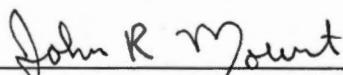
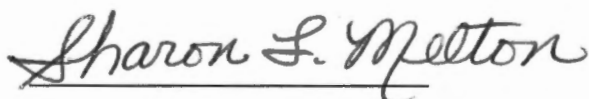


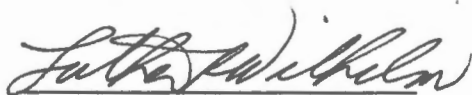
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**EFFECTS OF OSMOTIC TREATMENT IN CORN SYRUP
AND MODIFIED ATMOSPHERE PACKAGING
ON PEELED WHITE POTATOES**

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

**MING QIAN
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Abstract

The quality changes in terms of color, moisture, texture, and respiration of peeled potato cubes were studied. Potatoes were treated by holding in a control solution [1 % (w/w) ascorbic acid and 1% (w/w) citric acid aqueous solution], a 10 % (w/w) corn syrup in the control solution, and a 20 % (w/w) corn syrup in the control solution for three osmotic times (0.5, 1.0, and 1.5h). The treated potatoes were packaging in barrier film under an air or a gas mixture (5 % O₂ : 10 % CO₂ : 85 % N₂) atmosphere. The packaged potatoes were stored at 5 °C and sampled after 1, 4, 7, 10, and 14 d. In addition, the effective inhibition of enzymatic browning on the surface of peeled potato cubes among the different treatments also was determined.

Osmotic treatment with corn syrup did not reduce the moisture content of potato, but resulted in a softer potato. The gas mixture atmosphere in packages reduced the rate of respiration in treated potato cubes and enhanced the efficiency of inhibition of browning. There was no change in texture during the two week storage at 5 °C.

The combination of corn syrup osmotic treatments and a gas mixture atmosphere packaging resulted in a synergistic effect and produced an average 54.1 % inhibition of enzymatic browning which was more effective than the average 15.4 % inhibition produced by the combination of osmotic treatments and air atmosphere treatment. Overall, 1.0-1.5h osmotic times produced the more effective inhibition of enzymatic browning.

The combination treatment of 10 % corn syrup and the gas mixture

(5 % O₂ : 10 % CO₂ : 85 % N₂) atmosphere packaging resulted in an average 59.2 % inhibition of enzymatic browning during the 14 d of storage, maintained a nonperceptible color difference ($\Delta E < 3$) in the potatoes for more than 14 days at 5 °C, and produced less softening than the treatments utilizing 20 % corn syrup. Therefore, the treatment of 10% corn syrup for 1.0h osmotic time and packaged with gas mixture atmosphere is recommended to prevent enzymatic browning in peeled potatoes during a 14 d refrigerated (5 °C) storage.

TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION.....	1
II.	REVIEW OF LITERATURE.....	4
	Potatoes	4
	Potato growth.....	4
	Nutritional values of potato.....	5
	Quality changes of potato during storage.....	6
	Cold temperature	6
	Postharvest respiration.....	7
	Potato processing	8
	History of potato processing	8
	Prepeeled potato	9
	Ways to extend shelf life of peeled potatoes.....	9
	Modified atmosphere packaging.....	9
	Mechanism of its action.....	9
	Modified atmosphere packaging of potatoes.....	10
	To control enzymatic browning.....	11
	Mechanism of enzymatic browning.....	11
	The ways to control enzymatic browning.....	12
	Osmotic concentration	13
	Mechanism and its application	13
	The osmotic agent	14
	Osmotic concentration of potato.....	15
III.	MATERIALS AND METHODS	17
	Potatoes and osmotic agents.....	17
	Osmotic solution preparation.....	17
	Osmotic concentration of potato.....	17
	Modified atmosphere packaging	18
	Measurement of moisture and total solid content	18
	Gas analysis.....	20
	Color analysis.....	20
	Texture analysis.....	22
	Statistical analysis.....	22
IV.	RESULTS AND DISCUSSIONS	24
	Moisture content of potato cubes.....	24

CHAPTER	PAGE
Gas composition.....	28
Color changes.....	36
Inhibition of enzymatic browning.....	45
Texture changes	48
V. SUMMARY AND CONCLUSIONS	56
REFERENCES	59
APPENDICES	67
Appendix A.....	68
Appendix B.....	81
VITA	85

LIST OF TABLES

TABLE	PAGE
1. Analysis of variance of moisture content for fresh potatoes, control (treatment A), and osmotically coating [10% corn syrup (treatment B) or 20% corn syrup (treatment C)] potato cubes for different osmosis times	25
2. Mean of moisture content for fresh potatoes, control (treatment A), and osmotically coating [10% corn syrup (treatment B) or 20% corn syrup (treatment C)] potato cubes for different osmosis times	26
3. Analysis of variance of gas composition for treated potato cubes under an air atmosphere at 5°C	29
4. Analysis of variance of gas composition for treated potato cubes under a gas mixture atmosphere at 5°C	30
5. Analysis of variance of ΔE values for treated potato cubes under an air atmosphere at 5°C	38
6. Analysis of variance of ΔE values for treated potato cubes under a gas mixture atmosphere at 5°C	39
7. Analysis of variance of inhibition (%) of enzymatic browning for treated potato cubes during storage at 5°C	46
8. Mean of inhibition (%) for control (A) and osmotic coating treatment [10% corn syrup (B) or 20% corn syrup (C)] potato cubes during storage under an air or a gas mixture atmosphere and for different osmotic times	47
9. Mean of inhibition (%) of enzymatic browning for control (A) and osmotic coating treatment [10% corn syrup (B) or 20% corn syrup (C)] potato cubes during storage time under an air or a gas mixture atmosphere	49
10. Analysis of variance of texture for control (treatment A) and osmotically coating [10% corn syrup (treatment B) or 20% corn syrup (treatment C)] potato cubes under an air or a gas	

TABLE	PAGE
mixture atmosphere.....	50
11. Mean of compress for control (treatment A) and osmotically coating [10% corn syrup (treatment B) or 20% corn syrup (treatment C)] potato cubes	55
A1. Mean of gas composition and mean of compress for control (treatment A) and osmotically coating [10% corn syrup (treatment B) or 20% corn syrup (treatment C)] potato cubes under an air atmosphere	69
A2. Mean of gas composition and mean of compress for control (treatment A) and osmotically coating [10% corn syrup (treatment B) or 20% corn syrup (treatment C)] potato cubes under a gas mixture atmosphere.....	70
A3. Analysis of variance of Hunter L, a_L , and b_L values for treated potato cubes under an air atmosphere at 5°C.....	71
A4. Analysis of variance of Hunter L, a_L , and b_L values for treated potato cubes under a gas mixture atmosphere at 5°C	72
A5. Mean Hunter L, a_L , b_L , and ΔE values for control (treatment A) and osmotically coating [10% corn syrup (treatment B) or 20% corn syrup (treatment C)] potato cubes under an air atmosphere at 5°C.....	73
A6. Mean Hunter L, a_L , b_L , and ΔE values for control (treatment A) and osmotically coating [10% corn syrup (treatment B) or 20% corn syrup (treatment C)] potato cubes under a gas mixture atmosphere at 5°C.....	74
A7. Mean of Hunter L, a_L , b_L , and ΔE values for control solution (treatment A) potato cubes under an air atmosphere.....	75
A8. Mean of Hunter L, a_L , b_L , and ΔE values for control solution (treatment A) potato cubes under a gas mixture atmosphere	75
A9. Mean of gas composition and compress (g) for control solution (treatment A) potato cubes under an air atmosphere.....	76

TABLE	PAGE
A10. Mean of gas composition and compress (g) for control solution (treatment A) potato cubes under a gas mixture atmosphere.....	76
A11. Mean of Hunter L, a_L , b_L , and ΔE values for osmotically coating in 10% corn syrup (treatment B) potato cubes under an air atmosphere	77
A12. Mean of Hunter L, a_L , b_L , and ΔE values for osmotically coating in 10% corn syrup (treatment B) potato cubes under a gas mixture atmosphere	77
A13. Mean of gas composition and compress (g) for osmotically coating in 10% corn syrup (treatment B) under an air atmosphere	78
A14. Mean of gas composition and compress (g) for osmotically coating in 10% corn syrup (treatment B) under a gas mixture atmosphere	78
A15. Mean of Hunter L, a_L , b_L , and ΔE values for osmotically coating in 20% corn syrup (treatment C) potato cubes under an air atmosphere	79
A16. Mean of Hunter L, a_L , b_L , and ΔE values for osmotically coating in 20% corn syrup (treatment C) potato cubes under a gas mixture atmosphere	79
A17. Mean of gas composition and compress (g) for osmotically coating in 20% corn syrup (treatment C) under an air atmosphere	80
A18. Mean of gas composition and compress (g) for osmotically coating in 20% corn syrup (treatment C) under a gas mixture atmosphere.....	80

LIST OF FIGURES

FIGURE		PAGE
1.	A flow diagram for experimental procedure.....	19
2.	Moisture content of potato cubes treated with control (treatment A), 10% corn syrup (treatment B), or 20 % corn syrup (treatment C) for different osmosis times.....	27
3.	Changes in oxygen (%) in packages of potato cubes under an air or a gas mixture atmosphere at 5 ⁰ C. Within each atmosphere packages, means with the same letter are not significantly different (p < 0.05) using the SNK mean separation test.....	32
4.	Changes in carbon dioxide (%) in packages of potato cubes under an air or a gas mixture atmosphere at 5 ⁰ C. Within each atmosphere packages, means with the same letter are not significantly different (p < 0.05) using the SNK mean separation test.....	33
5.	Average changes in oxygen (%) in packages of potato cubes (n = 45) either contact with control (treatment A), or 10 % corn syrup (treatment B), and 20% corn syrup (treatment C) under an air or a gas mixture atmosphere at 5 ⁰ C. Within each atmosphere packages, means with the same letter are not significantly different (p < 0.05) using the SNK mean separation test	34
6.	Average changes in carbon dioxide (%) in packages of potato cubes (n = 45) either contact with control (treatment A), or 10 % corn syrup (treatment B), and 20% corn syrup (treatment C) under an air or a gas mixture atmosphere at 5 ⁰ C. Within each atmosphere packages, means with the same letter are not significantly different (p < 0.05) using the SNK mean separation test	35
7.	Changes (ΔE value) in color of treated potato cubes either packaging with an air or a gas mixture atmosphere during storage times at 5 ⁰ C. Within each atmosphere packages, means with the same letter are not significantly different (p < 0.05) using the SNK mean separation test.....	40

8.	Average changes (ΔE value) in color ($n = 45$) of potato cubes treated by control (treatment A), 10 % corn syrup (treatment B), and 20% corn syrup (treatment C) either packaging with an air or a gas mixture atmosphere at 5°C . Within each atmosphere packages, means with the same letter are not significantly different ($p < 0.05$) using the SNK mean separation test	41
9.	Changes (ΔE value) in color of potato cubes for control (treatment A) and osmotically coating [10% corn syrup (treatment B) or 20% corn syrup (treatment C)] potato cubes under an air atmosphere during storage time	43
10.	Changes (ΔE value) in color of potato cubes for control (treatment A) and osmotically coating [10% corn syrup (treatment B) or 20% corn syrup (treatment C)] potato cubes under a gas mixture atmosphere (Gas-mix) during storage time	44
11.	Average maximum force ($n = 90$) required to penetrate potato cubes treated by control (treatment A), 10 % corn syrup (treatment B), and 20% corn syrup (treatment C). Means with the same letter are not significantly different ($p < 0.05$) using the SNK mean separation test	52
12.	Average maximum force ($n = 90$) required to penetrate treated potato cubes for different osmosis times. Means with the same letter are not significantly different ($p < 0.05$) using the SNK mean separation test	53
B1.	Changes (Hunter L value) in color of treated potato cubes either packaging with air or a gas mixture atmosphere during storage times at 5°C	82
B2.	Changes (Hunter a_L value) in color of treated potato cubes either packaging with air or a gas mixture atmosphere during storage times at 5°C	83
B3.	Changes (Hunter b_L value) in color of treated potato cubes either packaging with air or a gas mixture atmosphere during storage times at 5°C	84

Chapter I

Introduction

The storage life of peeled or cut raw potatoes is limited by the onset of enzymatic browning at cut surfaces. The discoloration of peeled potato results from the polyphenol oxidase-catalyzed oxidation of phenolic compounds to quinones and their subsequent condensation to dark-colored pigment (Matheis, 1986). Sulfite-containing additives have been used as anti-browning agents to keep potato fresh looking (Smith, 1987). However, because sulfites were linked to 13 deaths and many illnesses, mainly among asthmatics, the Food and Drug Administration prohibited the use of sulfite preservatives in fresh vegetables and fruits (FDA, 1986). A regulation excluding sulfites to control enzymatic browning in fresh potatoes was also promulgated by US Food and Drug Administration (Anon., 1990). The elimination of sulfites seriously affected processors attempts to maintain potato quality. Commercially viable sulfite alternatives are required which preserve color, texture, flavor and microbial safety of peeled potatoes during refrigerated storage.

Various sulfite substitutes have been marketed and generally contain combinations of ascorbic acid with citric acid, calcium salt or sodium acid pyrophosphate, and cysteine (Duxbury, 1987; 1988). These alternatives, however, are less effective than sulfites and do not meet the desired shelf-life (14 days) of industry requirements for peeled, cut potatoes without vacuum packaging or cover solution (Langdon, 1987; Santerre et al., 1991).

An atmosphere enriched with CO₂ is generally assumed to reduce respiration of harvested vegetables (Kader, 1986; 1987). A modified atmosphere package, used in combined with dipping of peeled potatoes strips in a 10% ascorbic acid solution, can extend fresh peeled potato shelf life to 6 days at 5°C (O' Beirne and Ballantyne, 1987). However, potato processors indicated a need for 10-14 days of refrigerated shelf life of peeled potatoes, without sulfating agents. Vacuum packaging alone or combined with dipping in 5% ascorbic acid could extend storage life of peeled potatoes at refrigerated temperatures up to 14 days (Anderson and Zapsalis, 1975; Kiejbets, 1981). Anaerobic conditions prevailing in vacuum packaging, however, could result in off-flavor development in prepeeled cut raw potatoes. Anaerobic conditions also may facilitate growth and toxin production by Clostridium botulinum at an abuse temperature above 5°C (Haim et al., 1994; Solomon et al., 1994).

Osmotic dehydration can protect against enzymatic browning. Islam and Flink (1982) found peeled potatoes osmotically treated in 40 % sucrose before dehydration had a more attractive color than the non-osmosed, dried product. The sugar uptake can avoid or limit the use of SO₂ (Maltini et al., 1991) and increase the stability of pigments during osmotic processing and subsequent storage period (Kim, 1990). Although the color of the osmosed, dried product was more attractive, the texture of dry products was very different from the fresh products.

A treatment to prevent color change in peeled potatoes for more than 14 d is needed that does not use sulfites, vacuum packaging or holding the potatoes in a solution. This may be possible by using modified atmospheres and osmotic treatments. The

objectives of this study were (1) to investigate the relative effect of air and modified atmosphere packaging in conjunction with osmotic concentrations of potatoes in corn syrup at different concentrations and osmotic times for controlling enzymatic browning in peeled potatoes, and (2) to evaluate the effects on weight loss, texture, and respiration in different treated peeled potato cubes during storage at 5°C.

Chapter II

Review of Literature

Potatoes

Potato growth

The potato (*Solanum tuberosum L.*) belongs to the family Solanaceae which includes over 2000 species (Hooker, 1986). It was introduced to Europe from South America at the end of the sixteenth century and spread from Europe throughout the world within a few centuries. Today the potato, with an annual production of nearly 300 million metric tons, is grown in a wide variety of soils and climatic conditions and is produced in 130 of the world's 167 independent countries (Rastovski et al., 1987).

Potato is one of the major food crops in the world. The amount of potatoes consumed fresh or processed has reached tens of millions of tons in the world (Lisinska and Leszczynski, 1989). Potatoes used for fresh consumption should exhibit the following characteristics: (1) no defects such as bruises and injuries that lower the quality; (2) desirable organoleptic features such as flavor, aroma, consistency and color after cooking; (3) suitability for long term storage; (4) low susceptibility to darkening of the products either in the fresh product or after cooking.

Nutritional values of potato

The potato is an excellent source of energy, high quality protein and dietary fiber and contains significant amounts of phosphorus, potassium, calcium, and vitamins especially vitamin C (Lisinska and Leszczynski, 1989). On the average, it contains 78.96% water, 17.98% carbohydrate, 2.07% protein, 0.1% total lipids and 0.89% ash, and it provides a total of 79 kcal energy per 100 g (USDA, 1990). The biological value of potato protein is rather high with an index of 72 as compared to a complete protein with an index of 100 (Schupan and Postel, 1959). The quality of potato protein is rated higher than soybean protein. In comparison with wheat, potato protein contains more of the essential amino acids except histidine and the amount of lysine is similar to that in a typical animal protein. It has been estimated that potato supplies approximately 6% of the total energy of human diet, 5% of the protein, 0.5% of the fat, 9.6% of the iron, 7.8 % of the riboflavin, and about 34% of the ascorbic acid (Salunkhe et al., 1991).

Potatoes are also a good source of several water soluble vitamins. They are particularly effective in providing human with daily requirements of vitamin C. According to Mondy and Munshi (1988), fresh potatoes may contain 30 mg or more vitamin C per 100g when newly harvested, although values decline when potatoes are stored, cooked or processed. The potato is a plant that is perhaps the largest producer of carbohydrates, proteins, thiamin, ascorbic acid, and minerals on per acre dry-weight basis than any other cultivated crop (Salunkhe et al., 1991).

Quality changes of potato during storage

Cold temperature

Potatoes are generally processed before consumption. Processing potatoes to extend the shelf life during storage are frequently needed to prevent seasonal surpluses and to increase the availability of potatoes to consumers throughout the year. In developing countries, losses greater than 50% result from spoilage, contamination, and attack by microorganisms and insects during storage due to not being stored properly.

Several changes occur in nutritional composition of potatoes during storage and processing. Mazza (1983) presented the following processes taking place in the stored potatoes: (1) respiration, which utilizes sugar by converting them to carbon dioxide, water, and energy; (2) conversion of starch to sugar by amylolytic enzymes; and (3) conversion of sugar to starch, presumably by starch synthesizing enzymes. Storage at low temperature can increase shelf life of potato tubers by reducing the rate of respiration but promotes transformation of starch to sugar (Sherman, and Ewing, 1983). A large increase in sugars, primarily reducing sugar, occurs in potatoes stored at 1.1 to 2.2°C. Potatoes stored at 4°C can have five times more sugar than those stored at 10°C. This amount can be twenty fold higher if the tubers are kept at 1°C. The high levels of reducing sugar will cause undesirable darkening in processed potato products. Samotus and Schwimmer (1963) reported that when potatoes are stored in nitrogen at 0°C, sugar accumulation is completely suppressed. Parkin and Schwobe (1990) found that a low oxygen atmosphere appeared to reduce sucrose accumulation and the rate of sucrose conversion to hexose during storage. Rastoveki and coworkers (1987) concluded that the mechanism of starch

decomposition does not depend on oxygen supply whereas the occurrence of sugar accumulation requires the presence of oxygen.

Postharvest respiration

Fresh potatoes are living organisms and still respire after harvest. Therefore, in handling and storing fresh potato, respiration must be considered. During respiration, the sugars of tubers are converted into water and carbon dioxide by absorption of oxygen from the environment, heat energy thereby being evolved. Respiration rate is mostly expressed in terms of the rate at which carbon dioxide is released or the rate of heat generation. The respiration intensity of tubers depends mainly on the variety, maturity, and temperature and time of storage. The lowest intensity of potato respiration was observed at temperatures from 3 to 5 °C.

The process of respiration results in weight losses of the potato tubers due to decreased content of the dry matter mainly starch. Decreased starch content diminishes the nutritional and physical quality of tubers.

Minimally processed vegetables such as prepeeled diced potatoes are products that have characteristics similar to those of fresh products but are more convenient to use (Bolin et al., 1979; Kim et al., 1993). In most cases the minimally processed product is in its raw state and the tissue is still alive. A major disadvantage of prepeeled potatoes is that they are highly perishable. Handling and storage of these products are even more complex than the fresh products. Respiration studies, under various packaging or storage

conditions, can assist in predicting the shelf life of these vegetables (Pal and Buescher, 1993).

Potato processing

History of potato processing

Potato processing was started after World War I in the United States, but the growth of industrial processing was limited by the peeling and frying equipment (Talbert, 1967). Since 1960, potato production and consumption of potato products have been significantly increased in developed and developing countries. Research and development have produced from potato tubers more convenient and high quality processed products, such as potato chips, French fried potatoes, diced potatoes, potato starch, prepeeled potatoes, and many more products (Salunkhe et al., 1991).

According to data collecting from FDA, 31% of potatoes are sold fresh, 27% are processed and frozen, 12% are prepared into chips, 8% are dehydrated and 3% are peeled and refrigerated whole in the USA (Anon., 1990). The biochemical composition of the potato tuber, including the total solids and carbohydrate content (reducing and nonreducing sugars), and the physical properties including the textural characteristics of the potato tuber and color changes, constitute the important quality parameters for processing potatoes (Salunkhe et al., 1991).

Prepeeled potato

Potato peeling is one of the important traditional processes commonly employed before direct consumption of boiled potatoes or processing of peeled potatoes into various products. In developing countries, the production of prepeeled potatoes has increased during the last decade (Salunkhe et al., 1991). Prepeeled potatoes are supplied to restaurants, cafeterias, and retail establishments, but they are extremely perishable and have a relatively short shelf life. One of the important problems associated with the prepeeled potatoes is browning or darkening (Smith and Davis, 1968)

Ways to extend shelf life of peeled potatoes

Modified atmosphere packaging

1. Mechanism of its action

Modified atmosphere packaging (MAP) is a preservation method which controls spoilage by replacing the air inside a package with other gases. The replacement gases usually consist of higher concentrations of carbon dioxide or nitrogen. Controlled atmosphere and or modified atmosphere packaging generally results in reduced respiration rates for plant products by maintaining O₂ and CO₂ levels within levels tolerated by the commodity (Berrang et al., 1990). Controlled atmosphere storage of vegetables has resulted in greater ascorbic acid retention and shelf life extension in contrast to air stored vegetables (Barth et al., 1993; Kader, 1987; Kader et al., 1989). Moleyar and Narasimham (1994) reviewed the use of modified atmosphere packaging to extend the shelf life of fresh vegetables. They concluded that modified atmosphere packaging can reduce water loss,

respiration, metabolism, and microbial spoilage. The main advantage of using a MAP system is an extended product quality and shelf life and therefore reduced economic loss. The disadvantages is the processing cost is increased (Berrang et al., 1990).

2. Modified atmosphere packaging of potatoes

Modified atmosphere packaging in conjunction with low temperature storage has been recognized as a promising and inexpensive way to improve shelf life of fresh vegetables (McLachlan and Stark, 1985; Priepke et al., 1976). The controlled or modified atmosphere also can lessen sugar accumulation of potatoes during lower temperature storage. The optimal O₂ and CO₂ concentrations to achieve these effects are dependent on the individual product and its storage temperature (Isenberg, 1979; Smock, 1979). Burton (1978) concluded that increased CO₂ was a possible means of preventing the undesirable accumulation of reducing sugars in potatoes held at moderately low temperatures. In a sealed package containing vegetables, a modified atmosphere is produced as a result of their respiration. When the establishment of the equilibrium-modified atmosphere by respiration is too slow to prevent discoloration or retard physiological changes, flushing the package with a pre-selected gas mixture containing low O₂ and elevated CO₂ concentration in conjunction with low temperature can prolong and extend shelf life of fresh fruits and vegetables. Parkin and Schwobe (1990) found that an atmosphere containing 2.5-3.0 % oxygen reduced the accumulation of sugars and rate of sucrose conversion to hexoses in potato tubers during refrigerated storage (4°C).

O' Beirne and Ballantyne (1987) found that the modified atmosphere package used in combination with dipping potato strips in a 10% ascorbic acid solution, can inhibit enzymatic discoloration for 6 days at 5°C. Vacuum packaging with dipping in ascorbic acid can extend storage life of peeled, whole and chipped potatoes at cold temperature about 10-14 days (Anderson and Zapsalis, 1957), but the anaerobic conditions prevailing in vacuum packages may result in off-flavor development in some products including pre-peeled potatoes (Kiejbets, 1981; McLachlan and Stark, 1985). The anaerobic condition also would facilitate growth and toxin production by *Clostridium Botulism* at storage temperatures > 5°C (Haim et al., 1994; Solomon et al., 1994; Tamminga et al., 1978).

To control enzymatic browning

1. Mechanism of enzymatic browning

Enzymatic browning occurs when fresh potatoes are cut or peeled, due to the oxidation of phenolic compounds by enzyme phenolase. There are two major phenolic substrates found in potatoes, namely, chlorogenic acid and the amino acid, tyrosine. The former is readily oxidized in the presence of the enzyme, but its products are not deeply colored. The oxidation products of tyrosine are dark brown in color, with subsequent formation of melanin pigments. This reaction results in the change of fresh color through red to brown. The process is known as enzymatic darkening or enzymatic discoloration of raw potatoes.

The natural phenolic substrates in fresh potatoes are separated from phenolase and enzymatic browning does not occur. Once the potato is peeled and exposed to air, the

enzyme tyrosinase catalyzes the conversion of tyrosine into quinones, resulting in the development of brown pigment.

2. The ways to control enzymatic browning

For enzymatic browning to occur, four essential components must be present: oxygen, enzyme, copper, and substrate. To prevent or delay enzymatic browning, one or more of the four components required for the reaction must be controlled. The treatment regimens can be divided as follow: (1) antioxidants including sulfite-containing additives, ascorbic acid, erythorbic acid (Rodrigues and Zaritzky, 1986), ascorbic acid 2-phosphate (Saper et al., 1989a; 1989b), and L-cysteine; (2) enzyme inhibition or inactivation by blanching, irradiation, or metal chelating with citric acid (Santerre et al., 1991); (3) inhibition of enzymes with sodium chloride, pH adjustment ($< \text{pH } 5$), or temperature control; or (4) oxygen removal-by immersion of product in water, syrup, or brine solution (Karst et al., 1990) or vacuum packaging in oxygen barrier containers (Giannuzzi et al., 1988; Langdon, 1987).

The use of chelating agents will only slow the browning reaction and will not completely eliminate its occurrence. The most effective method is to inactivate the enzymes by heat treatment such as steam blanching and to immerse potato in sulfite-containing additives. However, in the fresh potatoes, heat treatment causes thermal damage, leaching of nutrients and possible environmental pollution. Sulfites are a highly effective browning inhibitor, however, because of adverse health effects on some

asthmatics, use of sulfite on fresh products such as peeled potato has been banned by USDA (Anon., 1990).

Compounds that have been marked to replace sulfites, generally include ascorbic acid as an antioxidant. Adjuncts such as citric acid, calcium salts, sodium acid pyrophosphate, or cysteine, have been added as metal chelators (Duxbury, 1987; 1988; Molnar-Perl and Friedman, 1990). However, these products are less effective than sulfites, and treated products may require vacuum packaging (Langdon, 1987; O'Beirne and Ballantyne, 1987) or packing in a solution containing preservatives (Santerre et al., 1991) to achieve the desired storage life of 14 days (Saper and Miller, 1992).

Osmotic concentration

1. Mechanism and its application

Osmotic concentration is a water removal process which is based on placing cellular materials (such as fruit or vegetable) into aqueous solutions of sucrose, glucose, fructose, sodium chloride or other osmotic agents to reduce water activity, so that microbial growth will be inhibited (Bolin et al., 1983). The difference in the osmotic pressure between the solution and the intracellular fluid drives water out of the food tissue because the cell membranes are semi-permeable and allow water to pass through them easily. As moisture is removed, soluble solids in solution may penetrate the material and some soluble solids present in the material also may leach out (Biswal et al., 1991; Ponting et al., 1966).

Osmotic concentration is another method of food processing to maintain a high quality of food. (Pointing et al., 1966). The osmosed product may be further dried, pasteurized, or frozen (Islam and Flink, 1982). In addition to reducing the energy requirements at the further processing steps, the advantages of direct osmosis are minimized heat damage, less discoloration of fruit by enzymatic browning, increased retention of volatiles, and improved textural quality. Osmotic concentration also decreases the respiration rates of fruits under atmospheric air. It has been successfully used as a pre-drying treatment on several plant and fruit materials such as apples, bananas, and potatoes. (Karel et al., 1975; Le Maguer, 1988; Yang and Atallah, 1985). A review of the osmotic concentration processes is given by Torreggiani (1993).

2. The osmotic agent

The osmotic solution used must have a low A_w , and moreover, the solute must be harmless and have a good taste. Sodium chloride and sucrose are the major osmotic agents. Sodium chloride can more easily diffuse through the cell membrane, resulting in higher solids gained and a salty taste. Sucrose is effective in preventing fruit discoloration by enzymatic oxidative browning, thus precluding the use of sulfur dioxide but it produces a sweet taste and added cost (Hawkes and Flink, 1978; Nanjundaswamy et al., 1978).

Corn syrup is another osmotic agent that has been used instead of sucrose. Corn syrup has pH values in the range of 4.0-5.5. It is identified based on the dextrose equivalent (DE). A 26 DE corn syrup contains 5% dextrose, 8% maltose, 11% maltotriose, and 76% high saccharides (dry matter basis on DMB); and a 43 DE contains

higher mono and disaccharide including 19% dextrose, 14% maltose, 13% maltotriose, and 54% higher saccharides (DMB) (Anon., 1992). The color of corn syrups depend on time and temperature of storage, DE value, and pH.

There is some information available on osmotic concentration of fruits and vegetables by using corn syrup as the osmotic agent prior dehydration (Contreras and Smyrl, 1981; Bolin et al., 1983;). They found that solids uptake from the corn syrup solids was much less than for sucrose, since the corn syrup solids contain a large proportion of high molecular weight carbohydrates. The solids uptake by apple rings after osmotic dehydration in 26 DE corn syrup solution was much less than in sucrose solution. After 4 hours of contact with 43% (w/w) corn syrup solution at 55°C, the weight of apple rings was reduced by 70%. For a given temperature / concentration combination, the moisture loss from potatoes in 43 DE corn syrup solution was greater than 26 DE corn syrup solution (Biswal and Bozorgmehr, 1992), because high DE corn syrup contains a higher amount of monosaccharides which results in higher osmotic pressure in the solution. Temperature of the osmotic solution is another important factor. The water loss is increased by increasing the temperature of process because molecule movement is increased by increasing process temperature.

3. Osmotic concentration of potato

Studies on osmotic concentration of potatoes have been reported by Garcia and Mcfeeley (1978), Islam and Flink (1982) and Biswal and Bozorgmehr (1991). They found

the feasibility of osmotic concentration of potato using aqueous solutions of sucrose, salt, or sucrose-salt binary mixtures. Potatoes concentrated in mixed sucrose-salt solution (45% sucrose/15% salt) had lower water activity than in pure sucrose solution. The osmosed potatoes appeared microbiologically stable and protected against enzymatic browning. Lenart and Flink (1984a; 1984b) also studied spatial distribution of the osmosis effect during osmotic concentration of potato. The spatial distribution of solids and moisture was dependent upon solute type, solution concentration, osmosis time, osmosis temperature, and solution agitation. The loss of ascorbic acid during osmotic concentration is less than during commercial air dehydration. No work has been reported on the study of osmotic concentration of peeled potato by using corn syrup solutions instead of the blanching process to prevent enzymatic browning.

Chapter III

Materials and methods

Potatoes and osmotic agents

Large Russet skinned Irish potato tubers (>50 mm diameter) were obtained from a local market. Stock 42 DE corn syrup was obtained from A.E. Staley, Decatur, IL.

Osmotic solution preparation

The 42 DE corn syrup was diluted to 20% and 10% total solids (w/w) with a 1% ascorbic acid and 1% citric acid potable water solution. The concentration of osmotic solution was determined using an Abbe refractometer (Model Cm5501, Bausch and Lomb Optical Co., Rochester, N Y).

Osmotic concentration of potato

The potatoes were peeled and cut into desired size cubes (1 x 1 x 1 in.) by using a Model 64142 Hobart Vegetable Mechanical Slicer (The Hobart Manufacturing Company, Troy, OHIO), and held under deionized water until the entire batch was prepared. Just prior to starting the osmotic concentration step, the potatoes were removed from the water and their surfaces gently blotted with absorbent paper. The potato cubes were weighed and covered with one of the two osmotic solutions (10% and 20% corn syrup) or the control solution [1% (w/w) ascorbic acid and 1% (w/w) citric acid] for 0.5, 1.0, and

1.5 h. The potato cubes were added to the initial osmotic solutions in a 1:5 ratio (potatoes : solution). Each osmotic solution surrounding the potato cubes was constantly agitated by a magnetic stirrer. The solutions were held in a 20°C water bath.

Modified atmosphere packaging

After osmotic concentration, the potato cubes were rinsed for 3 minutes, and then gently blotted with an absorbent paper to remove surface moisture. Approximately 50 g were weighed and packaged in a barrier film bag [B-620 film, oxygen transmission rate cc @ 73°F. (m², 24 hr., 1 atm.)/30-50, Cryovac, Duncan, SC]. Air or a gas mixture (CO₂: O₂: N₂ 10: 5: 85) was injected at a 50 % setting into a single package by a KOCH Model X-200 Vacuum Packaging Machine (KOCH Supplies Inc., Kansas City, MO). The samples then were stored at 5°C.

Three complete replications were completed for each condition (3 osmotic treatments x 3 osmosis times x 2 gas atmosphere packages x 5 storage times). A flow diagram for this study is shown in Figure 1.

Measurement of moisture and total solid content

Samples were analyzed prior to and at the end of each osmotic process (0.5 h, 1.0 h, and 1.5 h). Moisture content was determined by using the AOAC vacuum oven method 14.003 (AOAC, 1990). Samples of approximately 2g of potato were weighed and dried in a vacuum oven Model 5851-9 Industrial and Laboratory Heater (Heinicke

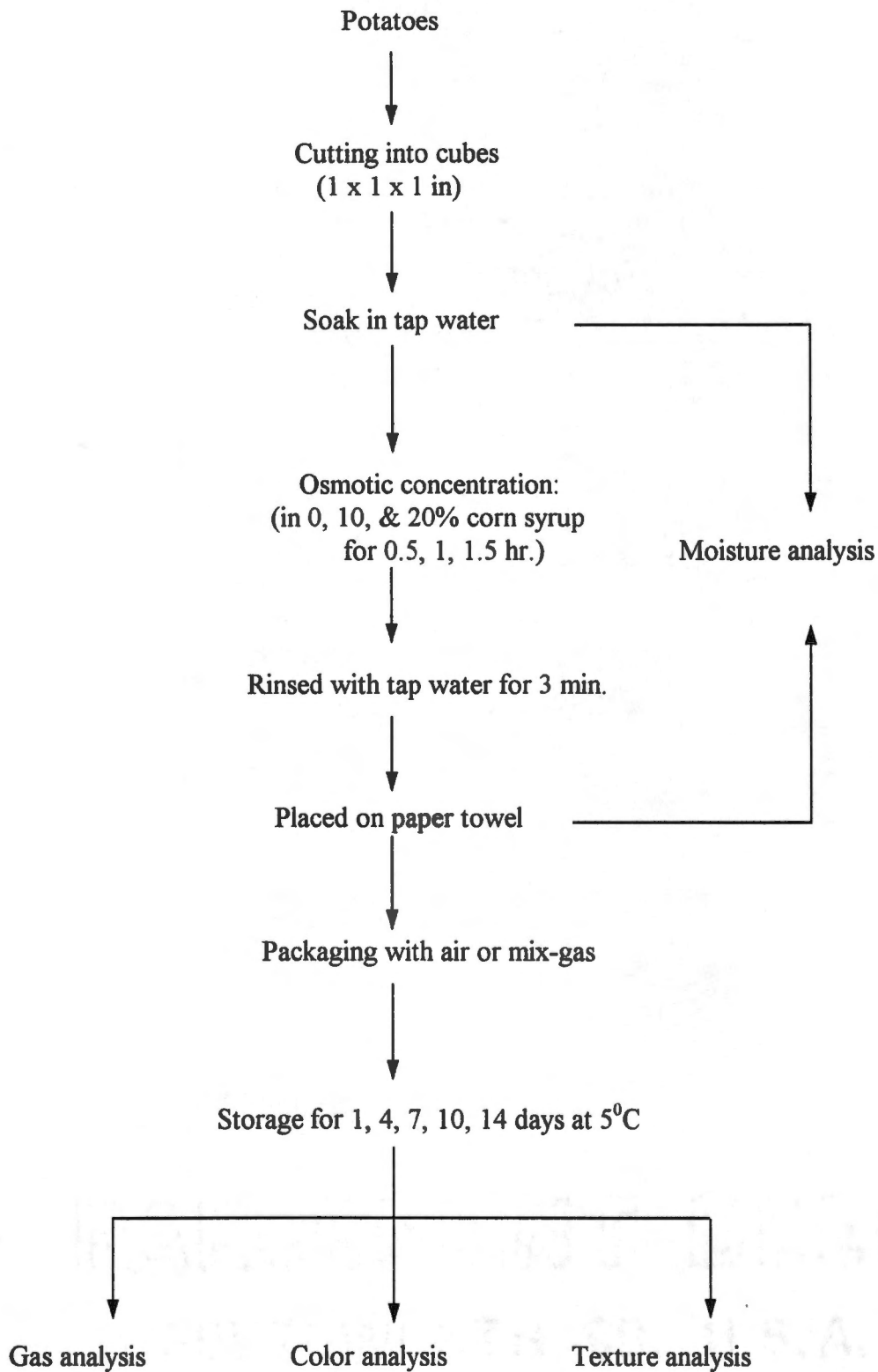


Figure 1. A flow diagram for experimental procedure.

Company, Portland, Oregon), at 70°C, 175 mm Hg for 24h. The following variables were determined for each sample: % water content, water loss (WL), and % total solid (TS).

Gas analysis

Oxygen and carbon dioxide levels in packages with air and CO₂:O₂:N₂ (10: 5: 85) at the end of each storage interval (1, 4, 7, 10, and 14 days) were measured by gas chromatography to calculate the respiration rate of the potato cubes. A 5 mL sample of the headspace gas was withdrawn from each treatment bag by using a 5 mL syringe. Immediately after withdrawal, the needle of the syringe was stuck into a rubber stopper to prevent loss of headspace gases. The percentage oxygen and carbon dioxide were analyzed on a stainless steel CTRI column (Alltech Associates, Inc., Deerfield, IL) attached to a Hewlett Packard Model 5890A Series II Gas Chromatography equipped with a thermal conductivity detector (TCD) at a oven temperature of 25°C. The analyses were done at a helium gas flow rate of 40 mL/min. at column temperature of 25°C and a TCD temperature of 30°C. The percentages of oxygen, carbon dioxide, and nitrogen were determined from a standard curve obtained using Scotty I analyzed calibration gases (Supelco, Inc., Bellefonte, PA) at the end of different storage periods (1, 4, 7, 10, and 14 day).

Color analysis

Color of potato cubes from each treatment at the end of each storage interval

(1, 4, 7, 10, and 14 day) was determined using a Hunter color difference meter (Model D25D2-M, Hunterlab, Reston VA) which was standardized with a white tile No. C2-21125 ($L = 91.03$, $a_L = -1.3$, $b_L = 1.6$). A sample was held in a cuvette on the specimen port to determine the Hunter L , a_L , and b_L values.

An index of treatment effectiveness, the percent inhibition used to compare treatment, was calculated from the ΔL values for treated samples and corresponding controls using the following equation (Saper and Douglas, 1987):

$$\% \text{ inhibition at time } t = (\Delta L_{\text{control}} - \Delta L_{\text{treatment}}) / \Delta L_{\text{control}} * 100$$

Where $\Delta L = L_t - L_{\text{initial}}$. A percent inhibition value of 50-60% is considered to be the limit of acceptability for raw potato.

From Hunter values of L , a_L , and b_L , the color difference ΔE of the potatoes, which is the total color difference between fresh potatoes and treated ones, after 1, 4, 7, 10, and 14 days of storage, is calculated by the following equation:

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$$

An ΔE value of 3 or less is considered to be a nonperceptible color difference (Hunter, 1975).

Texture analysis

Samples were analyzed at the end of each storage interval (1, 4, 7, 10, and 14 day). Texture of each treatment potato was measured with the TA.XT2 Texture Analyzer (Texture Technologies Corp. NY) using a test probe with a diameter of 0.5 cm I.D. Force vs. time of penetration of the probe into each sample was measured with pre-test speed 2.0 mm/s, test speed 3.6 mm/s, post-test speed 5.0 mm/s, trigger force was auto at 5 g, and distance of penetration was 20 mm.

Statistical analysis

This experiment was designed as a complete randomized block (3 concentrations of corn syrup x 3 osmotic times x 2 types MAP x 5 times storage day x 3 replications). The dependent variable, potato moisture content (wb) was analyzed as a function of osmotic treatment (fresh potatoes and concentration of corn syrup), osmotic time, and replication by the General Linear Model (GLM) of Statistical Analysis System (SAS) (1990). A probability level of $p < 0.05$ was considered significant. Significant different among means were examined by the Student-Newman-Keuls (SNK) test of SAS at 95 % confidence level (SAS, 1985)

The dependent variables, percentages of CO₂ and O₂ in headspace gases, Hunter color scale (L, a_L, b_L, and ΔE value), and firmness (g) of potatoes were analyzed as function of osmotic treatment, osmotic time, modified atmosphere package, storage time, and replication, and their interactions by the GLM in SAS institute, Inc. (1985). A probability level of $p < 0.05$ was considered significant. After an initial analysis, non-

significant ($p > 0.05$) interaction terms were moved into the error term. If the interaction term was significant, for example, Gas x Day or Gas x Treat, the dependent variables were separately analyzed as a function of treatment, osmosis time, storage time, and replication for each type of MAP. Significant differences among means were examined by the SNK test of SAS at 95 % confidence level (SAS, 1985).

The dependent variable, percentage of inhibition of enzymatic browning, was analyzed as a function of osmosis-gas combination treatment (5 types of Treat - Gas), osmotic time (3 types of time), storage time (4 times of Day), and replication (3 Rep) by using analysis of variance (ANOVA) of SAS (1990). The $p < 0.05$ level was used to designate significance. Significant differences among means were examined by the SNK test of SAS at 95 % confidence level (SAS, 1985).

Chapter IV

Results and discussions

Moisture content of potato cubes

The results of analysis of variance (ANOVA) of moisture content of potato cubes prior to and following the osmotic treatments are shown in Table 1. The main factors of treatments [fresh potatoes, control solution (treatment A), 10 % corn syrup (treatment B), and 20 % corn syrup (treatment C)] and osmotic times (0, 0.5, 1.0, and 1.5h) significantly affected the moisture content of potato cubes ($p < 0.05$).

The potatoes that were treated were all significantly higher in moisture content than fresh potatoes (Table 2). This increase was greatest in the potatoes that were held in the control (citric acid /ascorbic acid) treatment or the solution with 10% corn syrup added. The moisture content averaged 2.7 to 2.9% higher than in fresh potatoes. The potatoes held in 20% corn syrup were significantly lower in moisture content than the other treatments and averaged 1.7% higher moisture content than fresh potatoes. The greatest increase in moisture content occurred during the first 0.5h of soaking with subsequent significant ($p < 0.05$) decreases in moisture content after 1.0h and 1.5h of treatment (Table 2).

The moisture content changes in potato cubes after the different osmosis times for each of the 3 treatments are shown in Figure 2. Experimental data points shown on Figure 2 are the means of the three replications. The moisture contents reached the

Table 1. Analysis of variance of moisture content for fresh potatoes, control (treatment A), and osmotically coating [10% corn syrup (treatment B) or 20% corn syrup (treatment C)] potato cubes for different osmosis times.

Source	DF	Mean Square	Pr > F
Treatment	3	0.0003815	0.0001
Time	3	0.0013481	0.0001
Replication	2	0.0000633	0.0710
Error	22	0.0000212	

Table 2 Mean of moisture content for fresh potatoes, control (treatment A) and osmotically coating [10% corn syrup (treatment B) or 20% corn syrup (treatment C)] potato cubes for different osmosis times.

Factor	Moisture content (%)
<u>Treatment</u>	
Fresh	80.00 ^c
Control (A)	82.89 ^a
10% corn syrup (B)	82.67 ^a
20% corn syrup (C)	81.67 ^b
<u>Osmosis time</u>	
0.0h	80.00 ^d
0.5h	83.67 ^a
1.0h	82.33 ^b
1.5h	81.22 ^c

^{a-d} Within each factor, means with the same letter are not significantly different ($p < 0.05$) using the Student-Newman-Keuls mean separation test.

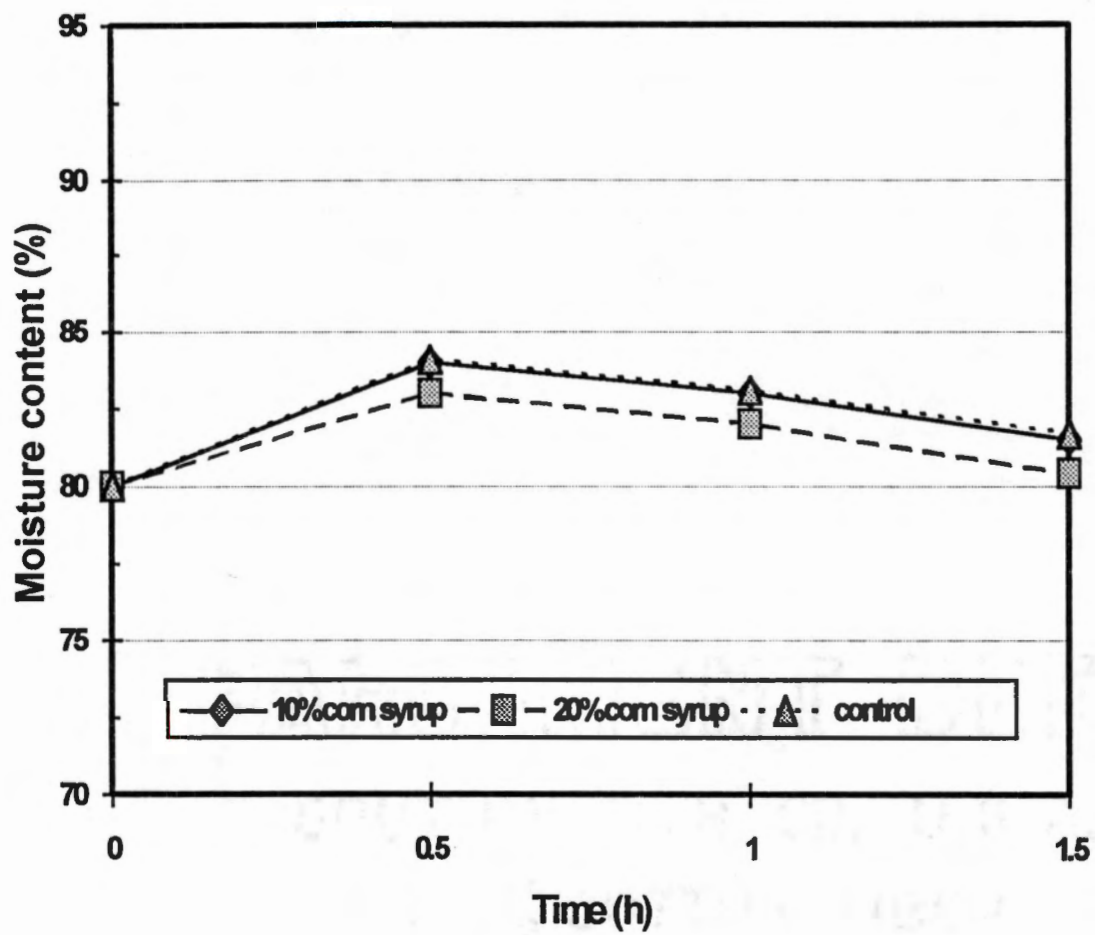


Figure 2. Moisture content of potato cubes treated with control (treatment A), 10% corn syrup (treatment B), or 20 % corn syrup (treatment C) for different osmosis times.

highest percent in each treatment at 0.5h. Also, the potatoes held in the higher concentration of corn syrup solution had less moisture content increase at all times. This behavior may be attributed to the rehydration of the cells on the surface of the potato cubes so a movement of water from the osmotic solutions would occur initially. During that time, some water soluble components such as ascorbic acid and citric acid may move into potato tissues. This would increase the ascorbic acid content and reduced the pH in potato cubes. The results were in agreement with previous findings of Hawkes and Flink (1978) and Moy et al. (1978) in the studies on osmotic concentration of fruit and vegetable slices. They found that water gain in potatoes occurred in lower osmotic solutions (0-25% sucrose) during the first one-half hour of osmosis and then the moisture content of potato decreased as osmosis process time increased.

Gas composition

The ANOVA of gas composition of the atmosphere within packages of potato cubes had a significant interaction between gas treatment and the days of storage. Therefore, ANOVA was determined for each gas treatment. The ANOVA for the gas compositions from packages flushed with either air or a gas mixture of 10% CO₂, 5% O₂ and 85% N₂ are shown in Table 3 and 4. The O₂ percentage in the both atmospheres was significantly affected by the days of storage and replications ($p < 0.05$). The % CO₂ in the both atmospheres was significantly affected by the osmotic treatments, days of storage and replications ($p < 0.05$).

Table 3. Analysis of variance of gas composition for treated potato cubes under an air atmosphere at 5°C.

Factor	Source	DF	Mean Square	Pr > F
% O ₂	Treatment	2	6.3793	0.1195
	Day	4	1051.6077	0.0001
	Time	2	0.6939	0.7908
	Replication	2	16.3866	0.0049
	Error	123	0.190942	
% CO ₂	Treatment	2	24.1645	0.0043
	Day	4	1578.9071	0.0001
	Time	2	0.9638	0.7969
	Replication	2	38.6088	0.0002
	Error	123	4.2381	

Table 4. Analysis of variance of gas composition for treated potato cubes under a gas mixture atmosphere at 5°C.

Factor	Source	DF	Mean Square	Pr > F
% O ₂	Treatment	2	0.11325	0.9717
	Day	4	62.23911	0.0001
	Time	2	0.66263	0.6036
	Replication	2	34.4944	0.0001
	Error	124	1.30706	
% CO ₂	Treatment	2	9.2382	0.0113
	Day	4	238.9791	0.0001
	Time	2	0.2904	0.8642
	Replication	2	1098.7633	0.0001
	Error	124	4.2381	

The average initial composition of gas measured in the air and the gas mixture packages containing potato cubes was 22.0 % O₂, 0.03 % CO₂ and 77.97 % N₂, and 7.0 % O₂, 11.5 % CO₂ and 81.5 % N₂, respectively. Atmospheric modifications inside the packages due to potato respiration were CO₂ accumulation and O₂ depletion over storage times at 5°C as shown in Figures 3 and 4. Experimental data points shown on Figures 3 and 4 are the means of the three replications. As shown in Figures 3 and 4, the % O₂ in the atmospheres significantly decreased and the % CO₂ significantly increased in the packages of potato cubes during storage at 5°C ($p < 0.05$). The % O₂ decreased and the % CO₂ increased more rapidly in the air atmosphere than in the modified atmosphere indicating a more rapid rate of respiration. The % O₂ did reach a constant level after 7 or 10 days, however, the % CO₂ continued to increase throughout the study indicating respiration was continuing. This would be expected since the level of O₂ and CO₂ content in the CO₂ gas mixture packages never reached the critical values (1 % O₂ and 30 % CO₂) of anaerobic respiration (Carlin et al., 1989; 1990) during the storage times (Fig. 3 and 4).

As indicated in Table 3 and 4, and shown in Figure 5, the % O₂ in the package atmospheres was not affected by the osmotic treatments ($p > 0.05$). The potato cubes treated with 20 % corn syrup solution produced significantly less CO₂ in both atmospheres than potato cubes treated in the control solution (Fig. 6). This reduction in the % CO₂ may be due to the potato cube surface being osmotically coated by the higher level of corn syrup. The increased level of corn syrup on the potato surface, as indicated by a lower moisture content in the 20% corn syrup treated potatoes, may block the

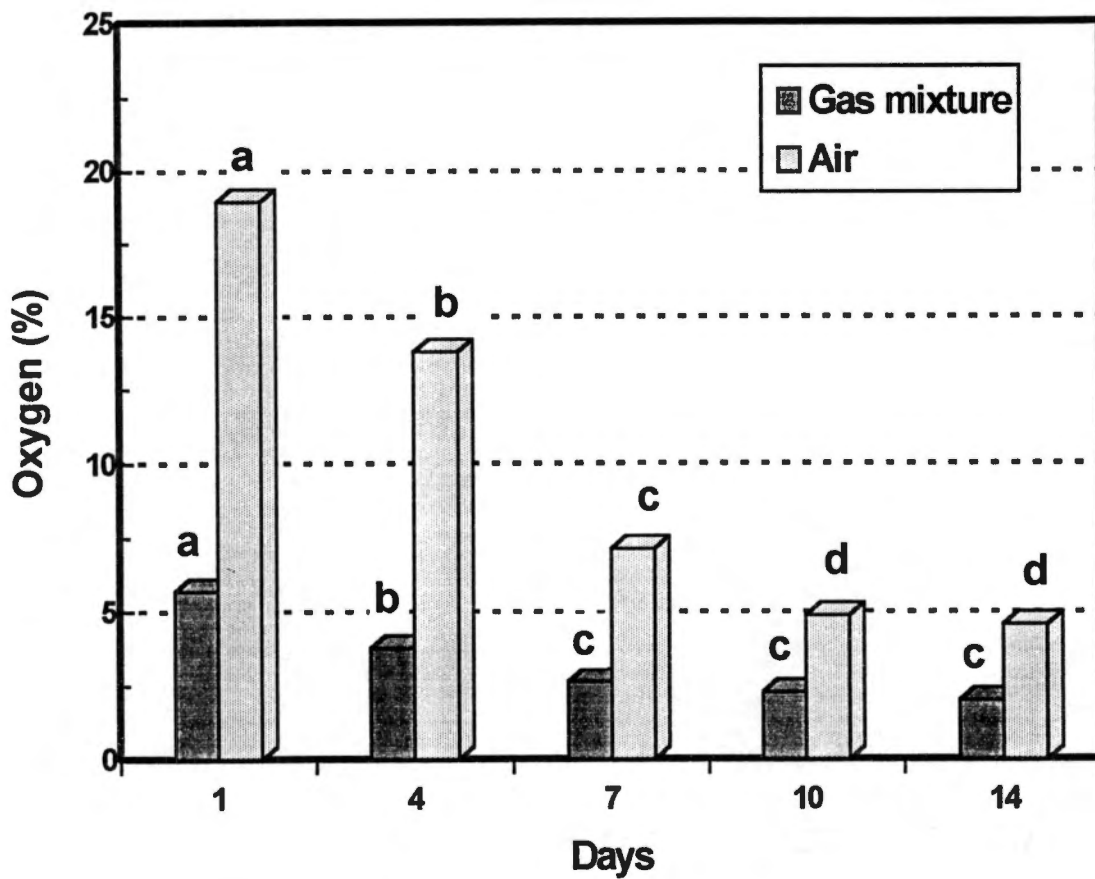


Figure 3. Changes in oxygen (%) in packages of potato cubes under an air or a gas mixture atmosphere at 5°C. Within each atmosphere packages, means with the same letter are not significantly different ($p < 0.05$) using the SNK mean separation test.

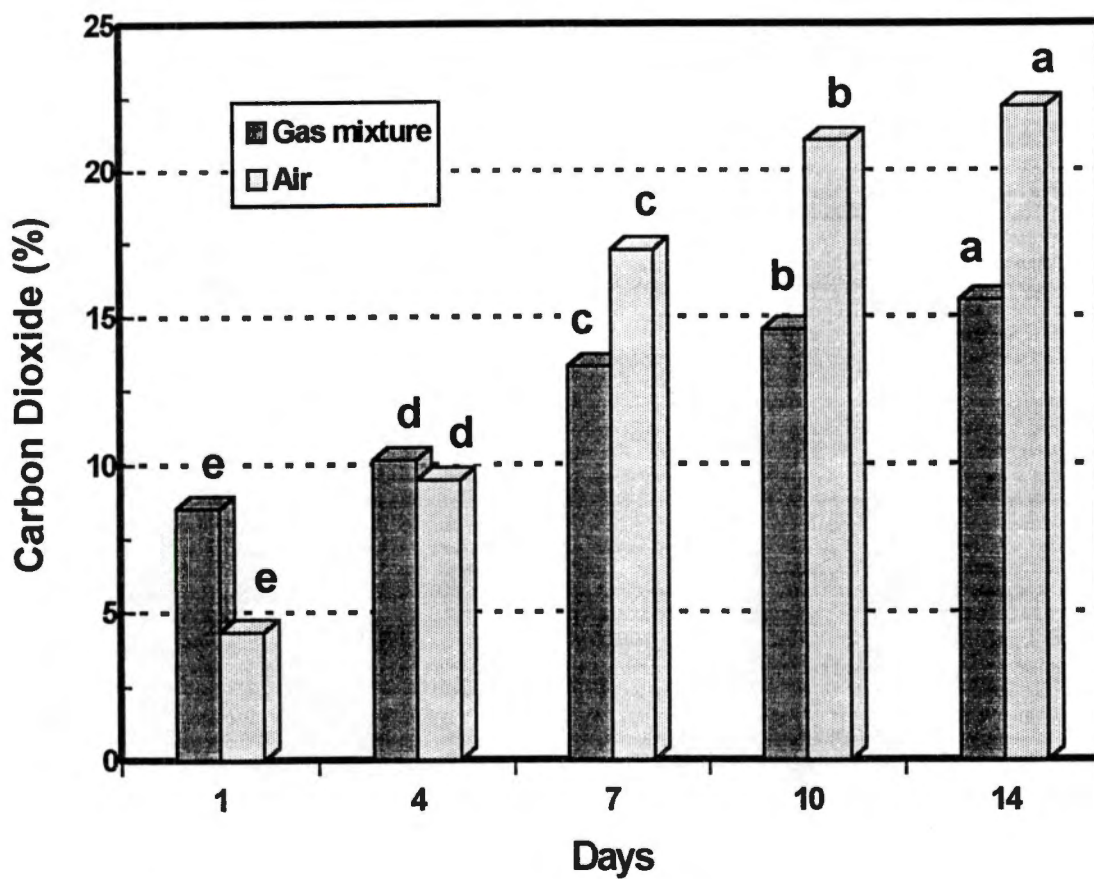


Figure 4. Changes in carbon dioxide (%) in packages of potato cubes under an air or a gas mixture atmosphere at 5°C. Within each atmosphere packages, means with the same letter are not significantly different ($p < 0.05$) using the SNK mean separation test.

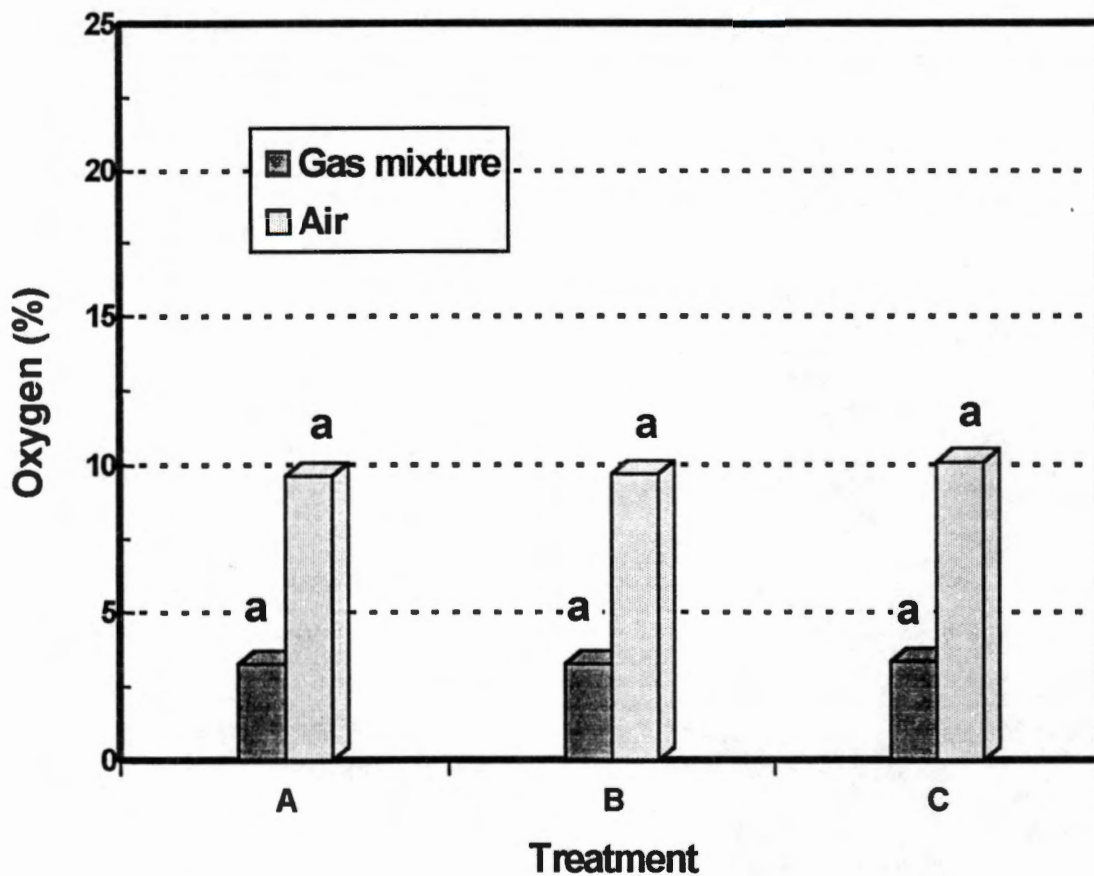


Figure 5. Average changes in oxygen (%) in packages of potato cubes ($n = 45$) either contact with control (treatment A), or 10 % corn syrup (treatment B), and 20% corn syrup (treatment C) under an air or a gas mixture atmosphere at 5°C . Within each atmosphere packages, means with the same letter are not significantly different ($p < 0.05$) using the SNK mean separation test.

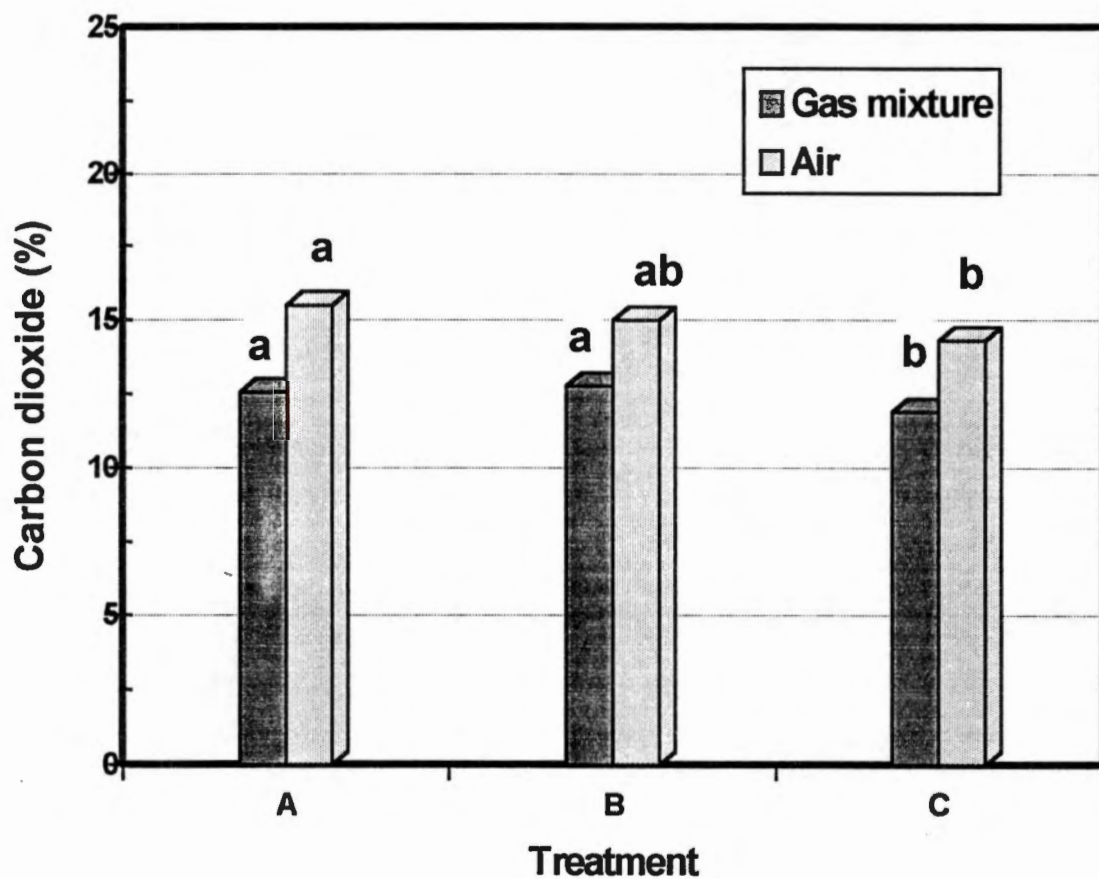


Figure 6. Average changes in carbon dioxide (%) in packages of potato cubes ($n = 45$) either contact with control (treatment A), or 10 % corn syrup (treatment B), and 20% corn syrup (treatment C) under an air or a gas mixture atmosphere at 5°C . Within each atmosphere packages, means with the same letter are not significantly different ($p < 0.05$) using the SNK mean separation test.

respiration of the cells in the potato. This result agrees with other researchers (Biswal et al., 1992). They found that higher concentration of osmotic solution resulted in lower water activity and lower respiration in the osmotically concentrated plant and fruit tissues than in the fresh counterpart.

The changes in the atmospheres within the packages of potatoes during storage at 5 °C indicated that the modified atmosphere had the greatest effect on the respiration rate of the potato cubes. The higher osmotic level of treatment also reduced the rate of CO₂ production. This reduction in the respiration rate should result in a longer shelf life for the potatoes.

The mean % O₂ and % CO₂ for potatoes from replication 1 were significantly lower ($p < 0.05$) than potatoes from replication 2 and 3 (Table A1, Appendix A). The gas composition affected by the replications may be caused by variations in potato maturity (Rastovki et al., 1987). Also, the potatoes in replication two and three seemed a poorer quality than potatoes in replication one.

Color Changes

The interaction between gas treatments and osmotic treatments in ANOVA of the color measurements was significant and therefore ANOVA were determined separately for each type of atmosphere within the packages of potatoes. The total color difference between fresh potatoes and each of the treatments for the packaged potatoes stored at 5 °C were determined as ΔE values. The ΔE values were significantly affected by osmotic treatments, days of storage and replications for potato cubes packaged and

stored in the air atmosphere ($p < 0.05$) (Table 5). The ΔE values also were significantly affected by the osmotic treatments and days of storage for potato cubes packaged and stored in the gas mixture atmosphere ($p < 0.05$) (Table 6).

As shown in Figure 7, the ΔE value significantly increased during storage. The means of the ΔE values for potato cubes stored in packages containing air, initially, increased more rapidly than for potato cubes packaged under the gas mixture initially. This was expected based on the respiration determinations since increased respiration would result in more darkening of the surface of the peeled potatoes. Potato packaged under the air atmosphere had an ΔE value greater than 3 after 4 days storage at 5 °C. An ΔE value greater than 3 is an indication of a perceptible color change (Hunter, 1975). Potatoes packaged under the gas mixture did not reach the limit value ($\Delta E \leq 3$) of a nonperceptible color difference until after 7 days and before 10 days (Figure 7). Therefore, the modification of the atmosphere to the gas mixture extended the storage life of the peeled potatoes at least 3 days at 5 °C. These results are in agreement with previous findings of Kader (1986) and Rij and Ross (1987).

The average color change during the 14 days of storage for potatoes stored in each atmosphere for each treatment are shown in Figure 8. The greatest color change occurred in the potatoes treated with only citric acid and ascorbic acid (control) within each of the storage atmospheres. The osmotic treatments reduced the average amount of color change in both storage atmospheres with 10 % corn syrup osmotic treatment being significantly lower than 20 % corn syrup osmotic treatment.

Table 5. Analysis of variance of ΔE values for treated potato cubes under an air atmosphere at 5°C.

Source	DF	Mean Square	Pr > F
Treatment	2	6.70227	0.0002
Day	4	69.43775	0.0001
Time	2	1.51558	0.1326
Replication	2	4.55091	0.0028
Error	124	0.73785	

Table 6. Analysis of variance of ΔE values for treated potato cubes under a gas mixture atmosphere at 5°C.

Source	DF	Mean Square	Pr > F
Treatment	2	22.032735	0.0001
Day	4	28.16741	0.0001
Time	2	0.84931	0.2884
Replication	2	0.78102	0.3184
Error	124	0.67624	

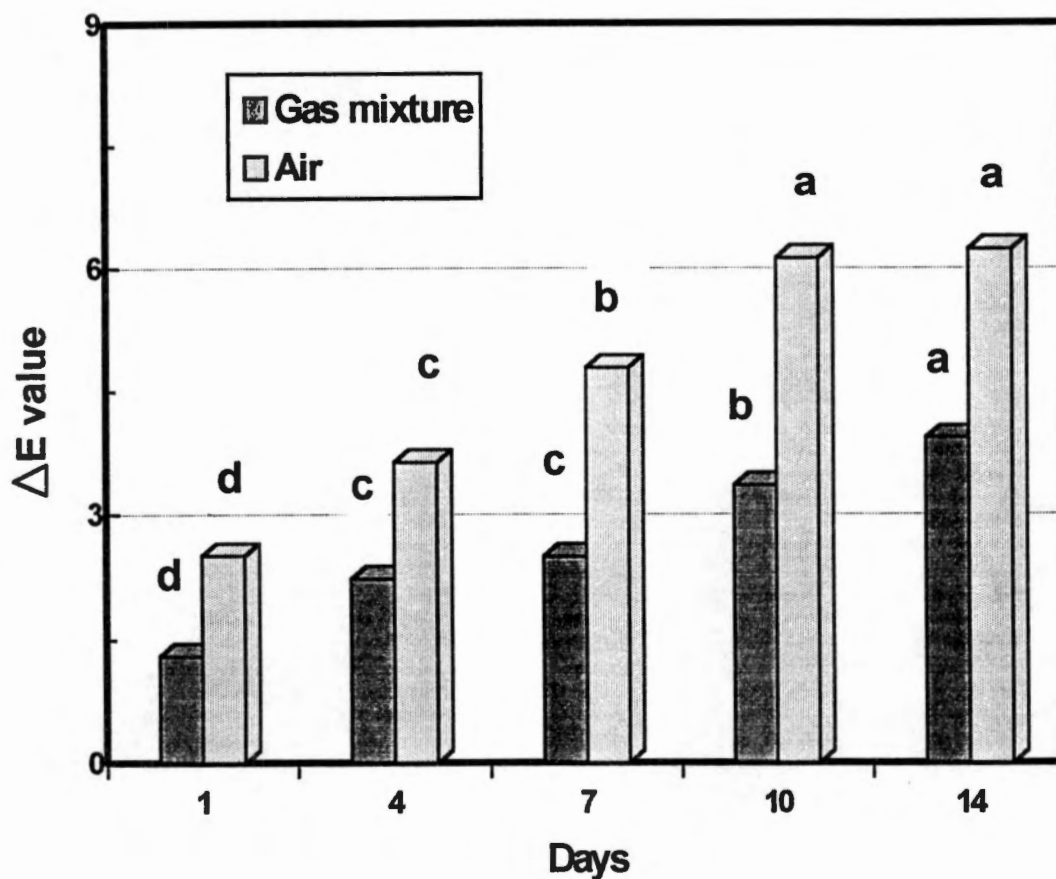


Figure 7. Changes (ΔE value) in color of treated potato cubes either packaging with an air or a gas mixture atmosphere during storage times at 5°C . Within each atmosphere packages, means with the same letter are not significantly different ($p < 0.05$) using the SNK mean separation test.

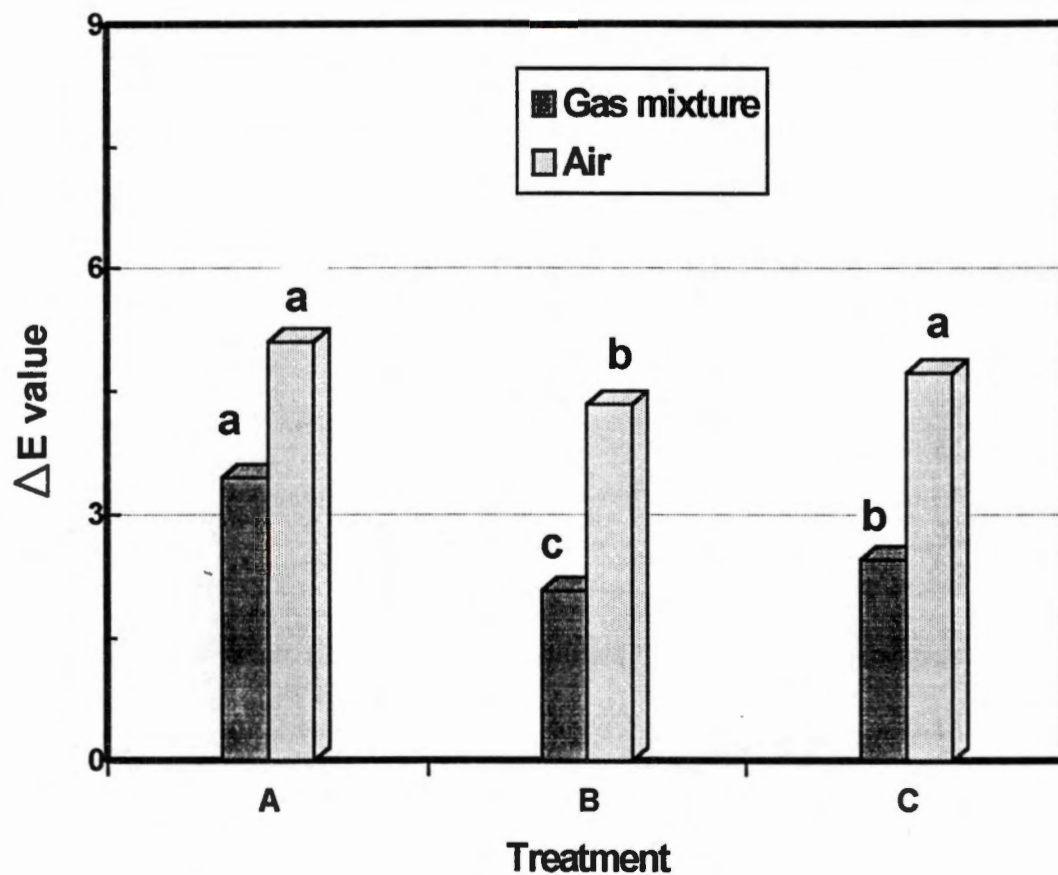


Figure 8. Average changes (ΔE value) in color ($n = 45$) of potato cubes treated by control (treatment A), 10 % corn syrup (treatment B), and 20% corn syrup (treatment C) either packaging with an air or a gas mixture atmosphere at 5°C . Within each atmosphere packages, means with the same letter are not significantly different ($p < 0.05$) using the SNK mean separation test.

Potato cubes stored in air reached a ΔE value greater than 3 before 4 d storage when treated in the control solution or 20 % corn syrup (Fig. 9). A ΔE value greater than 3 occurred before 7 d storage in all treatments. The gas mixture of increased % CO_2 and decreased % O_2 in the initial atmosphere combined with the osmotic treatment extended the storage days the peeled potatoes could be stored before an ΔE value greater than 3 was measured (Fig. 10). The control potatoes could be stored until day 7, the 20 % corn syrup osmotically treated potatoes could be stored until day 10 and the 10 % corn syrup osmotically treated potatoes could be stored more than 14 days at 5 °C. These results may be attributed to (1) the rate of ascorbic acid oxidation being reduced by higher % CO_2 and lower % O_2 in the atmosphere allowing the ascorbic acid to reduce the rate of enzymatic browning (Kim, 1990) and (2) the potato cubes osmotically treated by corn syrup having a carbohydrate polymer layer form on the surface of potato cubes and the carbohydrate polymers inhibiting browning by binding polyphenol oxidase substrates (Saper and Douglas, 1987).

The osmotic time did not have a significant effect ($p > 0.05$) on the color changes of potato cubes for all treatments under either the air or the CO_2 gas mixture atmosphere packages at 5 °C (Table 5 and 6). There was no significant change in the respiration rate for the potatoes due to the osmosis times ($p > 0.05$). The results also were in agreement with previous findings of Giangiacomo et al. (1987). The effectiveness of a browning inhibitor would depend on the residual ascorbic acid content in treated potatoes and polycarbohydrates coating on the surface of potato cubes.

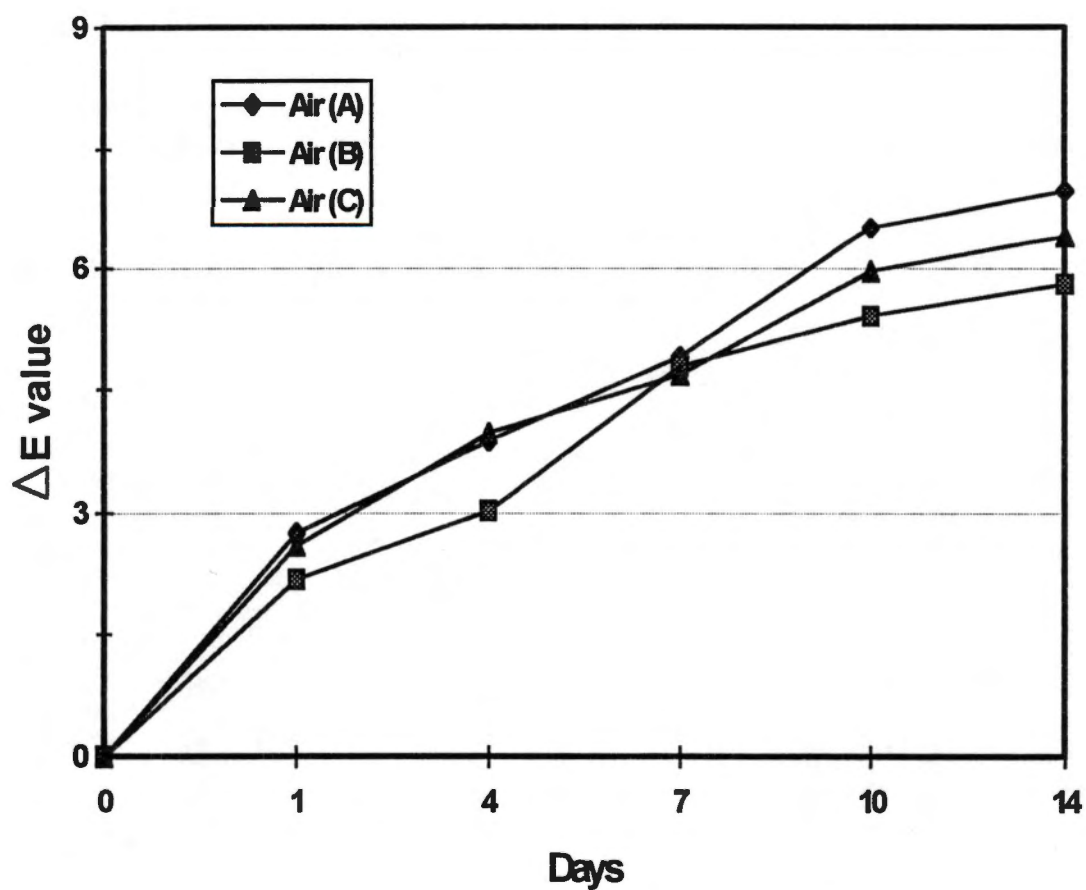


Figure 9. Changes (ΔE value) in color of potato cubes for control (treatment A) and osmotically coating [10% corn syrup (treatment B) or 20% corn syrup (treatment C)] potato cubes under an air atmosphere during storage time.

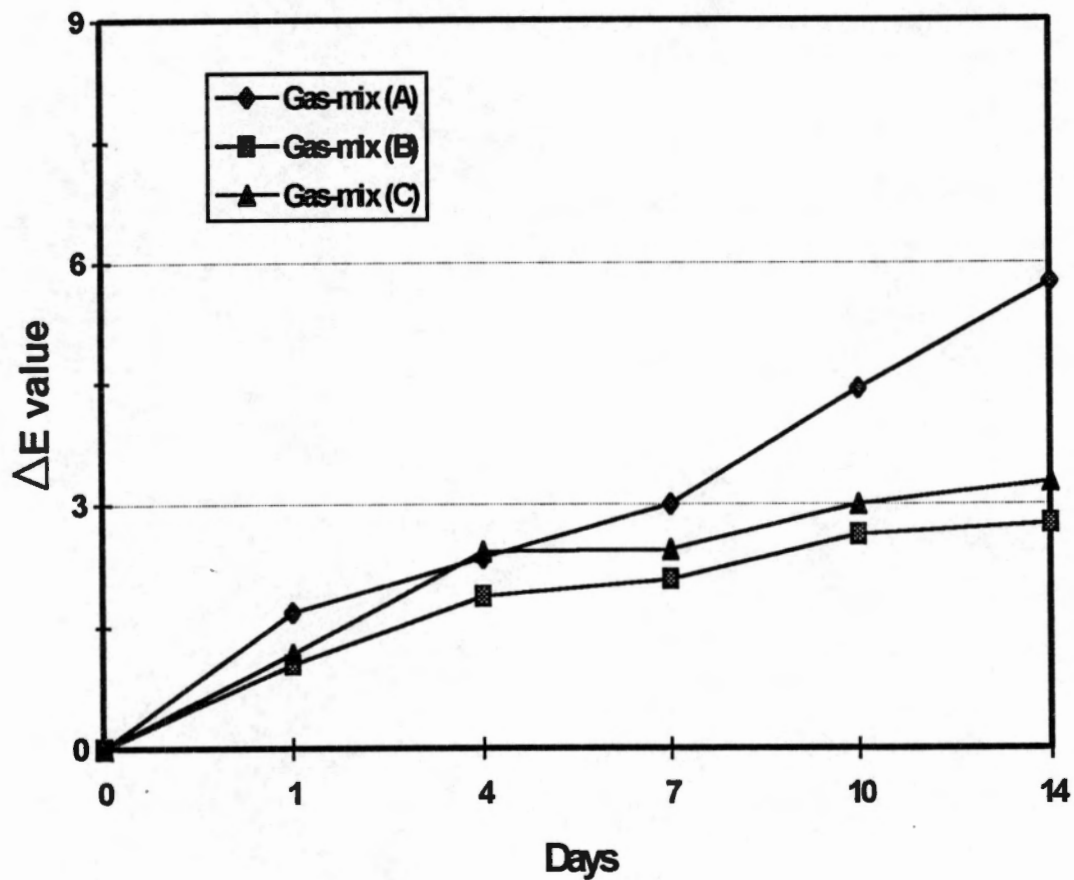


Figure 10. Changes (ΔE value) in color of potato cubes for control (treatment A) and osmotically coating [10% corn syrup (treatment B) or 20% corn syrup (treatment C)] potato cubes under a gas mixture atmosphere (Gas-mix) during storage time.

Inhibition of enzymatic browning

Results of the ANOVA of percent inhibition of enzymatic browning of peeled potatoes indicated that osmotic and atmosphere treatment combinations and time of osmotic treatments had significant effects on the percent inhibition ($p < 0.05$) (Table 7). The treatment combination that inhibited the enzymatic browning of peeled potatoes most effectively was osmotically treating the potatoes in 10% corn syrup and modifying the atmosphere in the package with the gas mixture (Table 8). This treatment combination resulted in a 59.2 % inhibition of the color change compared to the potatoes treated with only a citric acid- ascorbic acid treatment (control) and stored in packages with air as the initial atmosphere. The combination of 20 % corn syrup osmotic treatment and storage in the modified atmosphere was the next most effective combination. There was almost a 50 % inhibition of the browning of the potatoes using this treatment-gas combination. The only treatment that did not result in some inhibition of the color changes was the air and 20 % corn syrup combination that had a -0.8 % inhibition indicating the color changed almost the same for these treated potatoes compared to the control potatoes. These results indicated that modifying the atmosphere in the package of potatoes controlled the enzymatic browning but osmotically coating the surface of the potatoes with corn syrup increased the inhibition. The reason the potatoes treated in the 20% corn syrup had significantly less inhibition than those treated in 10% corn syrup may be due to movement of moisture from the center of the potato to the surface during these treatments. This moisture could carry both enzymes and substrates to the surface and result in more enzymatic activity.

Table 7. Analysis of variance of inhibition (%) of enzymatic browning for treated potato cubes during storage at 5°C.

Source	DF	Mean Square	Pr > F
Treatment-gas	4	26367.86	0.0001
Day	4	1252.55	0.0589
Time	2	9611.12	0.0001
Replication	2	1252.55	0.3859
Error	212	542.19	

Table 8. Mean of inhibition (%) for control (A) and osmotic coating treatment [10% corn syrup (B) or 20% corn syrup (C)] potato cubes during storage under an air or a gas mixture atmosphere and for different osmotic times.

Factor	Inhibition (%)
<u>Treatments (gas-osmotic solution)</u>	
Air-10% corn syrup (B)	31.54 ^c
Air-20% corn syrup (C)	-0.78 ^c
Gas mixture-Control (A)	16.28 ^d
Gas mixture-10% corn syrup (B)	59.21 ^a
Gas mixture-20% corn syrup (C)	48.93 ^b
<u>Treatment times (h)</u>	
0.5h	20.02 ^c
1.0h	30.45 ^b
1.5h	42.63 ^a

^{a-d} Within each factor, means with the same letter are not significantly different ($p < 0.05$) using the Student-Newman-Keuls mean separation test.

An increase in the time of osmotic treatments also significantly increased the inhibition of enzymatic browning at each time period (Table 8). The 1.5 h treatment was more than twice as effective in reducing the amount of color change on the surface of potatoes. The inhibition of enzymatic browning was not significantly affected over the days of storage (Table 9).

As reported by Saper et al. (1990), a percent inhibition value 50-60 % was considered to represent the limit of acceptability for inhibiting enzymatic browning on the surface of peeled potatoes. In our study, After 14 days stored at 5 °C, the treatment B (10 % corn syrup) and treatment C (20 % corn syrup) in combination with a CO₂ gas mixture resulted in 65 % and 55 % inhibition of browning, respectively. The combination system of treatment B for 1.0h. osmosis time and a CO₂ gas mixture atmosphere packages was more effective than any other combination treatment systems.

Texture changes

Texture evaluation on the firmness of the surface of the potato cubes was measured by the maximum force (g) required for a probe to puncture the potato a distance of 20 mm. Analysis of variance of the penetration data indicated that the firmness of potato cubes was significantly affected by different treatments, osmotic times and replications ($p < 0.05$) (Table 10). The atmosphere in the packages and the days of storage did not significantly affect texture ($p > 0.05$).

Table 9. Mean of inhibition (%) of enzymatic browning for control (A) and osmotic coating treatment [10% corn syrup (B) or 20% corn syrup (C)] potato cubes during storage time under an air or a gas mixture atmosphere.

<u>Inhibition (%) for enzymatic browning</u>					
Factor	B-air	C-air	A-mix	B-mix	C-mix
<u>Storage time</u>					
Day 1	35.4 ^{ab}	-11.4 ^a	28.1 ^a	53.1 ^a	48.9 ^a
Day 4	41.3 ^a	-1.5 ^a	21.0 ^a	54.7 ^a	35.7 ^a
Day 7	33.3 ^{ab}	-4.6 ^a	-4.4 ^a	58.0 ^a	48.6 ^a
Day 10	34.9 ^{ab}	15.5 ^a	27.6 ^a	65.2 ^a	56.3 ^a
Day 14	12.9 ^b	-1.9 ^a	9.0 ^a	65.0 ^a	55.2 ^a
<u>Osmosis time</u>					
0.5h	-0.4 ^c	-12.1 ^b	25.2 ^b	50.8 ^a	36.5 ^a
1.0h	16.2 ^b	-7.4 ^b	24.7 ^b	64.1 ^a	54.7 ^b
1.5h	33.0 ^a	17.2 ^a	44.7 ^a	62.7 ^a	55.6 ^b

^{a-c} Within each factor, means with the same letter are not significantly different ($p < 0.05$) using the Student-Newman-Keuls mean separation test.

Table 10. Analysis of variance of texture for control (treatment A) and osmotically coating [10% corn syrup (treatment B) or 20% corn syrup (treatment C)] potato cubes under an air or a gas mixture atmosphere

Source	DF	Mean Square	Pr > F
Treatment	2	4179458.5	0.0001
Gas	1	0.3	0.9968
Day	4	10748.9	0.6166
Time	2	551085.1	0.0001
Replication	2	144580.2	0.0002
Error	114	16155.7	

The firmness of potato cubes significantly decreased ($p < 0.05$) with increasing concentration of osmotic solution (corn syrup) (Fig. 11). The average firmness of potatoes treated in 10 % corn syrup and in 20 % corn syrup was decreased 3.5 % and 14.2 % , respectively, compared with the controls. The firmness of potato cubes also significantly decreased ($p < 0.05$) with osmotic treatment time increased (Fig. 12). The potatoes treated in 20 % corn syrup for 1.5h resulted in the softest texture in all of the treatments (2500g) (Table A17, Appendix A).

The softening of the osmotically treated potato cubes may be due to the changes that took place in the composition (such as calcium leaching) and structure of cell tissue (loss of cell turgidity) during the osmotic process. During the osmotic process, internal cellular texture of potato tissues was changed by plasmolysis, that is the protoplast of plant cell separates from the cell wall due to the efflux of water from the cell or osmotically coating formed in the extracellular space of cell. When the tissue was in equilibrium with osmotic solution, a loss of the integrity of the cell seemed to happen. The results are in agreement with other researchers (Monsalve-Gonzalez et al., 1993; Toupin, 1986). They found softening of tissue occurred within the first 2.0h of osmotic treatment. It also may be related to the water loss during osmotic treatment.

The fact that there was no significant difference in the hardness of potato cubes detected between the two atmospheres or the days of storage ($p < 0.05$) (Table 10) indicates the respiration rate was not influencing the texture of the potatoes significantly. It may be attributed to the film packages maintaining the moisture content and cell

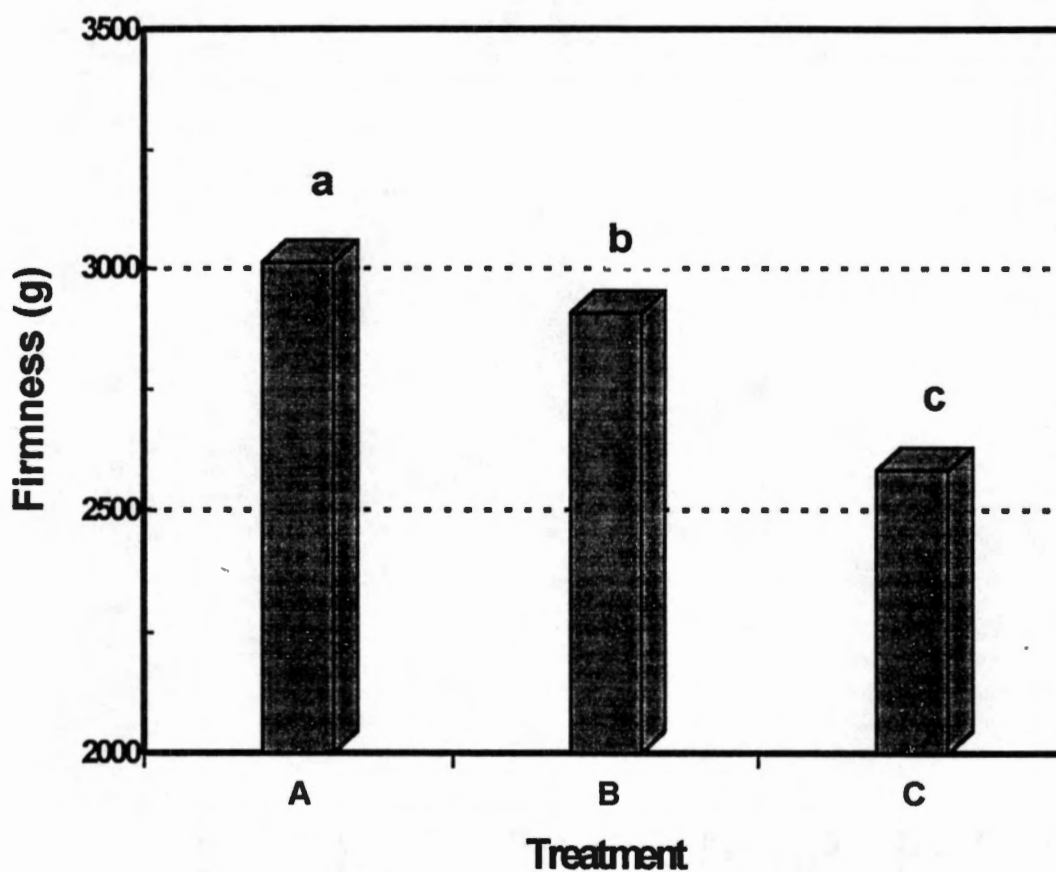


Figure 11. Average maximum force ($n = 90$) required to penetrate potato cubes treated by control (treatment A), 10 % corn syrup (treatment B), and 20% corn syrup (treatment C). Means with the same letter are not significantly different ($p < 0.05$) using the SNK mean separation test.

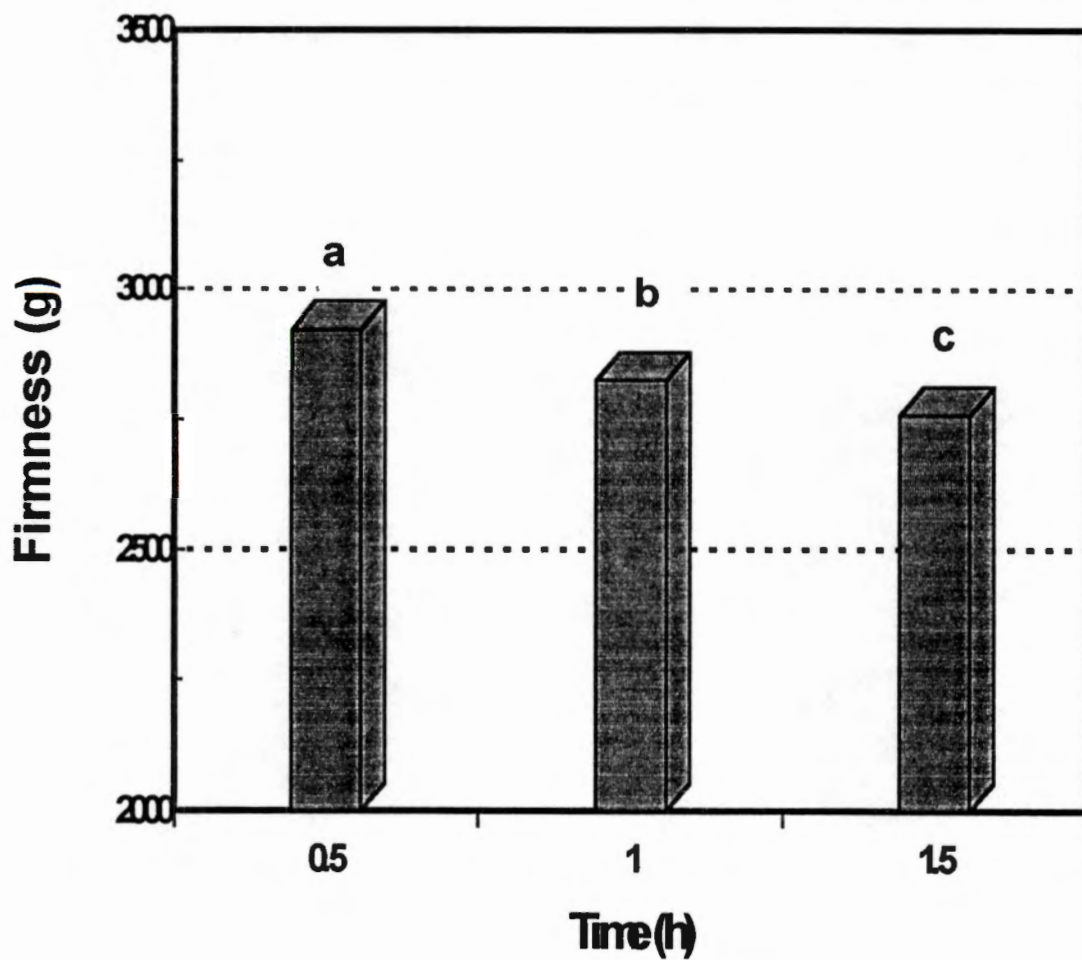


Figure 12. Average maximum force ($n = 90$) required to penetrate treated potato cubes for different osmosis times. Means with the same letter are not significantly different ($p < 0.05$) using the SNK mean separation test.

turgidity of potato cubes after treatment during the time stored at 5 °C (Shetty et al., 1991).

There was a significant difference between replications on the firmness of potato cubes ($p < 0.05$). The mean separations of maximum force of the different replications of potato cubes are shown in Table 11. A general pattern observed was that replication two and three were significantly different than replication one ($p < 0.05$). This may be attributed to the batches of potato which may been harvested at different maturity stages and were different levels of quality as previously mentioned.

Table 11. Mean of compress for control (treatment A) and osmotically coating [10% corn syrup (treatment B) or 20% corn syrup (treatment C)] potato cubes.

Factor	Compress (g)*
<u>Storage Time</u>	
Day 1	2844.45 ^a
Day 4	2840.24 ^a
Day 7	2835.85 ^a
Day 10	2831.79 ^a
Day 14	2819.41 ^a
<u>Replication</u>	
1	2883.37 ^a
2	2826.01 ^b
3	2803.05 ^b

^{a-b} Within each column, means with the same letter are not significantly different ($p < 0.05$) using the Student-Newman-Keuls mean separation test.

* Maximum force required for penetration.

Chapter V

Summary and Conclusions

The changes in moisture content, color, texture, and respiration of peeled potato cubes soaked in 0, 10, or 20% corn syrup (42DE) containing 1% ascorbic acid and 1 % citric acid for 0.5, 1.0, 1.5h (osmotic treatment) before storage in air or gas mixture (5% O₂ : 10% CO₂ : 85% N₂) filled packages for up to 14 d were investigated. Average moisture content of potato cubes was significantly different ($p < 0.05$) between fresh potatoes and treated potatoes (including control). In general, the rate of moisture change in each treatment of potato cubes was directly related to the concentration of osmotic solution (corn syrup) and osmotic time. Control and 10% corn syrup solutions resulted in similar moisture changes of potato cubes. Potato cubes treated in 20 % corn syrup solution contained approximately 1% less moisture than the other two treatments at each osmotic time.

Packaging in a gas mixture (5 % O₂ : 10 % CO₂ : 85 % N₂) significantly reduced the respiration rate of potatoes compared with packaging in air and did not result in an anaerobic condition during 14 d storage. Osmotic treatment with corn syrup reduced the respiration rate of potato cubes. The reduction in the respiration resulted in improved quality of potatoes in terms of color change.

The osmotic treatments of corn syrup combined with the gas mixture atmosphere

packaging resulted in a synergistic effect, producing a more effective percent inhibition of enzymatic browning on the surface of potatoes. The combinations of osmotic treatments with MAP extended shelf-life of potato cubes without color changes ($\Delta E < 3$) more than 10 days compared with the combination of osmotic treatments and the air atmosphere packaging. Overall, the more effective inhibition of enzymatic browning among three osmosis times was produced at 1.0-1.5h osmotic times.

The combination of osmotic treatment with 10% corn syrup in conjunction with MAP resulted in an average 59.2 % inhibition of enzymatic browning of peeled potato cubes and extended the shelf-life of peeled potato cubes without color change ($\Delta E = 2.76$ at day 14) to more than 14 days at 5 °C.

The texture of osmotically treated potato cubes was softer than controls. The average firmness of potatoes treated in 10 % corn syrup and 20 % corn syrup was reduced 3.5 % and 14.0 %, respectively, compared with controls. The longer osmotic treatment times also resulted in softer texture of potatoes during each osmotic treatment. No texture changes occurred in the potato cubes during storage.

In conclusion, the treatment of 10% corn syrup for 1.0h osmosis combined with MAP (5 % O₂ : 10 % CO₂ : 85 % N₂) resulted in a 64.1 % inhibition of enzymatic browning, with less texture changes (Firmness of potatoes decreased less than 3 %), lower respiration, and longer shelf life at 5°C ($\Delta E < 3$ more than 14 days). Therefore, this combination treatment system would be recommended to prevent the enzymatic browning in peeled potato cubes and to provide 14 days refrigerated (5 °C) shelf-life. Further

investigations on the texture and color changes of treated potatoes during different cooking procedures are needed.

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APPENDIXES

APPENDIX A

PARCHMENT DEED
SOUTHWORTH CO. U.S.A.
100% COTTON FIBER

Table A1. Mean of gas composition and mean of compress for control (treatment A) and osmotically coating [10% corn syrup (treatment B) or 20% corn syrup (treatment C)] potato cubes under an air atmosphere.

Factor	CO ₂	O ₂	Compress (g)*
<u>Treatment</u>			
Control (A)	15.49 ^a	9.63 ^a	3016.49 ^a
Treatment (B)	14.98 ^{ab}	9.68 ^a	2909.77 ^b
Treatment (C)	14.30 ^b	10.09 ^a	2577.48 ^{ac}
<u>Osmosis time</u>			
0.5 h.	15.21 ^a	9.58 ^a	2910.55 ^a
1.0 h.	14.92 ^a	9.80 ^a	2839.12 ^b
1.5 h.	14.67 ^a	10.02 ^a	2754.07 ^c
<u>Storage time</u>			
Day 1	4.33 ^c	18.95 ^a	2824.90 ^a
Day 4	9.48 ^d	13.79 ^b	2851.46 ^a
Day 7	17.23 ^c	7.13 ^c	2860.97 ^a
Day 10	21.02 ^b	4.87 ^d	2820.22 ^a
Day 14	22.18 ^a	4.58 ^d	2805.74 ^a
<u>Replication</u>			
1	14.10 ^b	10.36 ^a	2903.08 ^a
2	14.98 ^a	9.56 ^b	2818.95 ^b
3	15.69 ^a	9.49 ^b	2795.41 ^b

^{a-d} Within each factor, means with the same letter are not significantly different ($p < 0.05$) using the Student-Newman-Keuls mean separation test.

* Maximum force required for penetration.

Table A2. Mean of gas composition and mean of compress for control (treatment A) and osmotically coating [10% corn syrup (treatment B) or 20% corn syrup (treatment C)] potato cubes under a gas mixture atmosphere.

Factor	CO ₂	O ₂	Compress (g)*
<u>Treatment</u>			
Control (A)	12.56 ^a	3.25 ^a	3007.42 ^a
Treatment (B)	12.76 ^a	3.25 ^a	2905.35 ^b
Treatment (C)	11.90 ^b	3.25 ^a	2590.58 ^c
<u>Osmosis time</u>			
0.5 h.	12.32 ^a	3.19 ^a	2929.25 ^a
1.0 h.	12.47 ^a	3.41 ^a	2808.38 ^b
1.5 h.	12.44 ^a	3.23 ^a	2763.14 ^b
<u>Storage time</u>			
Day 1	8.52 ^c	5.71 ^a	2864.00 ^a
Day 4	10.14 ^d	3.77 ^b	2829.01 ^a
Day 7	13.30 ^c	2.63 ^c	2802.61 ^a
Day 10	14.54 ^b	2.28 ^c	2818.59 ^a
Day 14	15.54 ^a	1.99 ^c	2867.73 ^a
<u>Replication</u>			
1	14.65 ^b	4.11 ^a	2863.66 ^a
2	6.74 ^c	2.37 ^c	2833.23 ^a
3	15.83 ^a	3.35 ^b	2810.70 ^a

^{a-c} Within each factor, means with the same letter are not significantly different ($p < 0.05$) using the Student-Newman-Keuls mean separation test.

* Maximum force required for penetration.

Table A3. Analysis of variance of Hunter L, a_L , and b_L values for treated potato cubes under an air atmosphere at 5°C.

Factor	Source	DF	Mean Square	Pr > F
<u>L values</u>				
	Treatment	2	8.47207	0.0008
	Day	4	56.33981	0.0001
	Time	2	1.02363	0.4033
	Replication	2	3.15341	0.0635
	Error	124	1.11894	
<u>a_L values</u>				
	Treatment	2	0.820705	0.2414
	Day	4	11.442568	0.0001
	Time	2	0.005574	0.9903
	Replication	2	2.533725	0.0137
	Error	124	0.570763	
<u>b_L values</u>				
	Treatment	2	0.295509	0.5751
	Day	4	7.958714	0.0001
	Time	2	2.167336	0.0193
	Replication	2	1.313716	0.0887
	Error	124	0.531854	

Table A4. Analysis of variance of Hunter L, a_L , and b_L values for treated potato cubes under a gas mixture atmosphere at 5°C.

Factor	Source	DF	Mean Square	Pr > F
<u>L values</u>				
	Treatment	2	21.898741	0.0001
	Day	4	16.255370	0.0001
	Time	2	0.709852	0.4029
	Replication	2	0.512296	0.5182
	Error	124	0.77524	
<u>a_L values</u>				
	Treatment	2	0.994272	0.0067
	Day	4	15.294429	0.0001
	Time	2	0.177832	0.3968
	Replication	2	5.483283	0.0001
	Error	124	0.190942	
<u>b_L values</u>				
	Treatment	2	0.838634	0.1295
	Day	4	8.171349	0.0001
	Time	2	4.370501	0.0001
	Replication	2	5.620019	1.0001
	Error	124	0.403583	

Table A5. Mean Hunter L, a_L , b_L , and ΔE values for control (treatment A) and osmotically coating [10% corn syrup (treatment B) or 20% corn syrup (treatment C)] potato cubes under an air atmosphere at 5°C.

Factor	L	a_L	b_L	ΔE
<u>Treatment</u>				
Control (A)	36.68 ^b	3.04 ^a	8.76 ^a	5.01 ^a
Treatment (B)	37.52 ^a	2.79 ^a	8.87 ^a	4.34 ^b
Treatment (C)	36.92 ^b	2.83 ^a	8.72 ^a	4.72 ^a
<u>Osmosis time</u>				
0.5 h.	37.10 ^a	2.88 ^a	8.86 ^a	4.60 ^a
1.0 h.	36.87 ^a	2.90 ^a	8.95 ^a	4.86 ^a
1.5 h.	37.11 ^a	2.87 ^a	8.54 ^b	4.51 ^a
<u>Storage time</u>				
Day 1	39.14 ^a	2.17 ^c	8.34 ^c	2.51 ^d
Day 4	37.71 ^b	2.37 ^c	8.13 ^c	3.63 ^c
Day 7	36.89 ^c	3.07 ^b	9.01 ^b	4.79 ^b
Day 10	35.70 ^d	2.97 ^b	8.96 ^b	6.12 ^a
Day 14	35.76 ^d	3.83 ^a	9.47 ^a	6.23 ^a
<u>Replication</u>				
1	36.75 ^a	2.74 ^b	8.77 ^a	5.02 ^a
2	37.26 ^a	3.16 ^a	8.96 ^a	4.51 ^b
3	37.11 ^a	2.75 ^b	8.62 ^a	4.44 ^b

^{a-d} Within each factor, means with the same letter are not significantly different ($p < 0.05$) using the Student-Newman-Keuls mean separation test.

Table A6. Mean Hunter L, a_L , b_L , and ΔE values for control (treatment A) and osmotically coating [10% corn syrup (treatment B) or 20% corn syrup (treatment C)] potato cubes under a gas mixture atmosphere at 5°C.

Factor	L	a_L	b_L	ΔE
<u>Treatment</u>				
Control (A)	38.12 ^c	2.55 ^a	8.10 ^a	3.45 ^a
Treatment (B)	39.49 ^a	2.31 ^b	7.87 ^a	2.08 ^c
Treatment (C)	39.07 ^b	2.27 ^b	7.86 ^a	2.46 ^b
<u>Osmosis time</u>				
0.5 h.	38.76 ^a	2.44 ^a	8.25 ^a	2.82 ^a
1.0 h.	38.92 ^a	2.39 ^a	7.95 ^b	2.60 ^a
1.5 h.	39.00 ^a	2.31 ^a	7.63 ^c	2.56 ^a
<u>Storage time</u>				
Day 1	40.04 ^a	1.54 ^c	7.35 ^c	1.30 ^d
Day 4	39.11 ^b	1.90 ^d	7.55 ^{bc}	2.23 ^c
Day 7	38.96 ^b	2.26 ^c	7.80 ^b	2.50 ^b
Day 10	38.24 ^c	2.71 ^b	8.37 ^a	3.35 ^a
Day 14	38.11 ^c	3.48 ^a	8.66 ^a	3.93 ^a
<u>Replication</u>				
1	38.93 ^a	2.11 ^b	7.55 ^b	2.51 ^a
2	38.97 ^a	2.77 ^a	8.21 ^a	2.76 ^a
3	38.77 ^a	2.25 ^b	8.08 ^a	2.71 ^a

^{a-d} Within each factor, means with the same letter are not significantly different ($p < 0.05$) using the Student-Newman-Keuls mean separation test.

Table A7. Mean of Hunter L, a_L , b_L , and ΔE value for control solution (treatment A) potato cubes under an air atmosphere.

Factor	L	a_L	b_L	ΔE
<u>Osmosis time</u>				
0.5 h.	37.23 ^a	3.11 ^a	8.9827 ^a	4.56 ^a
1.0 h.	36.71 ^{ab}	3.04 ^a	8.9473 ^a	5.01 ^a
1.5 h.	36.11 ^{ab}	2.96 ^a	8.3473 ^a	5.47 ^a
<u>Storage time</u>				
Day 1	38.86 ^a	2.26 ^b	8.31 ^b	2.76 ^d
Day 4	37.46 ^b	2.46 ^b	8.30 ^b	3.89 ^c
Day 7	36.84 ^b	3.17 ^{ab}	8.85 ^{ab}	4.90 ^b
Day 10	35.49 ^c	3.25 ^{ab}	8.89 ^{ab}	6.98 ^a
Day 14	34.76 ^c	4.05 ^a	9.45 ^a	6.50 ^a

^{a-d} Within each factor, means with the same letter are not significantly different ($p < 0.05$) using the Student-Newman-Keuls mean separation test.

Table A8. Mean of Hunter L, a_L , b_L , and ΔE value for control solution (treatment A) potato cubes under a gas mixture atmosphere.

Factor	L	a_L	b_L	ΔE
<u>Osmosis time</u>				
0.5 h.	38.36 ^a	2.65 ^a	8.46 ^a	3.42 ^a
1.0 h.	38.16 ^a	2.59 ^a	8.28 ^a	3.66 ^a
1.5 h.	37.85 ^a	2.41 ^a	7.56 ^b	3.26 ^a
<u>Storage time</u>				
Day 1	39.76 ^a	1.64 ^d	9.33 ^a	1.69 ^d
Day 4	38.99 ^b	1.95 ^{cd}	8.79 ^a	2.36 ^{cd}
Day 7	38.42 ^b	2.24 ^c	7.63 ^b	3.00 ^c
Day 10	37.19 ^c	2.95 ^b	7.61 ^b	4.43 ^b
Day 14	36.37 ^c	3.95 ^a	7.16 ^b	5.76 ^a

^{a-d} Within each factor, means with the same letter are not significantly different ($p < 0.05$) using the Student-Newman-Keuls mean separation test.

Table A9. Mean of gas composition and compress (g) for control solution (treatment A) potato cubes under an air atmosphere.

Factor	% CO ₂	% O ₂	Compress (g)*
<u>Osmosis time</u>			
0.5 h	15.99 ^a	9.73 ^a	3075.57 ^a
1.0 h	15.45 ^a	9.62 ^a	3045.76 ^a
1.5 h	15.04 ^a	9.54 ^a	2928.14 ^a
<u>Storage time</u>			
Day 1	5.03 ^d	18.56 ^a	3049.80 ^a
Day 4	10.79 ^c	13.32 ^b	3049.01 ^a
Day 7	16.84 ^b	7.77 ^c	3043.30 ^a
Day 10	21.89 ^a	4.41 ^d	2978.01 ^a
Day 14	23.52 ^a	4.09 ^d	2971.27 ^a

^{a-d} Within each factor, means with the same letter are not significantly different ($p < 0.05$) using the Student-Newman-Keuls mean separation test.

* Maximum force required for penetration.

Table A10. Mean of gas composition and compress (g) for control solution (treatment A) potato cubes under a gas mixture atmosphere.

Factor	% CO ₂	% O ₂	Compress (g)*
<u>Osmosis time</u>			
0.5 h	12.75 ^a	3.52 ^a	3128.35 ^a
1.0 h	12.68 ^a	3.35 ^a	3003.19 ^a
1.5 h	12.28 ^a	2.87 ^a	2890.73 ^a
<u>Storage time</u>			
Day 1	8.40 ^b	5.78 ^a	3110.27 ^a
Day 4	10.38 ^{ab}	3.82 ^b	3016.93 ^a
Day 7	13.82 ^{ab}	2.46 ^c	2984.78 ^a
Day 10	14.92 ^a	2.11 ^c	2934.26 ^a
Day 14	15.31 ^a	2.06 ^c	2982.60 ^a

^{a-c} Within each factor, means with the same letter are not significantly different ($p < 0.05$) using the Student-Newman-Keuls mean separation test.

* Maximum force required for penetration.

Table A11. Mean of Hunter L, a_L , b_L , and ΔE values for osmotically coating in 10% corn syrup (treatment B) potato cubes under an air atmosphere.

Factor	L	a_L	b_L	ΔE
<u>Osmosis time</u>				
0.5 h.	38.01 ^a	2.82 ^a	8.92 ^a	4.59 ^a
1.0 h.	37.41 ^a	2.80 ^a	8.89 ^a	4.31 ^{ab}
1.5 h.	37.15 ^a	2.74 ^a	8.81 ^a	3.83 ^b
<u>Storage time</u>				
Day 1	39.67 ^a	2.10 ^a	8.60 ^{ab}	2.18 ^d
Day 4	38.28 ^b	2.20 ^b	7.93 ^b	3.03 ^c
Day 7	36.93 ^b	3.08 ^a	9.28 ^a	4.79 ^b
Day 10	36.54 ^c	3.00 ^a	9.18 ^a	5.41 ^{ab}
Day 14	36.17 ^c	3.56 ^a	9.38 ^a	5.81 ^a

^{a-d} Within each factor, means with the same letter are not significantly different ($p < 0.05$) using the Student-Newman-Keuls mean separation test.

Table A12. Mean of Hunter L, a_L , b_L , and ΔE values for osmotically coating in 10% corn syrup (treatment B) potato cubes under a gas mixture atmosphere.

Factor	L	a_L	b_L	ΔE
<u>Osmosis time</u>				
0.5 h.	39.29 ^a	2.29 ^a	8.12 ^a	2.24 ^a
1.0 h.	39.62 ^a	2.32 ^a	7.81 ^a	2.02 ^a
1.5 h.	39.54 ^a	2.21 ^a	7.69 ^b	1.97 ^a
<u>Storage time</u>				
Day 1	40.26 ^a	1.55 ^d	8.16 ^a	1.04 ^c
Day 4	39.50 ^{ab}	1.91 ^{cd}	8.24 ^a	1.88 ^b
Day 7	39.44 ^{ab}	2.22 ^{bc}	7.95 ^a	2.09 ^{ab}
Day 10	39.00 ^b	2.55 ^b	7.55 ^a	2.63 ^{ab}
Day 14	39.23 ^{ab}	3.14 ^a	7.47 ^a	2.76 ^a

^{a-d} Within each factor, means with the same letter are not significantly different ($p < 0.05$) using the Student-Newman-Keuls mean separation test.

Table A13. Mean of gas composition and compress (g) for osmotically coating in 10% corn syrup (treatment B) under an air atmosphere.

Factor	% CO ₂	% O ₂	Compress (g)*
<u>Osmosis time</u>			
0.5 h	15.06 ^a	10.16 ^a	2985.44 ^a
1.0 h	15.39 ^a	9.08 ^a	2903.27 ^{ab}
1.5 h	14.47 ^a	9.79 ^a	2840.59 ^b
<u>Storage time</u>			
Day 1	4.29 ^d	18.79 ^a	2931.63 ^a
Day 4	9.45 ^c	13.91 ^b	2886.72 ^a
Day 7	18.27 ^b	6.19 ^c	2933.97 ^a
Day 10	21.34 ^a	4.97 ^c	2900.20 ^a
Day 14	21.53 ^a	4.53 ^c	2889.58 ^a

^{a-d} Within each factor, means with the same letter are not significantly different ($p < 0.05$) using the Student-Newman-Keuls mean separation test.

* Maximum force required for penetration.

Table A14. Mean of gas composition and compress (g) for osmotically coating in 10% corn syrup (treatment B) under a gas mixture atmosphere.

Factor	% CO ₂	% O ₂	Compress (g)*
<u>Osmosis time</u>			
0.5 h	12.68 ^a	3.12 ^a	2960.97 ^a
1.0 h	12.90 ^a	3.28 ^a	2858.55 ^a
1.5 h	12.71 ^a	3.34 ^a	2893.19 ^a
<u>Storage time</u>			
Day 1	8.50 ^c	5.86 ^a	2946.90 ^{ab}
Day 4	10.38 ^c	3.66 ^b	2857.46 ^{ab}
Day 7	13.71 ^{bc}	2.25 ^c	2813.98 ^b
Day 10	14.78 ^{ab}	2.36 ^c	2922.13 ^{ab}
Day 14	16.44 ^a	2.10 ^c	3051.02 ^a

^{a-c} Within each factor, means with the same letter are not significantly different ($p < 0.05$) using the Student-Newman-Keuls mean separation test.

* Maximum force required for penetration.

Table A15. Mean of Hunter L, a_L , b_L , and ΔE values for osmotically coating in 20% corn syrup (treatment C) potato cubes under an air atmosphere.

Factor	L	a_L	b_L	ΔE
<u>Osmosis time</u>				
0.5 h.	36.93 ^a	2.78 ^a	8.68 ^{ab}	4.66 ^{ab}
1.0 h.	36.49 ^a	2.98 ^a	9.10 ^a	5.27 ^a
1.5 h.	37.34 ^a	2.72 ^a	8.37 ^b	4.23 ^b
<u>Storage time</u>				
Day 1	38.89 ^a	2.17 ^b	8.10 ^b	2.60 ^c
Day 4	37.40 ^b	2.46 ^b	8.17 ^b	3.98 ^b
Day 7	36.90 ^b	2.88 ^b	8.92 ^{ab}	4.68 ^b
Day 10	35.79 ^c	2.75 ^b	8.83 ^{ab}	5.96 ^a
Day 14	35.62 ^c	3.87 ^a	9.58 ^a	6.39 ^a

^{a-c} Within each factor, means with the same letter are not significantly different ($p < 0.05$) using the Student-Newman-Keuls mean separation test.

Table A16. Mean of Hunter L, a_L , b_L , and ΔE values for osmotically coating in 20% corn syrup (treatment C) potato cubes under a gas mixture atmosphere.

Factor	L	a_L	b_L	ΔE
<u>Osmosis time</u>				
0.5 h.	38.81 ^a	2.36 ^a	8.17 ^a	2.80 ^a
1.0 h.	39.28 ^a	2.32 ^a	7.78 ^a	2.18 ^b
1.5 h.	39.11 ^a	2.25 ^a	7.64 ^b	2.42 ^{ab}
<u>Storage time</u>				
Day 1	40.11 ^a	1.43 ^d	7.42 ^b	1.16 ^c
Day 4	39.00 ^b	1.83 ^{cd}	7.50 ^b	2.25 ^b
Day 7	38.86 ^b	2.32 ^{bc}	7.83 ^{ab}	2.42 ^{ab}
Day 10	38.82 ^b	2.61 ^b	8.09 ^{ab}	3.00 ^{ab}
Day 14	38.54 ^b	3.35 ^a	8.47 ^a	3.28 ^a

^{a-d} Within each factor, means with the same letter are not significantly different ($p < 0.05$) using the Student-Newman-Keuls mean separation test.

Table A17. Mean of gas composition and compress (g) for osmotically coating in 20% corn syrup (treatment C) under an air atmosphere.

Factor	% CO ₂	% O ₂	Compress (g)*
<u>Osmosis time</u>			
0.5 h	15.16 ^a	9.00 ^b	2670.63 ^a
1.0 h	13.91 ^a	10.56 ^a	2568.32 ^b
1.5 h	13.89 ^a	10.62 ^a	2493.49 ^b
<u>Storage time</u>			
Day 1	3.60 ^e	19.58 ^a	2565.04 ^a
Day 4	8.81 ^d	14.13 ^b	2618.64 ^a
Day 7	16.58 ^c	7.43 ^c	2599.13 ^a
Day 10	19.63 ^b	5.98 ^d	2589.20 ^a
Day 14	21.70 ^a	4.37 ^e	2484.33 ^a

^{a-e} Within each factor, means with the same letter are not significantly different ($p < 0.05$) using the Student-Newman-Keuls mean separation test.

* Maximum force required for penetration.

Table A18. Mean of gas composition and compress (g) for osmotically coating in 20% corn syrup (treatment C) under a gas mixture atmosphere.

Factor	% CO ₂	% O ₂	Compress (g)*
<u>Osmosis time</u>			
0.5 h	12.00 ^a	2.92 ^a	2698.43 ^a
1.0 h	11.77 ^a	3.61 ^a	2566.98 ^b
1.5 h	11.93 ^a	3.46 ^a	2506.33 ^b
<u>Storage time</u>			
Day 1	8.66 ^b	5.48 ^a	2535.84 ^a
Day 4	9.65 ^{ab}	3.83 ^b	2612.64 ^a
Day 7	12.38 ^{ab}	3.20 ^b	2609.09 ^a
Day 10	139.4 ^{ab}	2.36 ^b	2599.38 ^a
Day 14	14.87 ^a	1.80 ^b	2600.12 ^a

^{a-b} Within each factor, means with the same letter are not significantly different ($p < 0.05$) using the Student-Newman-Keuls mean separation test.

* Maximum force required for penetration.

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APPENDIX B

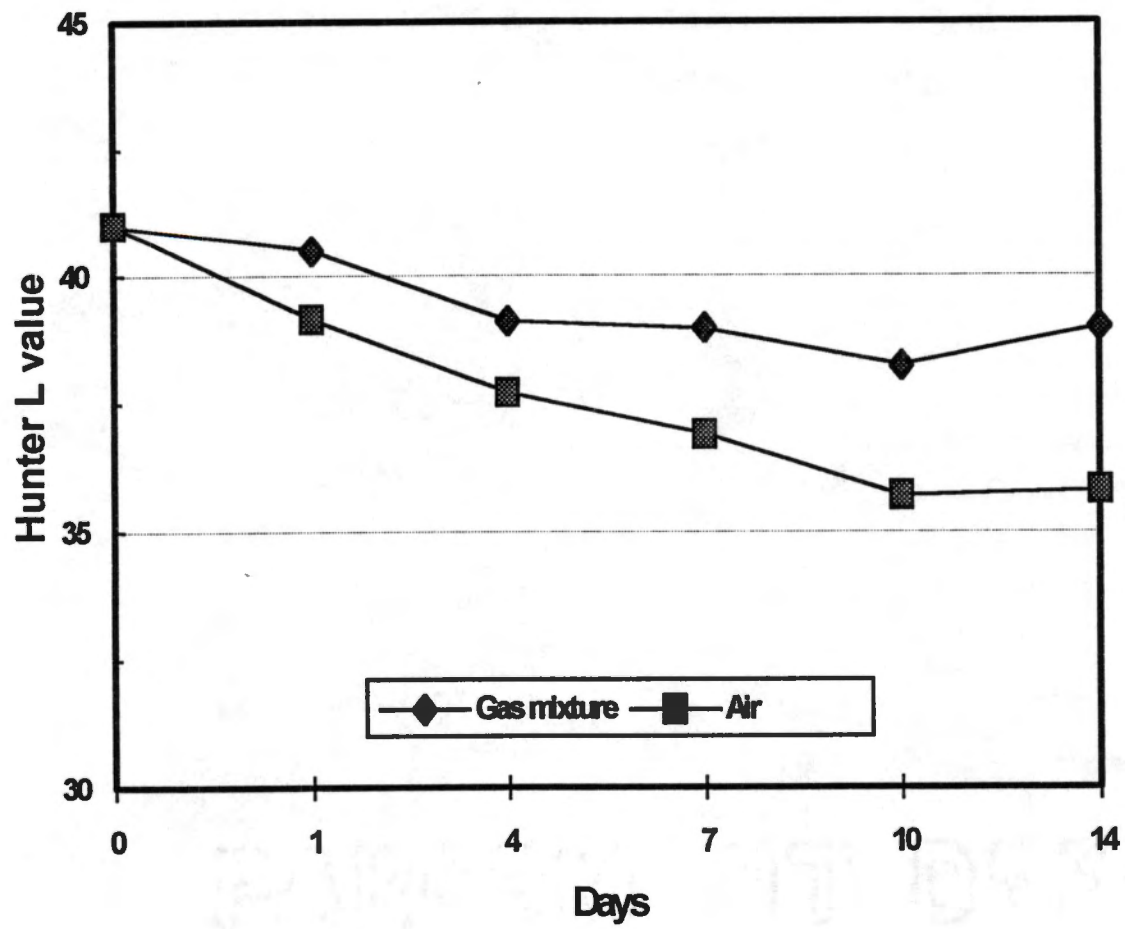


Figure B1. Changes (Hunter L value) in color of treated potato cubes either packaging with air or a gas mixture atmosphere during storage times at 5°C.

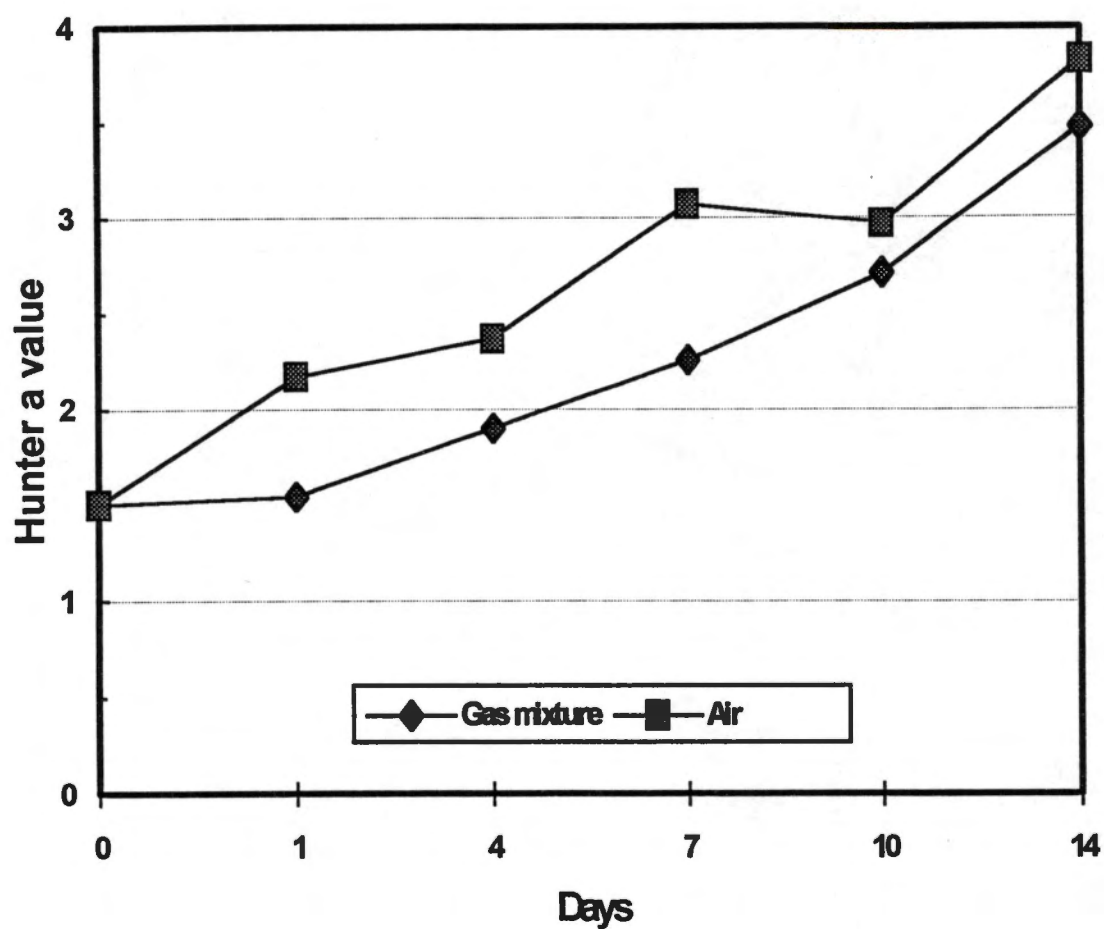


Figure B2. Changes (Hunter a_L value) in color of treated potato cubes either packaging with air or a gas mixture atmosphere during storage times at 5°C.

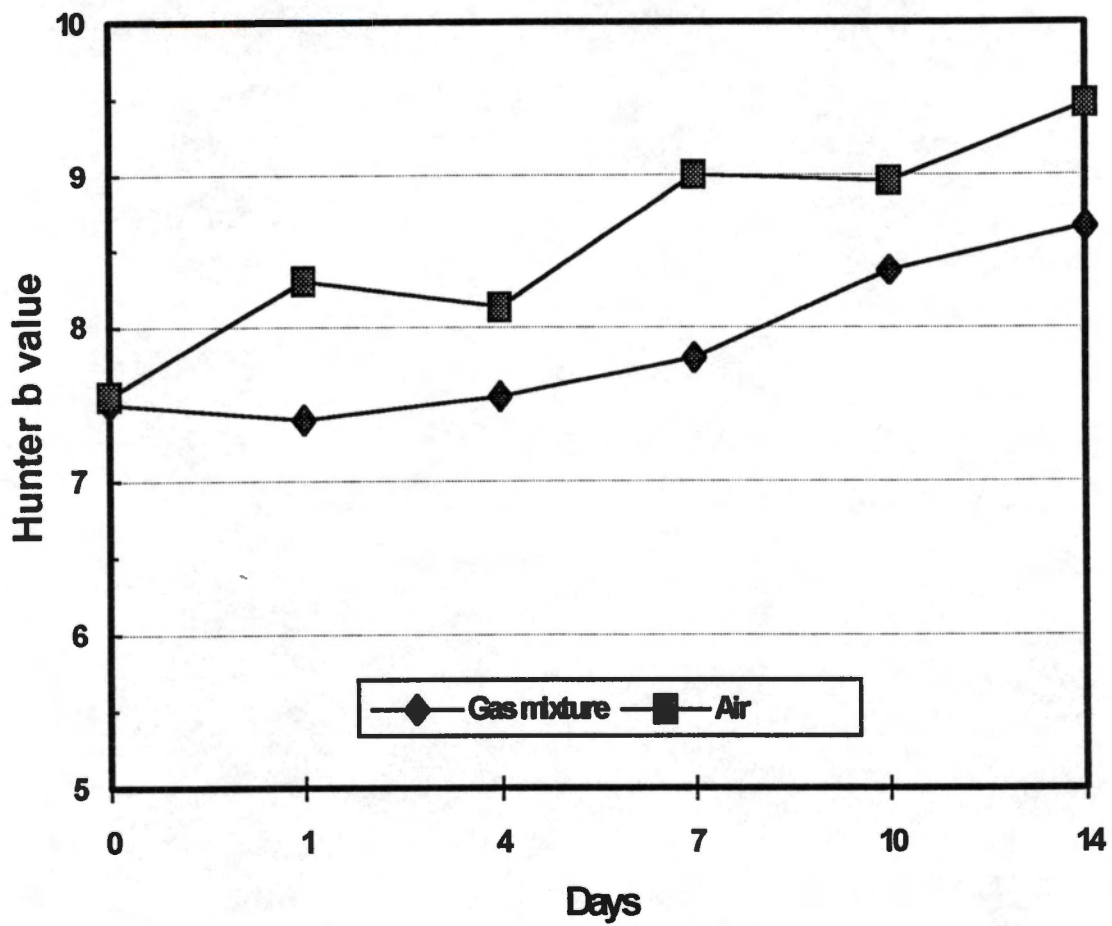


Figure B3. Changes (Hunter b_L value) in color of treated potato cubes either packaging with air or a gas mixture atmosphere during storage times at 5°C.

VITA

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