistan in July 1990 and worked for the Ahmed Food Industries (Pvt.) Ltd., Karachi, Pakistan, for half a year.

The author came back to the US in January 1991 and entered into a graduate program in Food Science and Technology. The MS degree was awarded in August 1992. During his academic curriculum at the University of Tennessee, Knoxville, he was twice awarded with the Krenshaw Award. Presently he is working at Ahmed Food Industries (Pvt.) Ltd., in Karachi, Pakistan. In future, the author wishes to continue for the Doctor of Philosophy degree. He is a member of the Institute of Food Technologists.