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OSMOTIC CONCENTRATION OF POTATO IN CORN SYRUP SOLUTIONS PRIOR TO FREEZING

A THESIS

PRESENTED FOR THE

MASTER OF SCIENCE

DEGREE

THE UNIVERSITY OF TENNESSEE, KNOXVILLE

YING CHEN

DECEMBER 1993

ACKNOWLEDGMENTS

The author would like to thank Dr. Rabindra N. Biswal, major professor, for his patience, guidance, and encouragement during this study and strong support in the completion of the thesis. She extends her sincere thanks to the other committee members, Dr. John R. Mount, Dr. Marjorie P. Penfield, and Dr. William C. Morris, for their expert advice and invaluable assistance throughout the research and completion of the thesis. Sincere appreciation is extended to:

Dr. Hugh O. Jaynes, Head of the Department of Food Science and Technology, for providing the opportunity and funding for her graduate studies;

Cyrus Bozorgmehr, A. Ruth Hill, Yobouet Dje, Emayet Spensor, Manuel A. Ortega, and Chularat Siangchin for their assistance and friendship during the research;

all faculty, staff, and graduate students of the Department of Food Science and Technology for their assistance and friendship;

all sensory panelists for their attendance and patience;

Tom's Food Inc. for supplying potatoes for the research.

Greatest appreciation is extended to author's parents, Chenggui Chen and Deyu Li, sister, Fang Chen, and brother, Zhengyu Chen, for their love and emotional support throughout the studies. Finally, the author expresses her deepest appreciation for her beloved husband, Lihan Huang for his prayers, understanding, and strong support throughout her studies, and to her sweet little one, Jiexin Huang for her being a very nice girl.

ABSTRACT

The feasibility of osmotic concentration of potato strips in corn syrup solutions, and the use of osmotic concentration as an intermediate step in producing frozen, French fried potato, were demonstrated. Potato strips were contacted with 26 DE and 43 DE corn syrup solutions at three solute concentrations (40, 50 and 60%, w/w) and three temperatures (20, 30 and 40°C) for six time intervals (0, 1, 2, 3, 4 and 5 h). Moisture loss from, and solids gain by, potato were monitored. In general, moisture loss for 43 DE corn syrup solutions was higher than that for 26 DE solutions. For each DE, moisture loss increased with increase in temperature and solute concentration. Moisture loss was very rapid at the beginning and decreased gradually with time of osmosis. Up to 70% of the original moisture content was removed, with a maximum solids gain of 0.43 kg/kg of original solids and a net weight reduction of about 50%.

Moisture loss was modeled using an exponential equation, assuming that the resistance to moisture movement remained in the potato tissue. Parameters of the model were estimated using non-linear regression with high R^2-like values (0.95 and 0.96 for 26 and 43 DE, respectively). Solids gain varied inconsistently with solute concentration, temperature and time of contacting. Leaching of soluble solids from potato tissue was also observed.

Potato strips, concentrated with 26 DE corn syrup solutions of 60% (w/w) solute concentration at 21°C for 3 h, were blanched in steam (atmospheric pressure), air-cooled, frozen in a CO_2 freezer and stored for 2 months. The "control" was similarly processed and stored as above but without osmotic concentration. At 0 and 2 mo, the control and osmotically treated frozen potato strips were deep fried in oil at 195°C for 4.5 and 1 min, respectively, and evaluated for moisture content, oil content, color, texture and sensory acceptability.

Initial moisture contents of fresh and osmotically concentrated potatoes were 80% and 65% (w.b.), respectively, with their respective final moisture contents of 47% and 53% (w.b.) after frying. Oil content of osmotically treated potato after frying was one-third of that of the control. Color of the osmotically treated potato was slightly darker than that of the control, although the color of both potatoes was within the acceptability range. Osmotically treated potato exhibited softer texture than the control. Sensory evaluation of fried potatoes by a 50-member panel, using an eight-point hedonic scale and a five-point purchase intent scale, indicated that the panelists preferred the control over the osmotically treated potatoes. They would more likely purchase the control than the osmotically treated potato. "Softer texture" and "inadequate frying" were identified to be reasons for lower acceptability of the osmotically treated potato. The acceptability of the osmotically treated French fried potato might be improved by taking into account "doneness" of potato during frying, instead of just the color acceptability.

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CHAPTER I

INTRODUCTION

Potato, *Solanum tuberosum*, is an important food crop in the United States. In 1990, the total production of potato was 18.2 million tons, 33% of which was processed as frozen potato products (USDA, 1992). During the last two decades, commercial production of frozen potato products has increased phenomenally. In 1972, the pack of all frozen potato products was 1.2 million tons, which constituted 54% of the total frozen vegetables (USDA, 1980). In 1990, the production of frozen potatoes increased to 6.0 million tons, constituting 60% of the total frozen vegetables (USDA, 1992).

Moisture content of raw potatoes is about 79% (USDA, 1984). Therefore, in producing frozen potato products, much of the energy is used in freezing the large quantity of water present in potato tissue. A significant portion of this energy, however, could be saved if potatoes were partially dehydrated prior to freezing (Huxsoll, 1982).

The most common method for dehydration of potato is air drying (Islam and Flink, 1982a). Osmotic concentration has been shown to be effective for partially concentrating fruits and vegetables under mild conditions (Ponting et al., 1966; Ponting, 1973). Several researchers have studied osmotic concentration of potato in aqueous solutions of sucrose, salt, or mixtures thereof (Islam and Flink, 1982a,b; Lenart and Flink, 1984a,b). The use of corn syrup solutions for osmotic concentration of fruits was successfully demonstrated by Contreras and Smyrl (1981) and Bolin et al. (1983). Its use for concentrating of vegetables such as potato, however, has not been studied. The quality attributes of osmotically concentrated, frozen potato also has not yet been studied.

The objectives of this research were (1) to study the kinetics of osmotic concentration of potato in corn syrup solutions of 26 and 43 DE (dextrose equivalent) at different concentrations and temperatures, and (2) to study the quality attributes of osmotically concentrated, frozen, French fried potatoes.

CHAPTER II

REVIEW OF LITERATURE

History of Potato and Potato Processing

Potato processing has a long history. Potatoes were cultivated in the mountainous areas of Peru as early as 200 A.D. (Talburt, 1967). The first introduction of potato into the United States was in 1621, but little work was done on potato processing until the World War I when some dehydrated potato products were processed for military use. Potato starch has been produced in the United States for over 100 years. Potato chips were first manufactured in this country in the middle of the nineteenth century, when the growth of industrial processing was limited by the peeling and frying equipment (Talburt, 1967). The frozen potato products industry began in 1945. The processing of frozen by-products such as patties, puffs, and mashed potatoes developed with the production of frozen French fries (Feustel and Kueneman, 1967).

Nutritional Value of Potato

Potato is a highly nutritious vegetable. On average, 100 g of potato contains 78.96 g water, 2.07 g protein, 0.10 g total lipids, 17.98 g carbohydrate, 0.44 g fiber, and 0.89 g ash, providing a total of 331 kJ (79 kcal) energy (USDA, 1984).

Potato is rich in vitamin C and folacin. Every 100 g of potato contains 19.7 g ascorbic acid which is about one-third of the Recommended Dietary Allowance (RDA) for an adult, and 12.8 g folacin which provides about 15% of the adult RDA. Potato is also a good source of thiamin (0.088 mg/100 g), riboflavin (0.035 mg/100 g) and niacin (1.2-2.3 mg/100 g) (USDA, 1984). The predominant mineral present in potato is potassium (543 mg/100 g). Phosphorus (46 mg/100 g), magnesium (21 mg/100 g), iron (0.76 mg/100 g), and zinc (0.39 mg/100 g) are also present, each providing 2.6-7.6% of the RDA requirement for an adult (USDA, 1984).

Dehydration of Potato

Water is the major component of potato, averaging about 79% (USDA, 1984). Removal of water from potatoes can be accomplished in several ways. The most common methods for drying potato are air and solar drying (Islam and Flink, 1982a). During air drying, the nutritional value of potato is reduced when it is exposed to high temperature for prolonged periods of time (Augustin et al., 1979).

Vacuum drying may also be used, but the energy usage is high. Frying is another process for removing water from potatoes. Frozen French-fried potatoes are produced by concentrating potatoes by par-frying prior to freezing. The highest quality dried potato products is produced by freeze drying which is one of the most expensive unit operations. In recent years, considerable attention has been given to osmotic concentration of fruits and vegetables, including potato, prior to air drying, freezing and freeze dehydration (Hawkes and Flink, 1978; Islam and Flink, 1982a, b; Kim and Toledo, 1987; Biswal and Bozorgmehr, 1991).

Osmotic Concentration

Definition

Osmotic concentration has been considered as a method of food processing to achieve high-quality products (Ponting et al., 1966). When plant materials, such as fruits and vegetables, are immersed in a hypertonic solution, i.e. high solute concentration, an osmotic pressure difference arises between the plant materials and the hypertonic solution. Since the hypertonic solution is higher in osmotic pressure and lower in water activity, water in the plant materials permeates through the cell wall and water is removed from the tissue. In an osmosis process, the membrane of the natural plant cell is semi-permeable and partially selective, therefore, there is soluble solids interchange between the plant materials and solution (Fig. 1). Osmotic concentration is a simultaneous water and solute diffusion process (Ponting et al., 1966).

Applications

Osmotic concentration has been used as an intermediate step in the processing of fruits and vegetables. Osmotic concentration has been followed by freeze drying (Hawkes and Flink 1978; Yang et al., 1987), air drying (Islam and Flink, 1982a; Kim and Toledo, 1987; Rahman and Lamb, 1991), vacuum drying (Ponting et al., 1966; Dixon et al., 1976), and freezing (Farkas and Lazar, 1969; Torreggiani et al., 1988; Biswal and Bozorgmehr, 1989). Intermediate moisture foods (IMF) can also be obtained by osmotic concentration (Karel et al., 1975; Yang and Atallah, 1985). In addition to reducing the energy

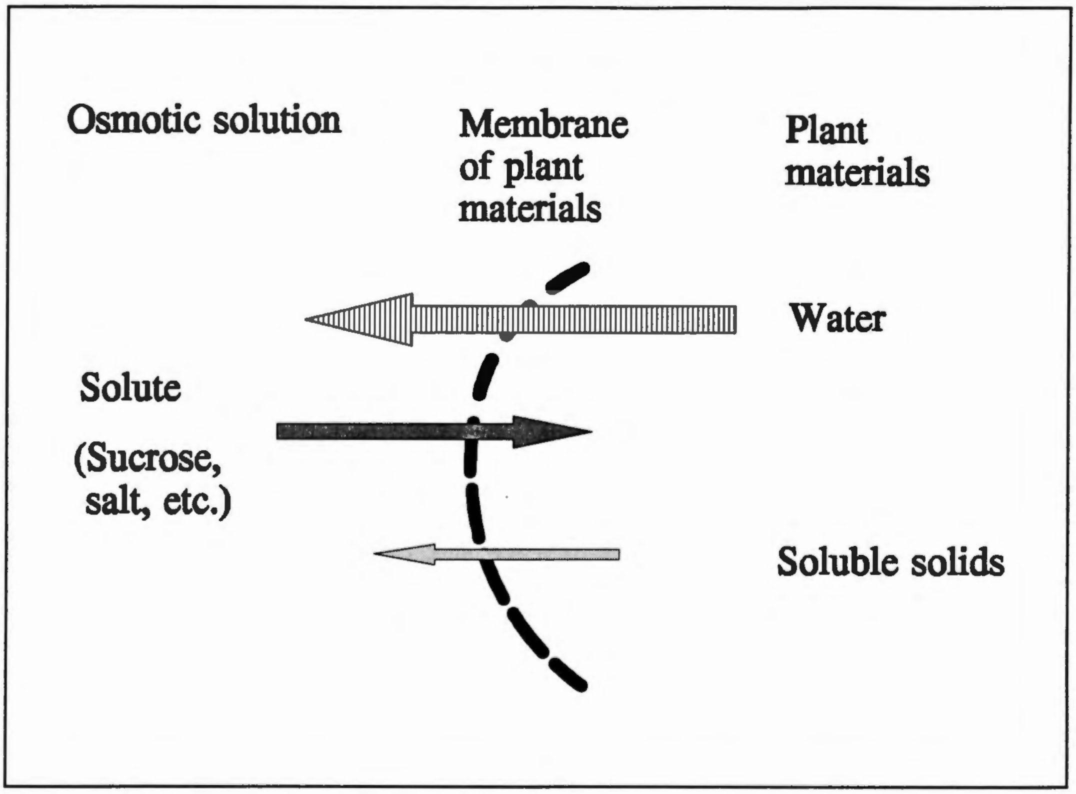


Fig.1 -- Osmotic phenomena.

requirements at the further processing steps (Huxsoll, 1982), osmotic pre-concentration improves the product quality (Ponting et al., 1966; Farkas and Lazar, 1969; Hawkes and Flink, 1978). A review of the osmotic dehydration process is given by Le Maguer (1988).

Factors Affecting Osmotic Concentration

The quantity and the rate of water removal during osmotic concentration depend on several variables and processing parameters. Many authors have investigated the effects of temperature and solute concentration on the kinetics of osmosis (Ponting et al., 1966; Farkas and Lazar, 1969; Hawkes and Flink, 1978; Contreras and Smyrl, 1981; Conway et al., 1983; Biswal and Bozorgmehr, 1989). In general, it has been shown that the weight loss in osmosed fruit or vegetable is increased by increasing solute concentration of the osmotic solution, immersion time and temperature, solution/food ratio, and specific surface area of the food and by using a low pressure system. It is not usually worthwhile to use osmotic concentration for a weight reduction greater than 50%, because of the decrease in rate of osmosis with time (Ponting et al., 1966).

Materials Studied

Many fruits and vegetables have been successfully concentrated by osmotic means; examples are apple (Ponting et al., 1966; Farkas and Lazar, 1969; Hawkes and Flink, 1978; Bolin et al., 1983; Biswal and Bozorgmehr, 1992a), apricot (Bolin et al., 1983), banana (Bongirwar and Sreenibasan, 1977), blueberry (Yang and Atallah, 1985; Kim and Toledo, 1987; Yang et al., 1987), cherry (Torreggiani et al., 1988), green beans (Biswal et al., 1991), peach (Bolin et al., 1983), pineapple (Rahman and Lamb, 1991), potato (Islam and Flink, 1982a,b; Lenart and Flink 1984a,b; Biswal and Bozorgmehr, 1991), and sweet potato (Biswal and Bozorgmehr, 1992b).

Osmotic Agents

Several osmotic agents have been successfully used for osmotic concentration of fruits and vegetables. The most commonly used osmotic agents are sucrose for fruits and sodium chloride for vegetables. The salty taste imparted by sodium chloride limits its use for osmotic concentration of fruits. Aqueous solutions of sucrose in the concentration range of 50-70^{o} Brix have been used for osmotic concentration of varieties of fruits and vegetables. A comprehensive list of products that have been concentrated by either pure sucrose solution or mixtures of sucrose and other osmotic agents has been given by Le Maguer (1988). Although the use of sucrose offers several advantages such as prevention of enzymatic oxidative browning of fruit (Ponting et al., 1966) and greater volatile retention due to higher solids content of the osmotically concentrated fruit (Hawkes and Flink, 1978), a major disadvantage is its cost. One way of reducing the cost of the osmotic agent is re-using the osmotic solution (Bolin et al., 1983). Ponting et al. (1966) suggested that invert syrup should theoretically be more effective than sucrose syrup of the same concentration because, when completely inverted, it has twice as many molecules per unit volume. However, little difference in the rate of osmotic concentration of fruit was found in the osmosis by sucrose or invert syrups of the same concentration and temperature. Although the sensory aspects of fruits concentrated with salt are questionable, dehydration of plant materials using mixtures of osmotic agents such as sodium chloride and sucrose have been found to be quite effective (Hawkes and Flink 1978; Islam and Flink, 1982a,b; Gianogiacomo et al., 1987; Biswal and Bozorgmehr, 1992a). Using corn syrup solids of 28 dextrose equivalent (DE) to concentrate apple rings, Contreras and Smyrl (1981) observed that the weight of the apple rings could be reduced by 70% during osmotic concentration. Bolin et al. (1983) observed that high-fructose corn syrup has higher diffusivity as compared to sucrose during osmotic concentration of apples, peaches, and apricots. This behavior is explained by the conventional diffusion procedure (Ray, 1960). Sucrose, being a disaccharide, would diffuse slower than the monosaccharide such as glucose and fructose. The feasibility of osmotic concentration of potato using aqueous solutions of sucrose, sodium chloride, and mixtures thereof was demonstrated by Islam and Flink (1982b), Lenart and Flink (1984a,b), and Biswal and Bozorgmehr (1991). No work has been reported on the study of osmotic concentration of potato using corn syrup solutions.

Corn Syrup

Corn syrup is manufactured by the wet milling process. It is usually defined as a purified, concentrated aqueous solution of nutritive saccharides. Three methods are commonly used to hydrolyze the starch of corn. These methods include acid conversion, acid-enzyme-conversion, and enzyme-enzyme conversion (Pancoast and Junk, 1980; Whistler and Daniel, 1985).

The pH values of most corn syrups are in the range of 4.0-5.5 with an average value of 5.0 (Pancoast and Junk, 1980). The color of corn syrups is usually "water white" when it is newly refined. Color changes may develop after manufacture. The reactions between traces of protein and reducing sugars in the syrup, commonly known as Maillard reaction, account for the normal color changes (Pancoast and Junk, 1980). Time, temperature, DE value, pH, and sulfur dioxide concentration may affect color formation in corn syrup.

Corn syrup is identified based upon the dextrose equivalent (DE). A 26 DE corn syrup contains 5% dextrose (monosaccharides), 8% maltose (disaccharides), 11% maltotriose (trisaccharides), and 76% higher saccharides; a 43 DE corn syrup contains 19% dextrose (monosaccharides), 14% maltose (disaccharides), 13% maltotriose (trisaccharides), and 54% higher saccharides (Anon., 1992). The typical industrial high-fructose corn syrups (HFCS) composition is as follows: 7-52% glucose, 42-90% fructose, and 3-6% oligosaccharides (Whistler and Daniel, 1985).

Corn syrup has been used as an osmotic agent to remove water effectively from fruits and vegetables (Contreras and Smyrl, 1981; Bolin et al., 1983). The syrup solutions can be reconcentrated and reused. Bolin et al. (1983) stated that fruits concentrated with HFCS had lower water activities than those concentrated with sucrose, and also had lower moisture contents. HFCS replaced more water in the cells because of its faster penetration rate. Results presented by Contreras and Smyrl (1981) showed that solids uptake by apple rings from 28 DE corn syrup solution was much less than from sucrose solution. Also, after 4 h contact with 43% (w/w) corn syrup solution at 55°C, the weight of apple rings was reduced by 70%.

Osmotic Concentration of Potato

Islam and Flink (1982b) studied osmotic concentration of potato in aqueous solutions of sucrose and sodium chloride. They found a two- to five-fold increase in product throughput after osmotic concentration in a 45% sucrose/15% salt solution, prior to solar drying. The reason for the increase in the throughput is the moisture loss and solids uptake in the osmosis step. Sensory quality of the product was judged to be good and ascorbic acid retention was similar to that reported for commercial concentration processes.

Lenart and Flink (1984a) studied osmotic concentration of potato to determine the conditions that define the equilibrium state between potato and osmotic solution. The results showed that the water activity and soluble solids concentration in the potato and in the osmotic solution are equal at equilibrium. Solids gain and solids concentration in the potato could be significantly reduced if the surface of potato was rinsed after osmotic concentration. Seventy-five percent of the soluble solids in the equilibrated potato came from the osmotic solution. Potatoes concentrated in mixed sucrose-salt solutions had a lower water activity than in the pure sucrose solution.

Lenart and Flink (1984b) also studied spatial distribution of the "osmosis effect" during osmotic concentration of potato. The depth of penetration of "osmosis effect" and the "moisture content of the surface relative to the initial moisture content" were investigated. The results showed that the spatial distribution of solids and moisture was dependent upon such factors as solute type, solution concentration, osmosis time, osmosis temperature and solution agitation. The spatial distribution curves for osmosis in sucrose solutions were found to be very different from those in salt solutions.

Nutrient Retention in Osmotically Concentrated Potato

All concentration or dehydration processes usually result in the loss of ascorbic acid from vegetable tissue. In commercial air dehydration of potato, there is only a 40% retention (Augustin et al. 1979). For osmosed potato, however, the retention of ascorbic acid was 61.3% (Islam and Flink, 1982b). The loss of ascorbic acid during osmotic concentration is attributed to the leaching of water soluble vitamins and minerals from potato into the osmotic solution (Islam and Flink, 1982a). Leaching of ascorbic acid could also take place during blanching and cooling steps (Jadhav et al., 1975).

Quality of French Fried Potatoes

Oil Content

Many factors affect the oil content of deep-fat fried potatoes. These factors include type of tuber, cultivation, storage conditions, and the processing conditions. The oil used in production, pre-frying processes, and conditions used in the frying operation are the major factors affecting the oil content in the final product (Smith, 1967). The effect of whole tuber specific gravity or solids content was studied by Sayre et al. (1975). Potato strips were found to be shriveled, limp and soggy if the original solids content was below 17%. With the original solids content of above 22%, potato strips were found to be rigid and crisp and had mealy interior. As reported by Adambounou and Castaigne (1981), low specific gravity tubers (1.062-1.070) yielded smooth, oily, and not crispy fries, while high density tubers (1.102-1.106) produced good quality fries. In the frying process, higher temperatures and lower residence times reduced the oil content of French fries (Gamble et al., 1987). The temperatures of blanching did not have significant influence on the oil content of par-fried French fries blanched for 15 min (Nonaka et al., 1977). There is no consistent influence of the melting point of the frying oil on the oil content of the par-fries. There is a proportional relationship between the amount of oil entering potato and the amount of moisture lost (Gamble et al., 1987). Without the formation of large surface-damage sites, slow and continuous moisture loss would result in low oil content. In a study on surface freezing of potato strips, Toma et al. (1986) found that partially frozen strips absorbed less oil during frying than the control (fresh potato strips).

Color

The normal color of French fries is light golden brown (Feustel and Kueneman, 1967). The variety of potato, storage conditions, and the process influence the color of the French fries. The major factor that controls the color of the fries is the level of reducing sugars present in potato. The reducing sugars required by the processor is 0.25-0.3% (Arthey and Hall, 1971). High specific gravity potatoes have low reducing sugar contents (Burton, 1989). The desirable storage temperature of potatoes for French fries is 7.2-10°C. A portion of the starch in the tubers converts to sugars if the storage temperature is lower than 7.2°C (Arthey and Hall, 1971). Accumulation of reducing sugars in tubers results in excessive Maillard browning during frying and a bitter taste of the product. The reducing sugars content would be lowered if the potato is reconditioned at about 21°C for a period of time and blanched before frying (Toma et al., 1986; Califano and Calvelo, 1987).

Texture

Acceptability in the texture of French fries is widely limited. Crispness without hardness, leatheriness or gumminess, sogginess and oiliness is considered to be desired characteristics of the product. The inner part of French fries should be firm and slightly mealy without separation between core and crust (Feustel and Kueneman, 1967; Arthey and Hall, 1971). The solids content of the raw tuber is considered the major factor affecting the texture of French fries. The solids content of the material for French fries should be between 20-22% (Sayre et al., 1975). The texture of cooked potato products is influenced by the degree of cell rupturing. Exuded gelatinized starch resulted in the gumminess of French fries (Reeve, 1977). A higher heating temperature results in an increased amount of ruptured cells (Nonaka, 1980). If there is over 4-5% cell rupturing in potatoes, the texture of both crust and interior of French fries could be gummy.

Influence of Storage on Quality of Frozen French Fried Potatoes

Kirkpatrick et al. (1956) investigated the effect of storage on quality of par-fried potatoes after storage for 2, 4, 6 and 9 mo at -32°C. French fries were produced immediately after harvest and after 2 and 4 mo of storage at 10°C. Increasing storage time decreased color acceptability due to increasing dullness of color. The newly harvested samples had higher acceptability scores for lack-of oiliness, crispness, and mealiness. All frozen samples, however, prepared either from the tubers immediately after harvest or after storage for 2 or 4 mo at 10°C, made satisfactory French fried potatoes. However, the samples stored for 4 mo scored low in mealiness (Feustel and Kueneman, 1967). When stored at -32°C frozen French fries exhibit more stability than most other vegetables (Feustel and Kueneman, 1967).

CHAPTER III

MATERIALS AND METHODS

Materials

Large, white potatoes were purchased from a local snack product manufacturing company (Tom's Foods, Inc., Knoxville, TN) on an as-needed basis. Corn syrups of 26 and 43 DE were obtained from A. E. Staley Manufacturing Company, Decatur, IL. Corn syrup solutions were prepared with tap water.

Osmotic Concentration Studies

Potatoes were cut into strips of 1 x 1 cm cross section, using a French fry cutter (Model 47713, Vollrath, Sheboygan, WI). The strips were cut into uniform lengths of approximately 6 cm and soaked in tap water for 1 h to standardize for moisture content. After soaking, the strips were blotted with paper towel to remove the surface moisture. Approximately 40 g of potato was weighted and contacted with 320 g of osmotic solution in a flask for each designated time period. The flasks were mounted in a temperature controlled water bath (Model MSB-1122A-1, Blue M. Electric Company, Blue Island, IL). Constant agitation of the osmotic solution was provided by shaking the flasks at 3 strokes/sec. For each DE (26 or 43 DE) of corn syrup, osmotic concentration of potato strips was conducted at 3 solute concentrations (40, 50 and 60% w/w), 3 temperatures (20, 30 and 40°C), and for 6 time intervals (0, 1, 2, 3, 4 and 5 h) with an initial solids-toliquid ratio of 1:8 (w/w). The experiments were replicated 3 times. Therefore, the total number of experimental runs was 54 (2 DE's x 3 concentrations x 3 temperatures x 3 replicates). At each time interval, solution from the flask was poured out and potato strips were given a quick rinse in distilled water and blotted to remove the excess solution adhering to the surface. Potato samples were weighed for monitoring the loss of weight, and samples were collected for measurement of moisture content.

Study of Quality Attributes during Storage

Based on the results of the kinetic studies for moisture removal and solids gain, and from the results of a preliminary study on acceptability of osmotically concentrated, frozen French fried potatoes, the optimum DE (26 DE), concentration (60%), temperature (21°C) and time (3 h) combination for osmotic pre-treatment of potato strips was selected. For each of two replicates, both control and osmotically concentrated strips were blanched in atmospheric steam for 30 sec, air-cooled by a fan, and frozen immediately in a CO_2 freezer. Frozen potato strips were packaged in quart size Ziploc® freezer bags (DowBrands, Household Products, El Paso, TX) and stored at -17°C for 0, 2, and 4 mo. At the beginning and the end of storage period, frozen potato strips were analyzed for moisture content. The strips were then fried at 195°C in a deep fryer (Model No. 8050, Gold Medal Products Co., Cincinnati, OH) with deep frying shortening (FRYMAX, Proctor and Gamble, Cincinnati, OH). The frying times for the control and osmotically dehydrated, frozen, French fried potatoes were 4.5 and 1 min, respectively. The quality attributes studied were moisture content; oil uptake; color, texture, and sensory acceptability of the control and osmotically concentrated, frozen, French fried potatoes. A flow chart of the quality attributes study is shown in Fig. 2.

Physical and Chemical Measurements

Moisture and Solids Content

Moisture content was determined using the AOAC vacuum oven method 14.003

NOT CORRECT

(AOAC, 1990). Samples of approximately 2 g of potato were weighed and dried in vacuum oven at 70°C, 175 mm Hg for 24 h. Moisture content was measured in triplicate for the kinetics of osmosis studies and in duplicate for quality attributes studies. The solids content was obtained by difference.

Concentration of Corn Syrup Solution

Concentration of corn syrup solids in the solution was measured by an Abbe refractometer (Model CM5501, Bausch & Lomb Optical Co., Rochester, NY).

Color of French Fried Potatoes

Color of fried potato strips was measured with a Hunter color difference meter (Model D25D2-M, Hunterlab, Reston, VA) which was standardized with a white tile (L=91.3, "a"=-1.3, "b"=1.6). The fried samples were cooled to room temperature (21°C), and approximately 30 g of sample was held in a cuvette with an optical glass bottom for color measurement.

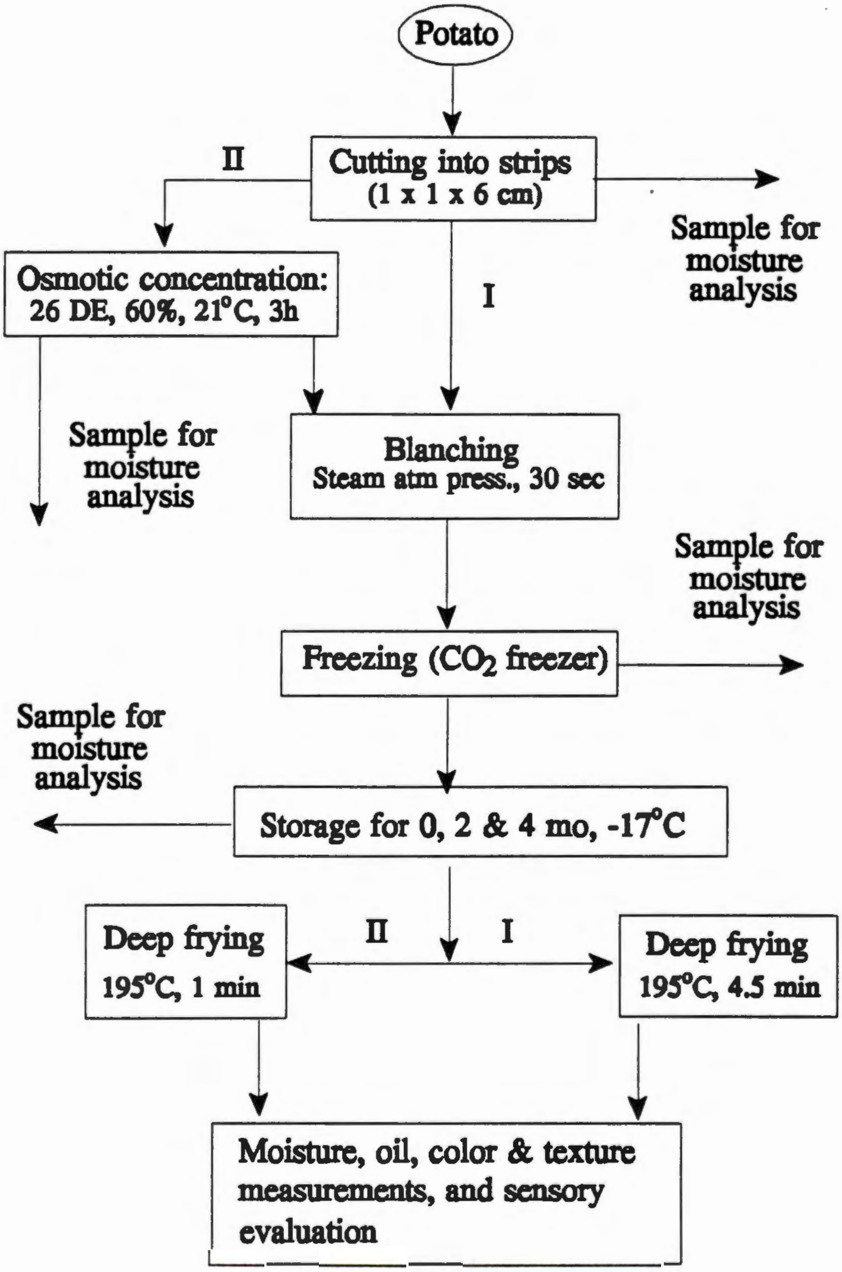


Fig. 2 -- A flow chart of the quality-attributes study of the osmotically concentrated, frozen, French fried potatoes (I. Control; II. Osmotically treated).

Texture of French Fried potatoes

The texture of French fried potatoes was measured with an Instron Universal Testing Machine (Model 1132, Instron Corporation, Canton, MA). A sample of 30 g of fried potatoes was placed in the Kramer shear cell such that the strips lay perpendicular to the blades. The hardness of samples was measured with crosshead and chart speeds of 10 cm/min and 500-kg full scale load with range set at 20.

Crude Fat

Dry samples (2 g) were extracted for 4 h with petroleum ether in a Goldfish apparatus using AOAC method 7.062 (AOAC, 1990). NOT CORRECT

Sensory Evaluation

Fried potato samples were evaluated on 8-point hedonic scales by a sensory panel (Larmond, 1977; Penfield, 1992). Panelists were recruited from faculty, staff, and students in the College of Agricultural Sciences and Natural Resources, The University of Tennessee, Knoxville. The control and osmotically concentrated potato strips were fried at 195°C for 4.5 and 1 min, respectively, just before serving. Samples were illuminated with white fluorescent lighting (Penfield, 1992). The warm samples were served for evaluation by panelists in individual booths of the sensory laboratory in Food Science and Technology Department. Each panelist received 2 samples of French fried potatoes in a balanced order. Each sample was coded with 3-digit random numbers and contained 2 pieces of fries. The test was conducted under white lights. Panelists were asked to complete a scorecard (Appendix A) for each of the samples tested.

Calculation Methods

Moisture loss (ML) from potato expressed as fraction of initial water present in the tissue, was calculated using Eq. 1.

$$ML = \frac{m_0 w_0 - m_\theta w_{w\theta}}{m_0 w_0} \qquad (1)$$

Where: m_0: mass of potato at time zero,

m_θ: mass of potato at time theta,

w_{w0}: mass fraction of water in potato at time zero, and

$w_{w\theta}$: mass fraction of water in potato at time theta.

Solids gain (SG) by the potato strips was expressed as kg of solutes taken up per kg of solids originally present in potato as given by Eq. 2.

$$SG = \frac{m_\theta w_{s\theta} - m_0 w_{s0}}{m_0 w_{s0}} \qquad (2)$$

Where: m_0: mass of potato at time zero,

m_θ: mass of potato at time theta,

w_{s0}: mass fraction of solids in potato at time zero, and

$w_{s\theta}$: mass fraction of solids in potato at time theta.

Model for Moisture Loss

A model was established to express the moisture loss as a function of temperature, solute concentration, and time of osmosis. A diffusion equation of Crank (1975) was modified and used as the model. The equation is given below.

$$ML = B_0 \left(1 - e^{-B_1 \theta} \right) \tag{3}$$

Where: ML: moisture loss from potato strips (fraction of original moisture content).

θ: time of osmosis (hour), and

B_0 and B_1: parameters of the model. These parameters are functions of temperature and solute concentration of the osmosis solution.

In using the diffusion model (Eq. 3), it was assumed that the resistance to the movement of water remained in the solid material. The model (Eq. 3) meets the condition that the moisture loss was equal to zero at time zero of osmosis.

Statistical Analysis

The study of the kinetics of osmosis was designed as a randomized complete block (2 DE's x 3 temperatures x 3 concentrations x 6 times) (Ott, 1988). The data on kinetics of osmosis were analyzed using the Statistical Analysis System (SAS Institute Inc., 1985). A probability level of $p<0.05$ was considered significant. The effects of DE, solute concentration and temperature on moisture loss, solute gain and net weight loss of potato strips were studied using analysis of variance (ANOVA). The non-significant ($p>0.05$) interaction terms were removed and data were reanalyzed. Significant differences among means were determined using Tukey's test within ANOVA (SAS Institute Inc., 1985). The parameters of the exponential model for moisture loss were estimated by non-linear regression (NLIN) within SAS (SAS Institute, Inc., 1988), and the effects of concentration and temperature of the osmotic solution on the parameters were studied by ANOVA. For each treatment combination i.e. solute concentration and temperature combination, B_0 and B_1 values were estimated with replicate runs pooled together. An R^2-like term, defined by Eq. 4, was used to evaluate the adequacy of fitting.

$$R^2\text{-like} = 1 - \frac{\text{Error Sum of Squares}}{\text{Corrected Total Sum of Squares}} \tag{4}$$

The effect of storage time on moisture content, color and texture of, and oil uptake by, potato strips during frying were evaluated by ANOVA. The sensory data were analyzed as factorials of a randomized incomplete block design due to missing data. The data were analyzed by General Linear Model (GLM). After an initial analysis, non-significant ($p>0.05$) interactions were removed from the model, and the data were reanalyzed. Significant differences among means were determined using Least-squares Means (LSMEANS) with the PDIFF option (SAS, 1985). Frequency tables (FREQ) were used to study the distribution of sensory scores at each storage time by gender of panelists and by frequency of consumption of French fries.

CHAPTER IV

RESULTS AND DISCUSSION

The Kinetics of Osmosis

Weight Loss of Potato Strips

The loss of weight of potato strips described by the ratio m_θ/m_0, where m_0 and m_θ are mass of potato at time 0 and θ, respectively, is the net result of moisture loss from, and solute gain by, the potato strips. As seen in Figs. 3-5, for all treatment combinations, i.e. DE, concentration and temperature combinations, the cumulative mass of moisture loss from potato strips at any time during osmosis was greater than the mass of solids gain by the strips. A maximum weight reduction of about 50% was obtained with osmotic concentration in 50 and 60% corn syrup solutions of 26 and 43 DE at 40°C.

The results of the analysis of variance (ANOVA) of m_θ/m_0 for the main factors and the interactions of DE, temperature, solute concentration and time of osmosis indicated there were significant ($p<0.05$) interaction terms involving DE (Table B1 in Appendix B). Therefore, the data were analyzed separately for the two DE's. Results of the analysis of variance of m_θ/m_0 for each DE (Table 1) showed the main factors (DE, temperature, solute concentration and time of osmosis significantly affected the weight loss for both 26 and 43 DE ($p<0.05$). The only interaction term that was significant ($p<0.05$) was concentration x time for 26 DE.

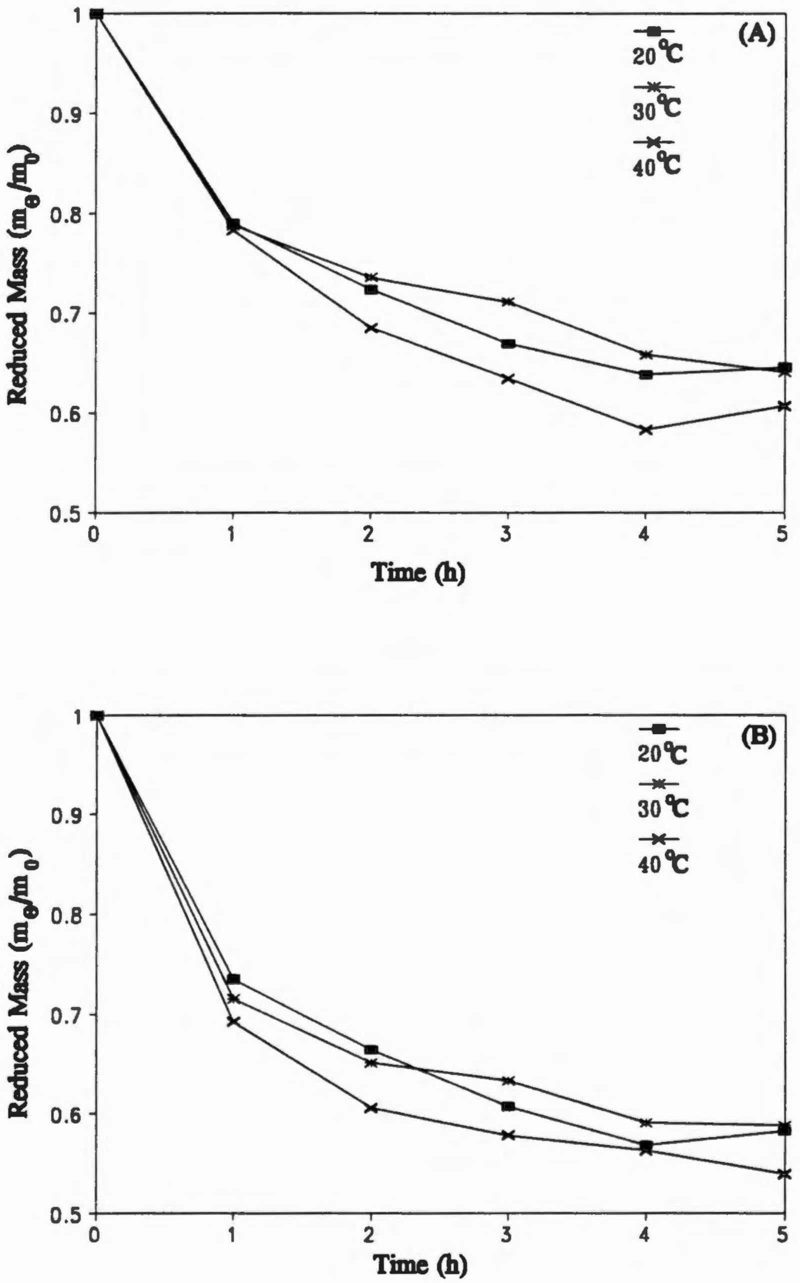


Fig. 3 -- Net weight loss of potato strips osmotically concentrated in 40% (w/w) corn syrup solutions of 26 DE (A) and 43 DE (B). (m_0 and m_θ: mass of potato strips at time zero and theta, respectively.)

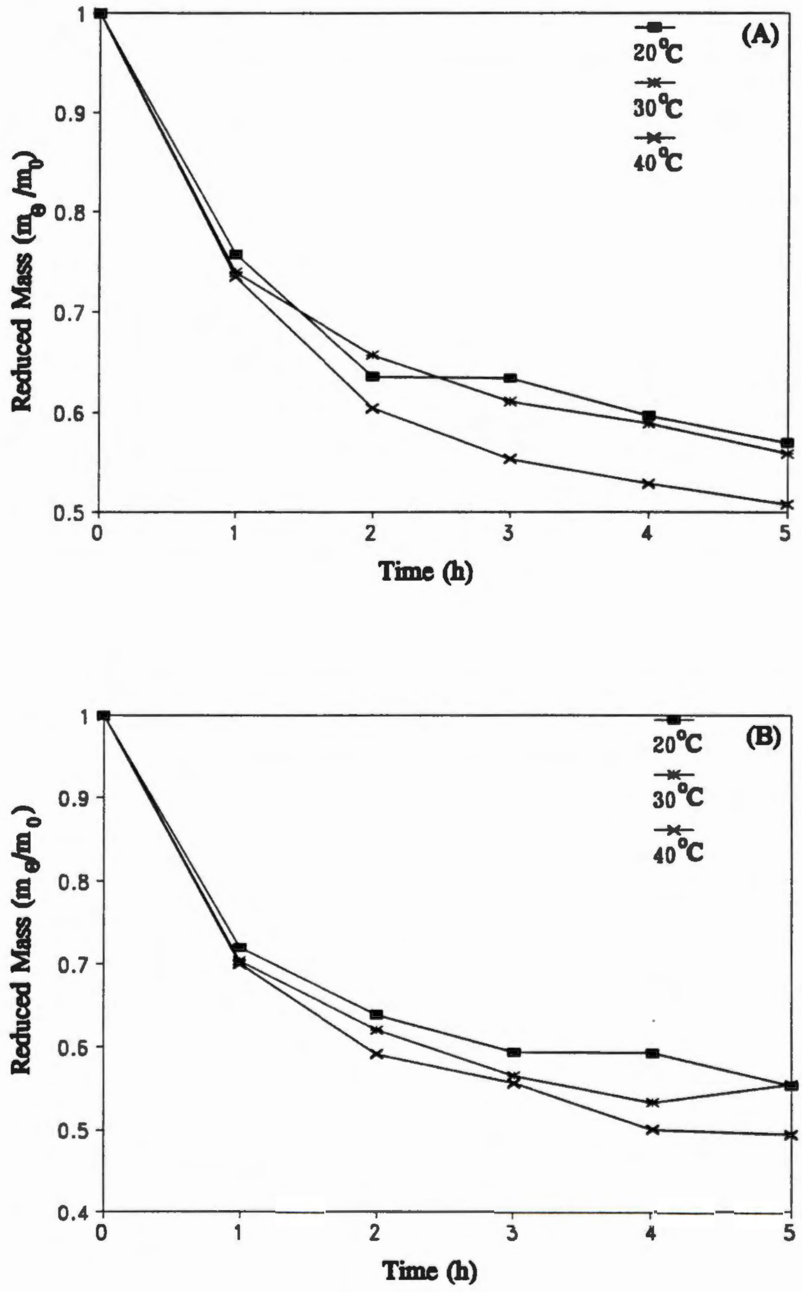
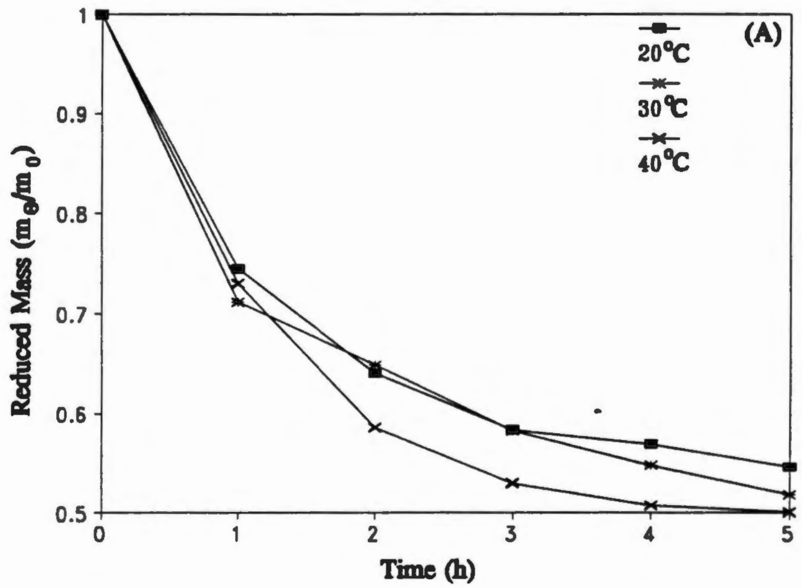


Fig. 4 -- Net weight loss of potato strips osmotically concentrated in 50% (w/w) corn syrup solutions of 26 DE (A) and 43 DE (B). (m_0 and m_θ: mass of potato strips at time zero and theta, respectively.)



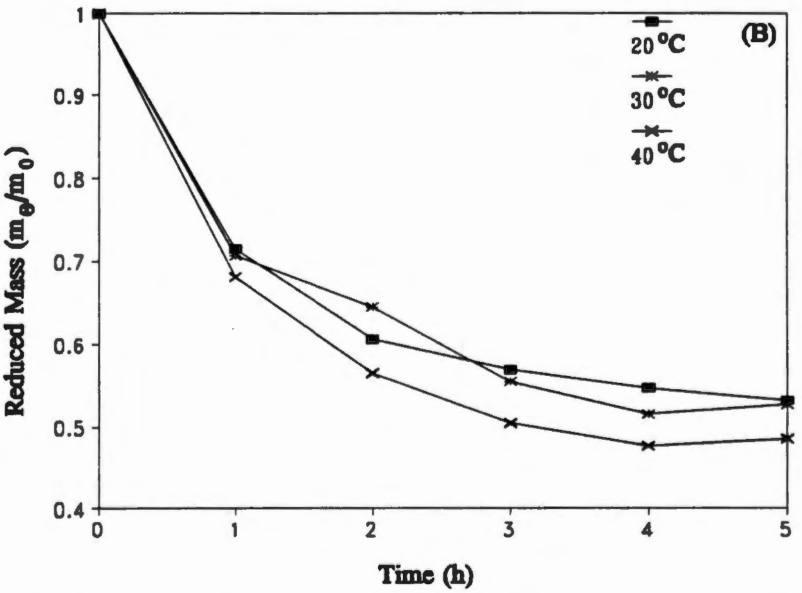


Fig. 5 -- Net weight loss of potato strips osmotically concentrated in 60% (w/w) corn syrup solutions of 26 DE (A) and 43 DE (B). (m_0 and m_θ: mass of potato strips at time zero and theta, respectively.)

Table 1 -- Analysis of variance of reduced mass $(m_\theta/m_0)^a$ of potato strips in contact with corn syrup solutions of 26 DE and 43 DE

Factor	DF	Sum of squares	Pr>F
26 DE			
Temperature	2	0.0469	0.0001
Concentration (C)	2	0.1642	0.0001
Time	5	3.6429	0.0001
C x Time	10	0.0432	0.0129
Error	142	0.2593	-
43 DE			
Temperature	2	0.0457	0.0001
Concentration (C)	2	0.0390	0.0001
Time	5	4.1841	0.0001
C x Time	10	0.0157	0.0897
Error	142	0.1319	-

[a] m_0 and m_θ: mass of potato strips at time zero and theta, respectively.

Results of the mean separation by Tukey's test within ANOVA (Table 2), suggested that for both 26 and 43 DE, increasing temperature from 30 to 40°C affected weight loss of potato strips significantly ($p<0.05$). Increasing the temperature from 20 to 30°C, however, did not affect the weight loss ($p>0.05$). The effect of solute concentration x time interaction was observed. For 26 and 43 DE, increasing contact time from 0 to 1 h and from 1 to 2 h significantly ($p<0.05$) reduced the mass at all concentrations. There was no significant decrease in mean mass when the contact time was 3 to 5 h for the 26 DE treatment. For 43 DE, the same pattern occurred when increasing contact time from 3 to 5 h, except at 40% concentration of solute solution increasing contact time from 3 to 5 h did significantly ($p<0.05$) reduce mass of the potato strips. In general, mean mass of the potato strips decreased as solute concentration increased for both DE corn syrups.

Moisture Loss from Potato Strips

Moisture loss, expressed as fraction of original moisture in potato strips, is shown in Figs. 6, 7, and 8, for 40, 50, and 60% (w/w) solute concentrations, respectively. Experimental data points shown on Figs. 6-8 are means of the three replicates. In general, moisture loss increased very rapidly at the beginning of osmosis and gradually reached almost a constant level with time. The data agree very closely with the weight loss indicating most of the mass loss was water as expected.

For a given temperature/concentration combination, the moisture loss from potato in 43 DE corn syrup solution was greater than 26 DE corn syrup solution which agrees with other research (Biswal and Bozorgmehr, 1992b). Because higher DE corn syrup

Table 2 -- Mean reduced mass (m_θ/m_0)[a] of potato strips in contact with corn syrup solutions at different temperatures, concentrations, and times

Factor	m_θ/m_0 (26 DE)			m_θ/m_0 (43 DE)		
Temperature (°C)						
20	0.7079[b]			0.6792[b]		
30	0.7054[b]			0.6724[b]		
40	0.6706[c]			0.6406[c]		
			Concentration			
Time (h)	40%	50%	60%	40%	50%	60%
0	1.0000[b]	1.0000[b]	1.0000[b]	1.0000[b]	1.0000[b]	1.0000[b]
1	0.7875[c]	0.7447[c]	0.7288[c]	0.7147[c]	0.7072[c]	0.7006[c]
2	0.7148[d]	0.6319[d]	0.6249[d]	0.6405[d]	0.6169[d]	0.6054[d]
3	0.6714[de]	0.5989[de]	0.5647[de]	0.6061[de]	0.5711[e]	0.5433[e]
4	0.6260[e]	0.5707[e]	0.5414[e]	0.5735[ef]	0.5415[e]	0.5135[e]
5	0.6304[e]	0.5452[e]	0.5215[e]	0.5700[f]	0.5337[e]	0.5154[e]
Mean[g]	0.7383	0.6819	0.6636	0.6842	0.6618	0.6463

[a] m_0, m_θ: mass of potato strips at time zero and at time theta, respectively.

[b-f] Means in a column within a factor not sharing same superscript are different ($p<0.05$).

[g] Mean m_θ/m_0 across time for concentration.

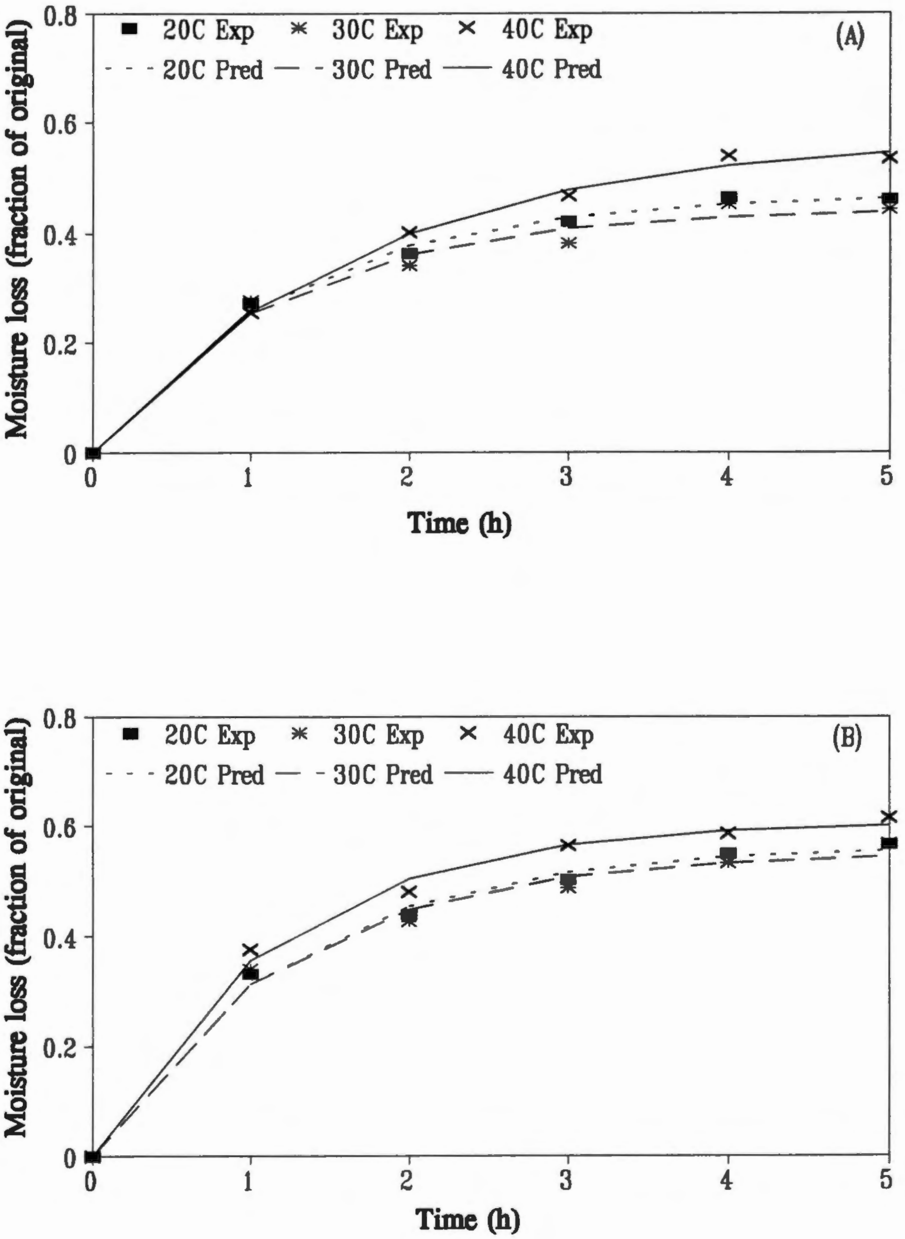
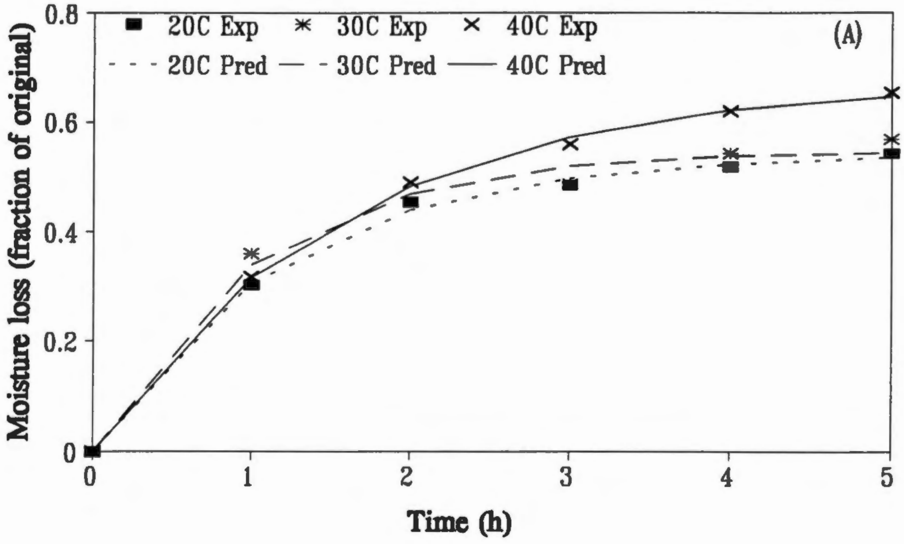


Fig. 6 -- Moisture loss (ML) from potato strips in contact with 40% corn syrup solutions of 26 DE (A) and 43 DE (B). (Exp: experimental; Pred: predicted from ML= B_o (1- $e^{-B_1\theta}$), where B_o and B_1 are constants and θ is time in h.)



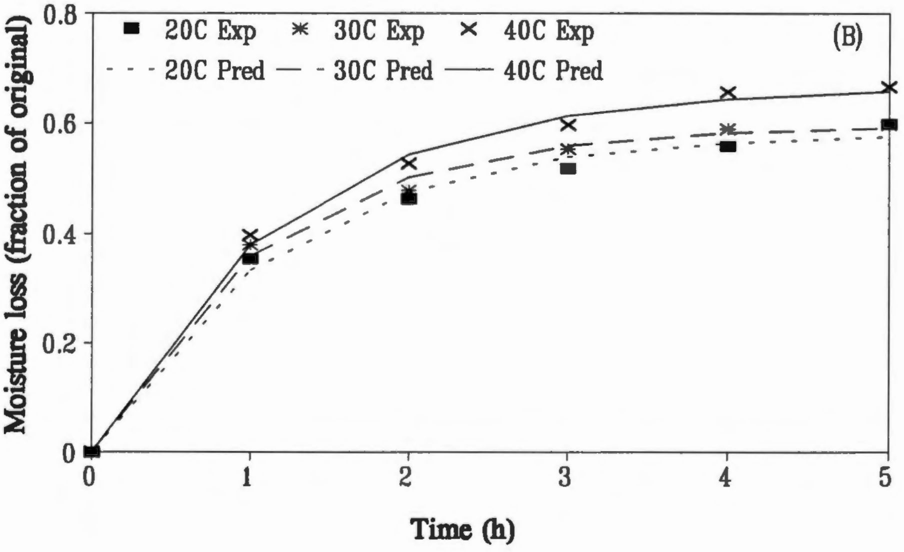


Fig. 7 -- Moisture loss (ML) from potato strips in contact with 50% corn syrup solutions of 26 DE (A) and 43 DE (B). (Exp: experimental; Pred: predicted from $ML = B_0(1 - e^{-B_1\theta})$, where B_0 and B_1 are constants and θ is the time in h.)

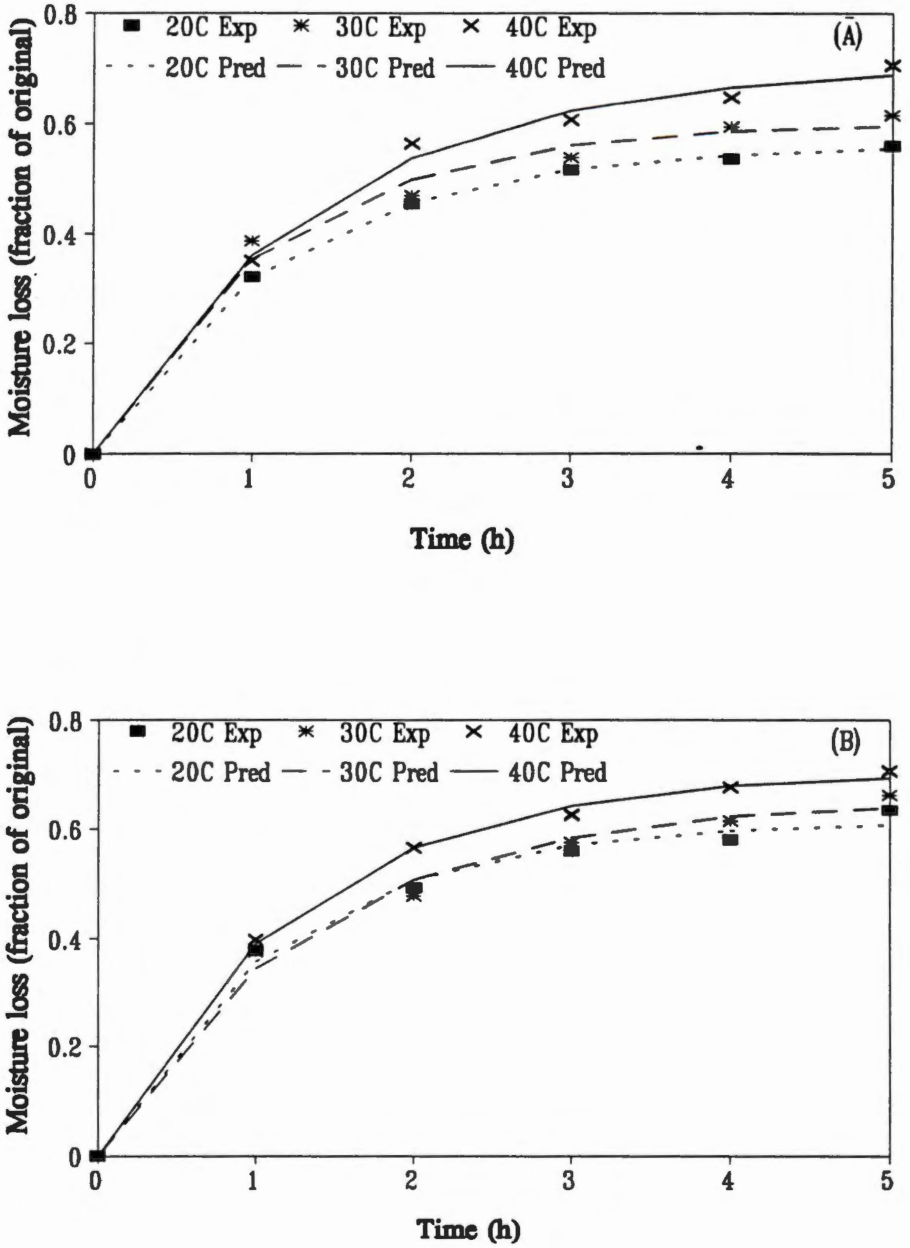


Fig. 8 -- Moisture loss (ML) from potato strips in contact with 60% corn syrup solutions of 26 DE (A) and 43 DE (B). (Exp: experimental; Pred: predicted from

$$\mathbf{ML} = \mathbf{B_0(1-e^{-B_1\theta})},$$ where B_o and B_1 are constants and θ is the time in h.)

contains a higher amount of monosaccharides which results in higher osmotic pressure in the solutions (Ponting et al., 1966; Le Maguer, 1988). The difference in DE corn syrup effects also is apparent since there were significant interaction terms involving DE (Table B2 in Appendix B), the data were analyzed separately again for the two DE's. Results of the analysis of variance of moisture loss from potatoes as affected by solute concentration, temperature and time of osmosis are given in Table 3 for 26 and 43 DE corn syrup solutions, separately. For both DE's, the main factors i.e. concentration, temperature and time of osmosis significantly affected moisture loss ($p<0.05$). The significant interaction terms were temperature x time and concentration x time ($p<0.05$). These interactions indicated that the effect of time of osmosis on moisture loss depends on the temperature and solute concentration of the osmotic solution.

A mean separation analysis was conducted for each DE as shown in Table 4. For potato strips in 26 DE, at 20, 30 and 40°C, increasing time from 1 to 2 h significantly increased moisture loss ($p<0.05$), while increasing time from 3 to 5 h did not ($p>0.05$) affect the moisture loss at all temperatures except at 30°C. For potato strips in 43 DE, at 20, 30 and 40°C, increasing time from 1 to 3 h significantly increased moisture loss ($p<0.05$), while increasing time from 3 to 4 h or from 4 to 5 h did not ($p>0.05$) affect the moisture loss. For 26 DE, at 40, 50 and 60%, increasing time from 1 to 2 h significantly increased moisture loss ($p<0.05$), while increasing time from 3 to 5 h did not ($p>0.05$) affect the moisture loss at all concentrations except at 50%. For 43 DE, at 40, 50 and 60%, increasing time from 1 to 3 h significantly increased moisture loss ($p<0.05$), and increasing time from 3 to 4 h or from 4 to 5 h did not ($p>0.05$) affect the moisture loss.

Table 3 -- Analysis of variance of moisture loss from potato strips in contact with corn syrup solutions of 26 DE and 43 DE

Factor	DF	Sum of squares	Pr>F
26 DE			
Temperature (T)	2	0.0983	0.0001
Concentation (C)	2	0.2862	0.0001
Time	5	6.1267	0.0001
Replication	2	0.0076	0.1949
T x Time	10	0.0715	0.0015
C x Time	10	0.0070	0.0017
Error	130	0.3008	-
43 DE			
Temperature (T)	2	0.0805	0.0001
Concentation (C)	2	0.0390	0.0001
Time	5	1.4591	0.0001
Replication	2	0.0170	0.0001
T x time	10	0.0023	0.0037
C x time	10	0.0023	0.0039
Error	130	0.1064	-

Table 4 -- Mean moisture loss (ML) from potato strips in contact with corn syrup solutions of 26 DE and 43 DE at different concentrations, temperatures, and times

Time (h)	ML (26 DE)			ML (43 DE)		
	Temperature					
	20°C	30°C	40°C	20°C	30°C	40°C
0	0.0000^{d}	0.0000^{d}	0.0000^{d}	0.0000^{e}	0.0000^{e}	0.0000^{e}
1	0.2986^{c}	0.3409^{c}	0.3076^{c}	0.3540^{d}	0.3652^{d}	0.3896^{d}
2	0.4238^{b}	0.4208^{b}	0.4854^{b}	0.4647^{c}	0.4600^{c}	0.5236^{c}
3	0.4749^{ab}	0.4689^{b}	0.5452^{ab}	0.5266^{b}	0.5378^{b}	0.5952^{b}
4	0.5075^{a}	0.5298^{a}	0.6022^{a}	0.5617^{ab}	0.5785^{ab}	0.6396^{ab}
5	0.5222^{a}	0.5430^{a}	0.6312^{a}	0.5996^{a}	0.6085^{a}	0.6616^{a}
Mean^{f}	0.3374	0.3833	0.3867	0.4176	0.4248	0.4748
	Concentration					
	40%	50%	60%	40%	50%	60%
0	0.0000^{d}	0.0000^{e}	0.0000^{d}	0.0000^{e}	0.0000^{e}	0.0000^{e}
1	0.2689^{c}	0.3262^{d}	0.3521^{c}	0.3488^{d}	0.3764^{d}	0.3836^{d}
2	0.3681^{b}	0.4654^{c}	0.4965^{b}	0.4483^{c}	0.4890^{c}	0.5112^{c}
3	0.4229^{ab}	0.5111^{bc}	0.5549^{ab}	0.5171^{b}	0.5557^{b}	0.5869^{b}
4	0.4855^{a}	0.5610^{ab}	0.5930^{a}	0.5553^{ab}	0.6010^{ab}	0.6235^{ab}
5	0.4795^{a}	0.5889^{a}	0.6281^{a}	0.5823^{a}	0.6202^{a}	0.6672^{a}
Mean^{g}	0.3374	0.4086	0.4372	0.4317	0.4402	0.4619

$^{a-e}$ Means in a column within a factor not sharing same superscript are different ($p<0.05$).

^{f} Mean moisture loss across time for temperature.

^{g} Mean moisture loss across time for concentration.

Overall, mean moisture loss across time increased with temperature and concentration at both DE's. Moisture loss from potato strips in 43 DE corn syrup solution at all temperature and concentration levels was greater than that from potato strips in 26 DE solution at the respective temperature and concentration levels. As given in Table 5, moisture loss from potato in 5 h of contacting ranged between 46 and 70% of the original moisture within the range of experimental conditions used in the study. At 40°C and 60% solute concentration, moisture loss from potato after 5 h contacting with 26 or 43 DE corn syrup solution was about 70% of the original moisture.

Solids Gain by Potato Strips

Solids gain (kg solute taken up/kg original solids present in potato tissue) was observed to vary inconsistently with DE of corn syrup, solute concentration, temperature, and the time of osmosis. Excessive variation of solids gain from replicate to replicate was observed also (Figs. C1-C9, Appendix C). For many treatment combinations, solids gain at different times of osmosis was found to be negative, which meant leaching of original soluble solids from the tissue was greater than solids uptake by the tissue. The only treatment combination for which no negative solids gain was found was 43 DE corn syrup solute at 50% solute concentration and 20°C (Fig. 9). For this treatment combination, a maximum solute uptake of 0.43 kg solute/kg of original solids was observed. In fact, 0.43 kg solids/kg of original solid was the highest solids uptake in the entire range of experimental conditions used. The lowest solute uptake was -0.3 kg/kg of original solids for the treatment combination of 43 DE/60% solute concentration at 20°C after 2 h of

Table 5 -- Moisture loss from potato strips in contact with 26 DE and 43 DE corn syrup solutions at three solute concentrations (40, 50, and 60%, w/w) and three temperatures (20, 30, and 40°C) for 5 hours

Solute concentration (%, w/w)	Temperature (°C)	Moisture loss (fraction of original)	
		26 DE	43 DE
40	20	0.461	0.565
	30	0.462	0.611
	40	0.488	0.644
50	20	0.544	0.599
	30	0.569	0.597
	40	0.654	0.665
60	20	0.561	0.635
	30	0.601	0.661
	40	0.705	0.705

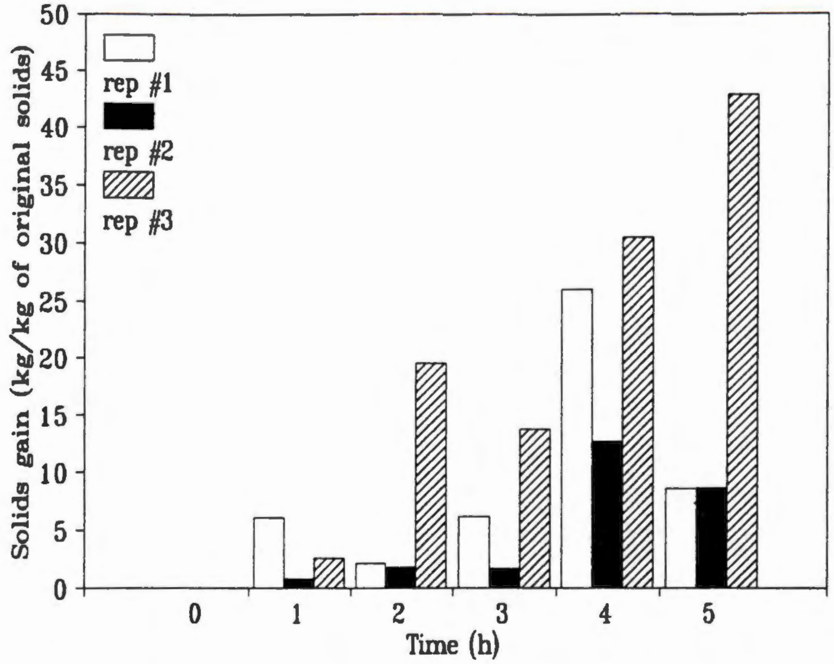


Fig. 9 -- Solids gain by potato strips in contact with 50% corn syrup solution of 43 DE at 20°C.

osmosis. Results of the analysis of variance of solids gain as affected by DE, solute concentration, temperature, and time of osmosis indicated that only the time of osmosis significantly affected the solids gain ($p<0.05$, Table 6). The only interaction term that was significant ($p<0.05$) was temperature x concentration.

In general, solids gain appeared to increase with time. Increasing time from 3 to 5 h significantly ($p<0.05$) increased solids gain by potatoes, increasing time from 1 to 4 h did not significantly ($p>0.05$) increase solids gain by potatoes. The mean values of solids gain by potatoes were the following: 1 h, 0.0171; 2 h, 0.0384; 3 h, 0.0509; 4 h, 0.0718; 5 h, 0.1252. In some cases solids gain changed from negative values in the early part of the contacting to positive values toward the end of contacting (Appendix C). This suggested that leaching might be occurring throughout the process of osmotic contacting, but whether it is noticeable or not depends on the net value of the solids movement (from solution into potato strips and vice versa). Therefore, with the increase in contacting time, as the solute uptake increased, the net movement of solutes appeared as solids gain rather than leaching.

One possible reason for leaching could be the "washing" of soluble solids from the ruptured cells at the surface of potato strips cut by French fry cutter; the other reason could be the high reducing sugar content of certain batches of potatoes used in the study. Leaching of soluble solids from potato tissue was particularly noticed for one replicate of almost all treatment combinations (Figs. C1-C9, Appendix C), which may be due to higher reducing sugar content of potatoes used in those experiments.

The corn syrups used in this study contained a very large percentage of their solids

Table 6 -- Analysis of variance of solids gain by potato strips in contact with corn syrup solutions of 26 and 43 DE at different concentrations and temperatures

Factor	DF	Sum of squares	Pr>F
DE	1	0.0080	0.4072
Temperature (T)	2	0.0010	0.9565
Concentration (C)	2	0.0041	0.8370
Time	5	0.5317	0.0001
T x C	4	0.1695	0.0064
Error	309	3.5940	-

content as polysaccharide (trisaccharide or higher molecular weight saccharide). The 26 DE corn syrup contained 87% and 43 DE contained 67% polysaccharide. For osmotic concentration with a disaccharide like sucrose, the most commonly used osmotic agent, a solids gain is always noticeable, because the solute uptake by the tissue is always greater than the solids loss from the tissue. For osmotic concentration with corn syrup solutions, the larger molecular weight solids could not penetrate the potato tissue, thus making the solids loss noticeable as leaching.

An extensive investigation of the leaching phenomenon is suggested. Fresh potato and corn syrups should be analyzed for their specific sugar contents. Composition of potato and corn syrup solutions should also be monitored at designated time intervals of the osmotic contacting to keep an account of the change in their sugar contents with time of osmosis; this will help understand the leaching phenomenon better.

A Model for Moisture Loss From Potato Strips

As discussed in the previous section, moisture loss from potato strips was affected by solute concentration, temperature, and time of osmosis. The equation given below was used as a model to express the moisture loss (ML) as a function of these factors.

$$ML = B_0 \left(1 - e^{-B_1 \theta} \right) \qquad (3)$$

The estimated values of B_0, B_1, and the corresponding R^2-like values are listed in Table 7. Sixteen of 18 R^2-like values were 0.95 or higher. The lowest R^2-like (0.91) was obtained for 26 DE/40%/40°C treatment combination where the variation in moisture loss

Table 7 -- Parameters B_0 and B_1 of the exponential model[a] for moisture loss frompotato strips in contact with corn syrup solutions of 26 and 43 DE at different concentrations and temperatures

DE	Solute Concentration (%, w/w)	Temperature (°C)	B_0	B_1	R^2-like
26	40	20	0.471	0.807	0.97
		30	0.443	0.842	0.96
		40	0.574	0.593	0.91
			(0.496)[b]	(0.722)[b]	(0.98)[b]
	50	20	0.544	0.823	0.95
		30	0.550	0.952	0.96
		40	0.677	0.626	0.95
	60	20	0.565	0.828	0.94
		30	0.604	0.881	0.98
		40	0.707	0.715	0.95
43	40	20	0.565	0.811	0.98
		30	0.552	0.838	0.97
		40	0.609	0.875	0.98
	50	20	0.583	0.851	0.98
		30	0.596	0.919	0.98
		40	0.668	0.836	0.98
	60	20	0.615	0.870	0.98
		30	0.655	0.744	0.96

[a] $ML=B_0\ [1-\exp(-B_1\theta)]$ where ML is the fraction of original moisture lost and θ is time of osmosis in h.
[b] Estimated from two similar replicates for temperature 40°C.

among the replicate runs was excessive; moisture loss from potato strips for one replicate was particularly different from the other two. The R^2-like value was improved to 0.98 when the moisture loss data of the two similar replicates were used. The uniqueness of Table 7 is that one can use the parameters B_0 and B_1 to calculate moisture loss at any time during osmosis for the designated DE, solute concentration and temperature combination.

An analysis of variance was conducted to study the effects of temperature and concentration on B_0 and B_1 for each DE. For 26 DE corn syrup solution (Table 8), B_0 was affected by solute concentration and temperature ($p<0.05$), while B_1 was affected only by the temperature ($p<0.05$). For 43 DE corn syrup solution (Table 9), parameter B_0 was affected by solute concentration and the temperature ($p<0.05$), while the parameter B_1 was affected neither by concentration nor temperature ($p>0.05$).

Significance of differences among mean values of B_0 and B_1 for moisture loss from potato in 26 DE corn syrup solutions is shown in Table 10. For The mean of B_0 at 40% concentration level was lower from those at 50 and 60% concentrations, which were not significantly different from each other. Mean values of B_0 and B_1 at 20°C were not significantly different from those at 30°C, while means for both temperature were significantly different from those at 40°C.

Significance of difference among mean values of B_0 for moisture loss from potato in 43 DE corn syrup solutions is given in Table 11. Increasing concentration from 40 to 50% or from 50 to 60% did not affect the mean value of B_0 ($p>0.05$). The difference between the mean values for 40 and 60% solute concentration, however, was significant

Table 8 -- Analysis of variance of parameters B_0 and B_1 of the exponential model[a] for moisture loss from potato strips in contact with 26 DE corn syrup solutions at three concentrations (40, 50, and 60%) and three temperatures (20, 30 and 40°C)

Source	DF	Sum of squares	Pr>F
Parameter B_0			
Concentration	2	0.02676	0.0018
Temperature	2	0.03034	0.0014
Error	4	0.00029	-
Parameter B_1			
Concentration	2	0.00666	0.2937
Temperature	2	0.09682	0.0057
Error	4	0.11136	-

[a] $ML=B_0\,[1-\exp(-B_1\theta)]$ where ML is the fraction of original moisture lost and θ is time of osmosis in h.

Table 9 -- Analysis of variance of parameters B_0 and B_1 of the exponential model[a] for moisture loss from potato strips in contact with 43 DE corn syrup solutions at three solute concentrations (40, 50, and 60%) and three temperatures (20, 30 and 40°C)

Source	DF	Sum of squares	Pr>F
Parameter B_0			
Concentration	2	0.00523	0.0072
Temperature	2	0.00455	0.0093
Error	4	0.00097	-
Parameter B_1			
Concentration			
Temperature	2	0.00594	0.4889
Error	2	0.00157	0.9777
	4	0.01381	-

[a] $ML = B_0\,[1 - \exp(-B_1\theta)]$ where ML is the fraction of original moisture lost and θ is time of osmosis in h.

Table 10 -- Mean values of parameters B_0 and B_1 of the exponential model[a] for moisture loss from potato strips in contact with 26 DE corn syrup solutions at different solute concentrations and temperatures

	B_0	B_1
Concentration (%)		
60	0.6253[b]	0.8078[b]
50	0.5903[b]	0.8017[b]
40	0.4962[c]	0.7473[b]
Temperature°C		
40	0.6527[b]	0.6448[c]
30	0.5326[b]	0.8916[b]
20	0.5266[c]	0.8204[b]

[a] $ML=B_0\,[1-\exp(-B_1\theta)]$ where ML is the fraction of original moisture lost and θ is time of osmosis in h.

[b, c] Means in a column within a factor not sharing same superscript are different ($p<0.05$).

Table 11 -- Mean values of parameters B_0 and B_1 of the exponential model[a] for moisture loss from potato strips in contact with 43 DE corn syrup solution at different solute concentrations and temperatures

	B_0	B_1
Concentration (%)		
60	0.6587[b]	0.8689[b]
50	0.6158[bc]	0.8415[b]
40	0.5752[c]	0.8061[b]
Temperature (°C)		
40	0.6609[b]	0.8382[b]
30	0.6011[c]	0.8341[b]
20	0.5878[c]	0.8442[b]

[a] $ML=B_0\ [1-\exp(-B_1\theta)]$ where ML is the fraction of original moisture lost and θ is time of osmosis in h.

[b, c] Means in a column within a factor not sharing same superscript are different ($p<0.05$).

($p<0.05$). The mean of B_0 at 20°C was not significantly different from that at 30°C, while the mean of B_0 at 30°C was significantly different from that at 40°C.

In summary, for osmotic concentration with 26 and 43 DE corn syrup solutions, the moisture loss parameter B_0 was found to be a function of solute concentration (c) in % solute, w/w, and temperature (t) in °C, i.e.

$$B_0 = f\,(c, t\,), \tag{5}$$

B_1 was a function of temperature for 26 DE corn syrup solutions,

$$B_1 = f\,(t), \tag{6}$$

and B_1 was neither a function of concentration nor a function of temperature for 43 DE corn syrup solutions (Eq. 7).

$$B_1 \neq f\,(c, t) \tag{7}$$

Using the above functionalities of B_0 and B_1 for 26 and 43 DE corn syrup solutions as the guideline, B_0 and B_1 were described in polynomials of "c" and "t" by excluding the non-significant terms ($p>0.05$). The significance of a term in the polynomial was based on the results of a multilinear regression (SAS Institute Inc., 1988). The terms that best described B_0 and B_1 for moisture loss from potato in contact with 26 DE corn syrup solutions are given by Eqs. 8 and 9, respectively.

$$B_0\ (26DE) = b_1 t + b_2 c + b_3 t^2 + b_4 c^2 \tag{8}$$

$$B_1\ (26DE) = b_5 t + b_6 t^2 \tag{9}$$

In Eqs. 8 and 9, b_1, b_2, b_3, b_4, b_5 and b_6 are constants, c is solute concentration in % solute (w/w) and t is temperature in °C. The parameter B_0 for moisture loss in 43 DE corn syrup solutions was best described by Eq. 10.

$$B_0\ (43DE) = b_0 + b_1 t + b_2 t^2, \tag{10}$$

where b_0, b_1, b_2 and b_3 are constants, and t is temperature in °C. (Although as per Eq.5, B_0 (43 DE) should be a function of both temperature and concentration, adding a concentration term to Eq. 10 did not improve the fitting.)

In summary, for 26 DE corn syrup solutions, Eq. 3 for moisture loss was re-written as

$$ML\ (26DE) = (b_1 t + b_2 c + b_3 t^2 + b_4 c^2)\ (1 - e^{(b_5 t + b_6 t^2)\theta}), \tag{11}$$

and for 43 DE corn syrup solutions, Eq.3 was re-written as

$$ML(43DE) = (b_0 + b_1 t + b_2 t^2)(1 - e^{B_1 \theta}). \tag{12}$$

The parameters of Eqs. 11 and 12 were estimated using non-linear regression

(NLIN) within SAS (SAS, 1988). The parameters estimated for moisture loss in 26 and 43 DE corn syrup solutions with R^2-like values of 0.95 and 0.96, respectively, are given by Eqs. 13-14.

$$\mathbf{B_0(26DE) = -0.027t + 0.027c + 0.0005t^2 - 0.0002c^2} \tag{13a}$$

$$\mathbf{B_1(26DE) = -0.066t + 0.001t^2} \tag{13b}$$

$$\mathbf{B_0(43DE) = 0.723 - 0.012t + 0.0003t^2} \tag{14a}$$

$$\mathbf{B_1(43DE) = -0.837} \tag{14b}$$

Using Eqs. 13-14 in conjunction with Eq. 3, one can calculate moisture loss from potato in contact with corn syrup solutions of 26 and 43 DE in a solute concentration range of 40-60%, w/w, temperature range of 20 to 40°C, and osmosis time range of 0 to 5 h.

Quality Attributes Studies

The control and osmotically concentrated (26 DE, 60% corn syrup solution, 21°C, 3 h) potato strips were frozen and stored at -17°C for 0, 2 and 4 mo, and then fried at 195°C for 4.5 and 1 min, respectively. Although the storage study was planned for 4 mo (0, 2, 4 mo of storage), the study was discontinued after 2 mo because of lower sensory acceptability of the osmotically concentrated potato in comparison to the control. The quality attributes studied were moisture content of potato before and after frying, oil uptake during frying, color, texture and sensory acceptability. The evaluation of product quality, the effects of storage for 2 mo on quality attributes, and the possible reasons for lower sensory acceptability of the product are given below. The possible approach to improving the acceptability of the product is also discussed.

Moisture Content

The mean moisture content of fresh potato (control) was 80.34% (w.b.). The mean moisture content of potato after osmotic concentration was 65.42% (w.b), which was significantly lower than that of the control. Moisture content of potato strips did not change during the storage of 2 mo ($p>0.05$, Table 12). Moisture content was also not affected by replicate ($p>0.05$). Both control and osmotically concentrated potatoes were fried approximately to the same moisture content. As given in Fig. 10 and Table E1 (Appendix E), mean moisture content of osmotically concentrated fried potatoes was 51.4% (w.b.) and that of control was 47.5% (w.b.). The difference between these two moisture contents was not significantly different ($p>0.05$). Therefore, during frying, more moisture was removed from fresh frozen than osmotically concentrated, frozen potato.

Oil Uptake

Oil content of potato after frying (kg oil/100 kg of moisture free potato) was greatly dependent on whether the material was osmotically treated or not ($p<0.05$, Table 13). Storage of potato strips for 2 mo did not affect oil uptake during frying ($p>0.05$). The

Table 12 -- Analysis of variance of moisture content of frozen French fried potatoes (before and after frying) as affected by osmotic treatment and storage for two months

Factor	DF	Sum of squares	Pr>F
Before frying			
Treatment	1	444.765	0.0027
Storage	1	10.649	0.3653
Replication	1	20.769	0.2273
Error	4	39.633	-
After frying			
Treatment	1	29.722	0.1490
Storage	1	27.011	0.1643
Replication	1	0.125	0.9135
Error	4	37.369	-

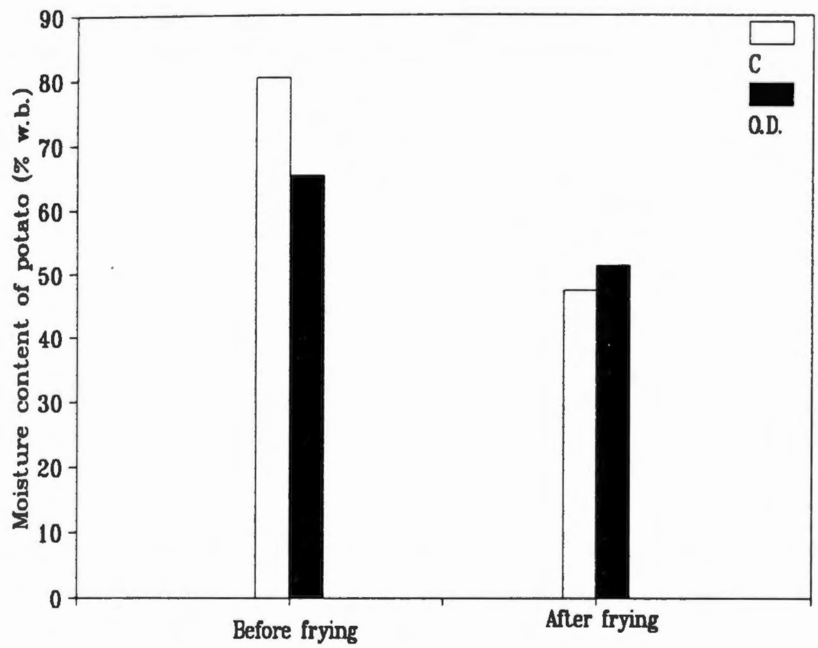


Fig. 10 -- Moisture content of fresh and osmotically concentrated potato, before and after frying. (C: control - fresh, frozen, stored for 0 and 2 mo; OD: osmotically concentrated in 26 DE corn syrup solution of 60% solute concentration at room temperature for 3 h, frozen, stored at -17°C for 0 and 2 mo.)

Table 13 -- Analysis of variance of oil content of French fried potatoes as affected by osmotic treatment and storage for two months

Source	DF	Sum of squares	Pr>F
Replication	1	14.96045	0.0356
Treatment	1	472.78125	0.0001
Storage	1	2.88000	0.2430
Error	4	6.1513	-

effect of replication (two batches of potatoes), however, was significant ($p<0.05$). After frying, the mean oil content of fresh frozen potato (control) was approximately 21.8 kg oil per 100 kg of moisture free potato as shown in Fig. 11 and Table E2 (Appendix E). The mean oil content of osmotically dehydrated, frozen, French fried potatoes was approximately 6.4 kg oil/100 kg of moisture free potato. Therefore, the oil uptake during frying of osmotically concentrated potato was about 30% of that of fresh, frozen potato. For example, 100 kg of raw potato contains approximately 80.3 kg of water and 19.7 kg of solutes. After frying to 47.5% moisture content (w.b.), the final product would contain 19.7 kg of dry solids, 5.5 kg of oil and 22.8 kg of water, giving a total weight of 48 kg. On the other hand, 100 kg of osmotically concentrated, frozen potato would contain approximately 65 kg of water and 35 kg of dry solids. After frying to a total moisture content of 51.4%, the product would contain 35 kg of dry solids, 2.4 kg of oil and 39.6 kg of water, giving a total weight of 77 kg. Therefore, for the same initial mass before frying, final oil content of the osmotically concentrated product is 44% of that of the fresh, frozen product. Also, for the same initial mass, the net mass of the osmotically treated product after frying is about 60% greater than that of fresh, frozen product.

The reduced oil uptake by the osmotically concentrated potato strips is attributed to the following two reasons: (1) greater resistance to penetration of oil, and (2) less mass of water being replaced by oil. As reported by Raoult-Wack et al. (1991), a compact outer layer develops in the plant tissue during osmotic concentration. Also, as reported by Keller et al. (1986) for French fried potatoes, the frying oil remains virtually on the surface and in the outer few layers of cells of the potato tissue. Therefore, a compact

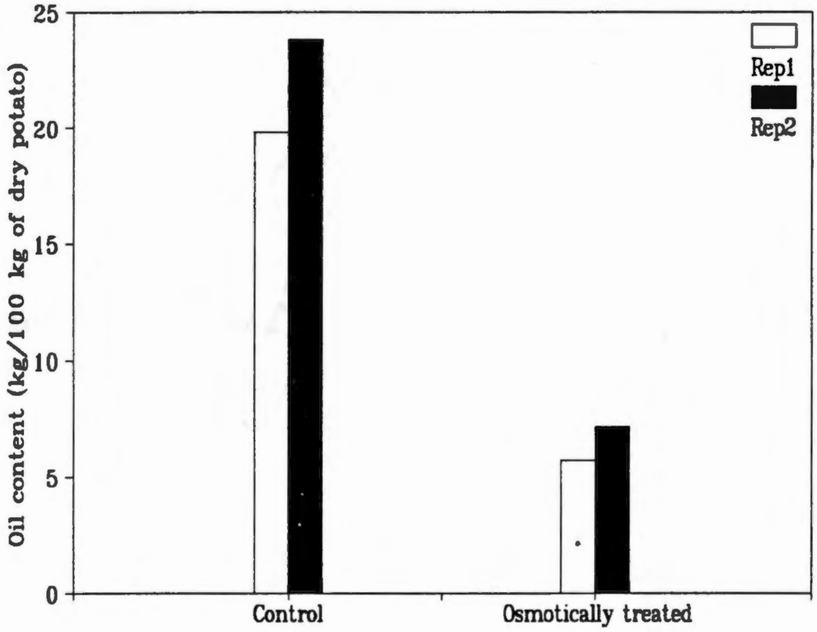


Fig. 11 -- Oil content of fresh and osmotically concentrated frozen, French fried potato. (Control- fresh, frozen, stored for 0 and 2 mo; osmotically dehydrated in 26 DE corn syrup solution of 60% solute concentration at 21°C for 3 h, and then frozen; Rep1: replicate 1; Rep2: replicate 2; oil content plotted for Rep1 and Rep2 are mean values of oil contents (after frying) of potatoes stored at -17°C for 0 and 2 mo.)

outer layer due to osmotic concentration would offer more resistance to oil penetration than the fresh, frozen tissue. As discussed in the previous section, much less moisture was removed during frying of osmotically concentrated potato than the fresh counterpart. (moisture content of fresh, frozen potato was reduced from 80.3 to 47.5% while that for osmotically concentrated, frozen potato was from 65.4 to 51.4%.). Gamble et al. (1987) reported that the amount of oil entering potato strips is directly proportional to the amount of moisture lost. Therefore, it is logical that during frying, the fresh, frozen potato strips gained more oil than the osmotically concentrated potato strips.

In a study on the effect of surface moisture on oil uptake during frying of potato strips Lamberg et al. (1990) found that during drying potato strips with dry air (2% relative humidity) an outer layer 'skin' was formed on potato strips which helped in reducing oil uptake during frying. They also observed that an increase in frying time increased oil uptake, which is consistent with the results of the present study. In the present study, the frying times at 195°C, were 4.5 and 1 min for control and osmotically treated, potato strips, respectively. These different times resulted in similar colored French fries.

Texture

Texture of French fried potatoes was evaluated using the maximum shear force (newton, N) as the indicator of relative hardness of the product. Results of the analysis of variance of texture as affected by treatment (with and without osmotic concentration), storage time (0 and 2 mo of storage) and replicate (Table 14) indicated that the effect of

Table 14 -- Analysis of variance of texture[a] of French fried potatoes as affected by osmotic treatment and storage for two months

Source	DF	Sum of squares	Pr>F
Replication (R)	1	222.605	0.1007
Treatment (T)	1	468.180	0.0368
Storage	1	54.080	0.3539
R x T	1	169.280	0.0235
Error	3	27.790	-

[a] The texture of samples was measured by Instron Universal Testing Machine.

treatment was significant ($p<0.05$), the effects of storage time and replicate were not significant ($p>0.05$), and the effect of replicate x treatment interaction was significant ($p<0.05$).

As shown in Fig. 12, texture of the osmotically treated potato was softer than the fresh counterpart. Although the difference in final moisture contents of the fresh and osmotically concentrated potatoes was statistically not significant ($p>0.05$), the difference in moisture content may cause the difference in their texture. After frying, the mean moisture content of osmotically treated potato was approximately 51.4% (w.b.) as opposed to 47.5% for fresh, frozen potato after frying.

The softness of osmotically concentrated, French fried potatoes may also be due to the changes that took place in the material during such steps as osmotic concentration, blanching and freezing, and frying. During osmotic concentration, the internal cellular texture of the tissue might have changed due to plasmolysis. Although the texture of the raw and osmotically concentrated potato were not monitored, osmotically concentrated potato strips were observed to be softer than the fresh strips (judged by pressing the strips between fingers). Shrinkage of the osmotically concentrated tissue was also observed. Blanching and freezing conditions for both treatments of potato were exactly the same; 30 seconds of blanching in atmospheric steam followed by air-cooling and quick-freezing in a CO_2 freezer. Therefore, the variation on texture due to the effects of blanching and/or freezing would be minimal. On the other hand, the extent of frying could have influenced the texture of French fried potatoes. The thickness of crust formed in potato during frying depends on the length of frying time and amount of moisture removed. A thick crust may

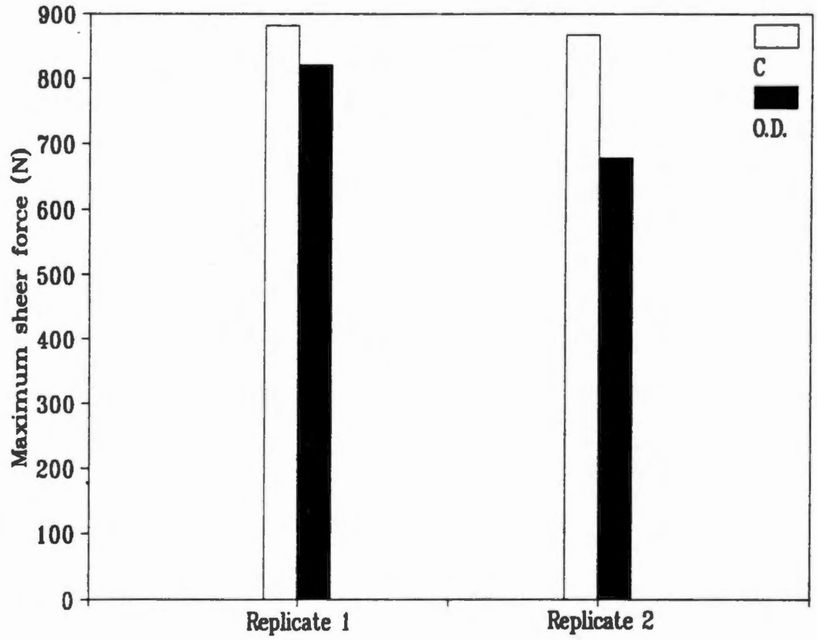


Fig. 12 -- Texture of fresh, frozen (control, C) and osmotically concentrated, frozen (OD) French fried potatoes. (The maximum shear force in newton (N) obtained from an Instron Universal Testing Machine when a Kramer shear cell was used to evaluate of hardness of French fried potatoes.)

represent hard texture and a thin crust soft texture. For osmotically treated potato, the final moisture content after frying was slightly greater than the control (even though the difference was statistically not significant), and the frying time was very short (1 min as opposed to 4.5 min for control). Therefore, it is probable that the crust formed in osmotically treated potato was thinner than in the control, leading to a softer texture.

It is worth mentioning that the frying time of 1 min at 195°C for the osmotically treated potato was based on the development of color of the strips during frying, not on final moisture content or "doneness". It would be interesting to extend the study to incorporate "doneness" and the exact final moisture content of both products.

Color

Color of French fried potatoes was significantly affected by treatment ($p<0.05$, Table 15). The Hunter L and "a" values of osmotically treated potato were significantly different from the respective values of the fresh, frozen potato. The "b" values were not significantly different ($p>0.05$). Smaller L and bigger "a" values for the osmotically concentrated, French fried potatoes meant that the fries were darker in color than the fresh frozen fries (Table 16). The darker color is attributed to the higher level of reducing sugar in potato gained during osmotic concentration, and therefore an increased Maillard reaction. However, the reducing sugar contents of the fresh and osmotically treated potato were not monitored.

As reported by Marquez and Anon (1986), L (luminosity) between 60 and 51 is acceptable for French fried potatoes. In the present study, L values of 60.9 and 53.2 were

Table 15 -- Analysis of variance of Hunter L, "a", and "b" for fresh and osmotically dehydrated, frozen, French fried potatoes

Factor	DF	Sum of squares	Pr<F
L values			
Replication	1	0.4278	0.8057
Treatment	1	118.1953	0.0120
Storage	1	9.3528	0.2866
Error	4	24.7838	-
"a" values			
Replication	1	0.0450	0.5357
Treatment (T)	1	28.1250	0.0004
Storage (S)	1	0.2113	0.2279
T x S	1	0.0800	0.4210
Error	3	0.2775	-
"b" values			
Replication	1	1.4028	0.3283
Treatment (T)	1	1.4878	0.3158
Storage (S)	1	2.1528	0.2402
Error	4	4.5338	-

Table 16 -- Mean Hunter L, "a" and "b" values for fresh and osmotically concentrated, frozen French fried potatoes

Treatment	L	"a"	"b"	"a/b"
Control	60.9[a]	1.6[b]	21.7[a]	0.07[b]
OD[c]	53.2[b]	5.4[a]	20.9[a]	0.25[a]

[a,b] Means within a column not sharing same superscripts are different ($p<0.05$).

[c] Potato strips were osmotically dehydrated in 26 DE corn syrup solutions of 60% solute concentration at room temperature for 3 h.

obtained for the control and osmotically treated potatoes, respectively. The chromaticity (the ratio "a/b") of osmotically concentrated French fried potatoes was greater than that of the fresh frozen potato, indicating that color of the osmotically treated product was darker than the fresh counterpart. The chromaticity ratio of 0.07 for fresh and 0.25 for osmotically treated products were within the limits of color acceptability. As reported by Marquez and Anon (1986), the limits of "a/b" for color acceptability are -0.20 to 0.35.

Sensory Evaluation

Acceptability and potential for purchasing scores of the osmotically treated potato were lower than the respective scores of the control (Table 17). On average, the osmotically concentrated product was considered "dislike slightly" to "like slightly", while the control was considered "like slightly" to "like moderately". The control is more likely to be purchased than the osmotically concentrated.

Comments of the panelists included "soft texture" and "inadequate frying" as the reasons for lower acceptability and lower potential for purchasing of osmotically treated French fried potatoes. None of the panelists made any comments about additional sweetness of the osmotically concentrated potato.

As was mentioned the osmotically treated potato strips were fried to a final acceptable color rather than "doneness". The cooking conditions need to be adjusted based on "doneness" so that the final product may not appear to be under-fried or have a softer texture. If the color of the fries become darker due to longer frying time, some seasoning coating might be added to the product, and the product may have to be evaluated and

Table 17 -- Least-squares mean sensory scores of acceptability and potential for purchasing French fried potatoes as affected by treatment

Factor	Acceptability[a]	Potential for purchasing[b]
<u>Treatment</u>		
Control	5.6^{c}	3.0^{c}
Dehydrated	4.6^{d}	2.3^{d}
<u>Storage (mo)</u>		
0	4.9^{c}	2.6^{c}
2	5.2^{c}	2.7^{c}
<u>Replication</u>		
1	5.0^{c}	2.6^{c}
2	5.2^{c}	2.7^{c}

N = 50 panelists across 2 treatment.

[a] 8 = like extremely; 7 = like very much; 6 = like moderately; 5 = like slightly; 4 = dislike slightly; 3 = dislike moderately; 2 = dislike very much; 1 = dislike extremely.

[b] 5 = I would buy this very often; 4 = I would frequently buy this; 3 = I would buy this now and then; 2 = I would hardly ever buy this; 1 = I would never buy this.

[c,d] Means in a column within a factor not sharing same superscript are different ($p<0.05$).

marketed as a seasoned French fried potatoes.

The results of sensory evaluation showed that several factors influenced the acceptability (like) of the final product (Table 18). The acceptability was affected ($p<0.05$) by treatment of the material, replication of experiment, gender and frequency of consumption of French fries by the panelists. Storage for 2 mo did not affect acceptability ($p>0.05$). Gender x storage and frequency x storage interactions had significant effect on acceptability of the final product. The potential for purchasing (buy) was affected by treatment of the material, gender of panelists, and frequency of consumption of French fries (Table 19). Frequency x storage interaction had significant influence on potential for purchasing of the final product ($p<0.05$). Least-squares mean sensory scores of acceptability and potential for purchasing osmotically concentrated frozen French fried potatoes were lower than those of the control (Table 17). "Like" scores for gender, frequency, gender x storage and frequency x storage interactions, and "buy" scores for gender, frequency, and frequency x storage interaction could not be estimated by the least-squares means procedure within GLM, due to missing data. Frequency tables (FREQ) were used to show trends in these sensory scores (Table D1-D6, Appendix D).

For 0 mo storage, 64.4% of male panelists and 59.62% of female panelists scored "like" higher than 5 (8=like extremely; 1=dislike extremely). For 2 mo storage, however, 76.72% of male panelists and 64.07% of female panelists scored "like" higher than 5 .

For 0 mo storage, 37.5% of those who consume French fries several times a year, 62.5% of those who consume French fries several time a month, and 58.5% of those who consume French fries several times a week scored "like" higher than 5. On the other hand,

Table 18 -- Analysis of variance of acceptability scores assigned of French fried potatoes as affected by osmotic treatment, storage for two months and different groups of panelists

Source	DF	Sum of squares	Pr>F
Treatment	1	102.838	0.0001
Replication	1	10.358	0.0318
Storage	1	5.866	0.1057
Gender	1	20.233	0.0028
Freqency	3	23.375	0.0158
Gender x Storage	1	8.292	0.0546
Freqency x Storage	2	27.028	0.0026
Error	391	872.433	-

Table 19 -- Analysis of variance of potential for purchasing scores assigned of French fried potatoes as affected by osmotic treatment, storage for two months and different groups of panelists

Source	DF	Sum of Squares	Pr>F
Treatment	1	6.651	0.0001
Replication	1	1.474	0.3430
Storage	1	0.884	0.3774
Gender	1	4.379	0.0001
Frequency	3	8.440	0.0126
Frequency x Storage	2	7.189	0.0230
Error	392	351.772	-

66.7% of those who consume French fries several times a year, 78.5% of those who consume French fries several time a month and 78.5% of those who consume French fries several times a week scored "like" higher than 5.

For zero month storage, 29.2% of those who consume French fries several times a year, 52.4% of those who consume French fries several times a month and 64.3% of those who consume French fries several times a week, scored "like" higher than 5. On the other hand, for 2 mo of storage, 55.6% of those who consume French fries several times a year, 64.5% of those who consume French fries several times a month and 59.4% of those who consume French fries several times a week scored "like" higher than 5.

CHAPTER V

SUMMARY AND CONCLUSIONS

Potato strips (1x1x6 cm) were osmotically concentrated in corn syrup solutions of 26 DE and 43 DE at three concentrations (40, 50 and 60% solids, w/w) and three temperatures (20, 30 and 40°C) for six time intervals (0, 1, 2, 3, 4 and 5 h). Moisture loss from and solids gain by the strips were monitored. A moisture loss of up to 70% of the original moisture content of potato was accomplished. The maximum solids gain observed was 0.43 kg solids/kg of original total solids present in potato, with a net weight reduction of about 50%.

The DE of corn syrup greatly influenced the moisture loss and solids gain. For a given treatment combination, potato strips in 43 DE yielded higher moisture loss than in 26 DE corn syrup. In general, the solids gain by strips in 43 DE was also higher. Within each DE, an increase in solute concentration, temperature and time increased the moisture loss. Moisture loss was also very rapid at the beginning and decreased gradually with contacting time. Solids gain varied inconsistently with concentration, temperature and the contacting time. The negative solids gain values (Figs C1-C9, Appendix C) indicated leaching of soluble solids from potato tissue. Leaching was particularly noticed for one replicate of almost all treatment combinations, which may be due to higher reducing sugar content of potatoes used in those experiments. Leaching could also be due to the "washing" of soluble solids from the ruptured cells at the surface of the potato strips. In the early part of the osmotic contacting, when solids gain by the potato was smaller than solids loss from the potato, leaching was noticeable. With the increase in contacting time, as the solids gain increased, the net effect of solids movement appeared to be as solids gain rather than leaching. Further investigation of the leaching phenomenon is suggested.

Moisture loss (ML) from potato strips into 26 DE and 43 DE corn syrup solutions was modeled using the following exponential equation:

$$ML = B_0 \left(1 - e^{-B_1 \theta} \right)$$

The parameters B_o and B_1, estimated by non-linear regression for each treatment combination, were analyzed for the effects of concentration and temperature. For 26 DE corn syrup, both concentration and temperature significantly affected B_o, while only temperature significantly affected B_1 ($p<0.05$). The final equation for moisture loss from potato into 26 DE corn syrup solutions, obtained by non-linear regression, was the following:

$$ML = (-0.027t + 0027c + 0.0005t^2 - 0.0002c^2)\left(1 - e^{(-0.066t + 0.001t^2)\theta}\right)$$

For 43 DE corn syrup, only temperature significantly affected the parameter B_o ($p<0.05$); neither the concentration nor the temperature significantly affected B_1 ($p>0.05$). The final equation for moisture loss from potato in contact with 43 DE corn syrup solutions was the following:

$$ML = (0.723 - 0.0121t + 0.0003t^2)(1 - e^{-0.837\theta})$$

ML represents fraction of original moisture lost; θ represents osmosis time (h); "c" and "t" represent solute concentration (%, w/w) and temperature (°C), respectively. The R^2-like values of the parameters for moisture loss equations for 26 and 43 DE, were 0.95 and 0.96, respectively.

Two batches of potatoes were cut into strips (1 x 1 x 6 cm) and processed by two procedures (two treatments) for obtaining French fried potatoes. Treatment 1 was the control (fresh, frozen) and treatment 2 was osmotically processed. For treatment 2, potato strips were osmotically concentrated in 60%, w/w, corn syrup solutions at 21°C for 3 h. A 3 h contact time was selected since little or no significant change occurred in moisture loss after 3 h. The 60% osmotic solution was selected to obtain the greatest amount of moisture loss during the 3 h. Potatoes in both treatments were blanched for 30 sec under atmospheric steam, frozen in a CO_2 freezer, packaged in freezer bags and stored at -17°C for 0, 2 and 4 months for quality attributes studies. The attributes studied were moisture content of potato before and after frying, oil uptake by the potato during frying, color, texture and sensory acceptability of French fried potato. The oil temperature used in frying was 195°C, and the frying times were 4.5 and 1 min for the control and osmotically treated potatoes, respectively. The storage study was discontinued after 2 mo due to lower sensory acceptability of the osmotically concentrated potato in comparison to the control. The following conclusions were drawn:

1. Moisture content of potato, with and without osmotic concentration, did

not change during the storage of 2 months. (The mean moisture contents of fresh and osmotically concentrated potatoes were about 80% and 65%, w.b., respectively.). Moisture content of osmotically treated potato after frying (51.4%, w.b.) was slightly higher than that of the control (47.5%, w.b.), although the difference between the moisture contents was statistically not significant ($p>0.05$).

2. Oil uptake by the osmotically treated potato during frying was about one-third of that of the control. (After frying, the mean oil contents of control and osmotically treated potatoes were 21.8 and 6.4 kg oil/kg of moisture free potato, respectively.)

3. Osmotically treated French fried potato was softer in texture than the control. (Maximum shear force recorded by the Universal Testing machine was used as the indicator of the relative hardness of the product.)

4. Color of the osmotically treated French fried potato was darker than that of the control, although the Hunter color parameters of both products were within the ranges of color acceptability. The reported, acceptable range for L value is 60 to 51, and for "a/b" ratio is -0.2 to 0.35 (Marquez and Anon, 1986). The L and "a/b" values obtained in the present study were the following: L (control) 60.9, L (osmotically treated) 53.2, "a/b" (control) 0.07, and "a/b" (osmotically treated) 0.25.

5. Overall, the acceptability of osmotically treated French fried potato was lower than that of the control. In hedonic scales of 1 to 8 (8 = like

extremely; 1= dislike extremely), the osmotically treated French fried potato was rated 4.6 which was between "dislike slightly" to "like slightly", while the control was rated 5.6 which was between "like slightly" to "like moderately". The mean scores for the potential for purchasing indicated that the control was rated "I would buy this product now and then", while the osmotically treated product was rated between "I would hardly ever buy the product" to "I would buy the product now and then". Storage for two months did not affect the acceptability or potential for purchasing of the products.

In conclusion, osmotic concentration of potato strips in corn syrup solutions and the concept of using osmotic concentration as an intermediate step in producing French fried potato, are feasible. The conditions of osmotic treatment (DE, solute concentration, temperature and time osmosis) would depend on the extent of moisture loss and solids gain desired. Further investigation on better control of solids gain is recommended. Although the sensory acceptability of osmotically concentrated, frozen French fried potato was lower than that of the conventionally produced (fresh, frozen) French fried potato, the potential for use of the technique does exist. The acceptability of osmotically treated French fried potato can be improved by taking into account "doneness" of potato during frying, instead of just the color acceptability.

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APPENDICES

APPENDIX A

A1. Sensory score sheet 1

Panelist number____________

1. Male ______ Female ______

2. How often do you eat French fries?

    _____ several times a week

    _____ several times a month

    _____ several times a year

    _____ never

3. Please indicate how well you like or dislike the sample of French fries by checking the term that best describes your feeling toward that sample. Rinse your month with water before testing the second sample.

Like extremely	__________
Like very much	__________
Like moderately	__________
Like slightly	__________
Dislike slightly	__________
Dislike moderately	__________
Dislike very much	__________
Dislike extremely	__________

4. Please check the appropriate comment for the sample of French fries.

I would buy this very often	__________
I would frequently buy this	__________
I would buy this now and then	__________
I would hardly ever buy this	__________
I would never buy this	__________

COMMENTS:

A2. Sensory score sheet 2

1. Please rinse your month with water before testing the second sample and indicate how well you like or dislike the sample of French fries by checking the term that best describes your feeling toward that sample.

Like extremely	________
Like very much	________
Like moderately	________
Like slightly	________
Dislike slightly	________
Dislike moderately	________
Dislike very much	________
Dislike extremely	________

2. Please check the appropriate comment for the sample of French fries.

I would buy this very often	________
I would frequently buy this	________
I would buy this now and then	________
I would hardly ever buy this	________
I would never buy this	________

COMMENTS:

APPENDIX B

Table B1 -- Analysis of variance of reduced mass (m_θ/m_0)[a] of potato strips in contact with corn syrup solutions of 26 and 43 DE

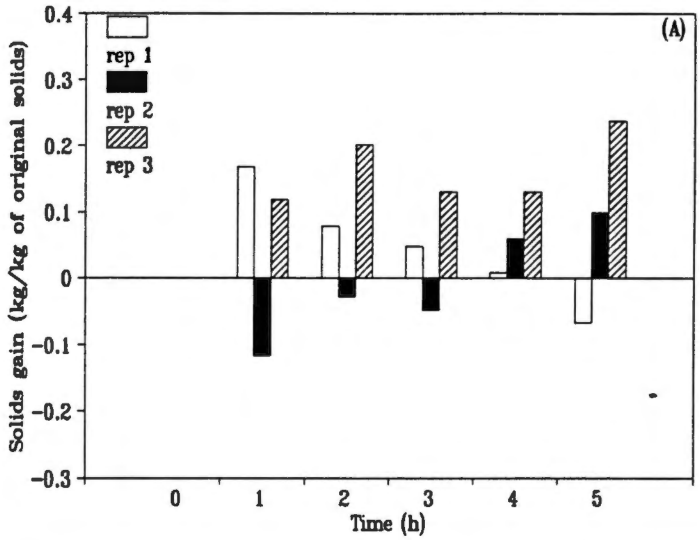
Factor	DF	Sum of squares	Pr>F
DE	1	0.0755	0.0001
Temperature (T)	2	0.0923	0.0001
Conccentration (C)	2	0.1803	0.0001
Time	5	18.1775	0.0001
T x Time	10	0.0336	0.0014
C x Time	10	0.0520	0.0001
DE x C	2	0.0228	0.0001
DE x Time	5	0.0178	0.0085
Error	284	0.3207	-

[a] m_0 and m_θ: mass of potato strips at time zero and theta, respectively.

Table B2 -- Analysis of variance of moisture loss from potato strips in contact with corn syrup solutions of 26 and 43 DE

Factor	DF	Sum of squares	Pr>F
DE	1	0.146	0.0001
Temperature (T)	2	0.178	0.0001
Concentration (C)	2	0.330	0.0001
Time	5	13.390	0.0001
T x Time	10	0.080	0.0001
C x Time	10	0.083	0.0001
DE x C	2	0.034	0.0001
DE x Time	5	0.032	0.0035
Error	284	0.438	-

APPENDIX C



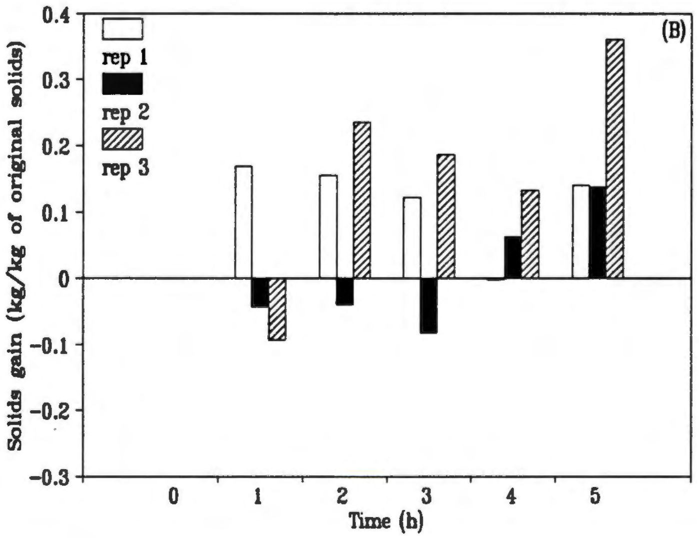


Fig. C1 -- Solids gain by potato strips in contact with 40 % corn syrup solution of 26 DE (A) and 43 DE (B) at 20°C.

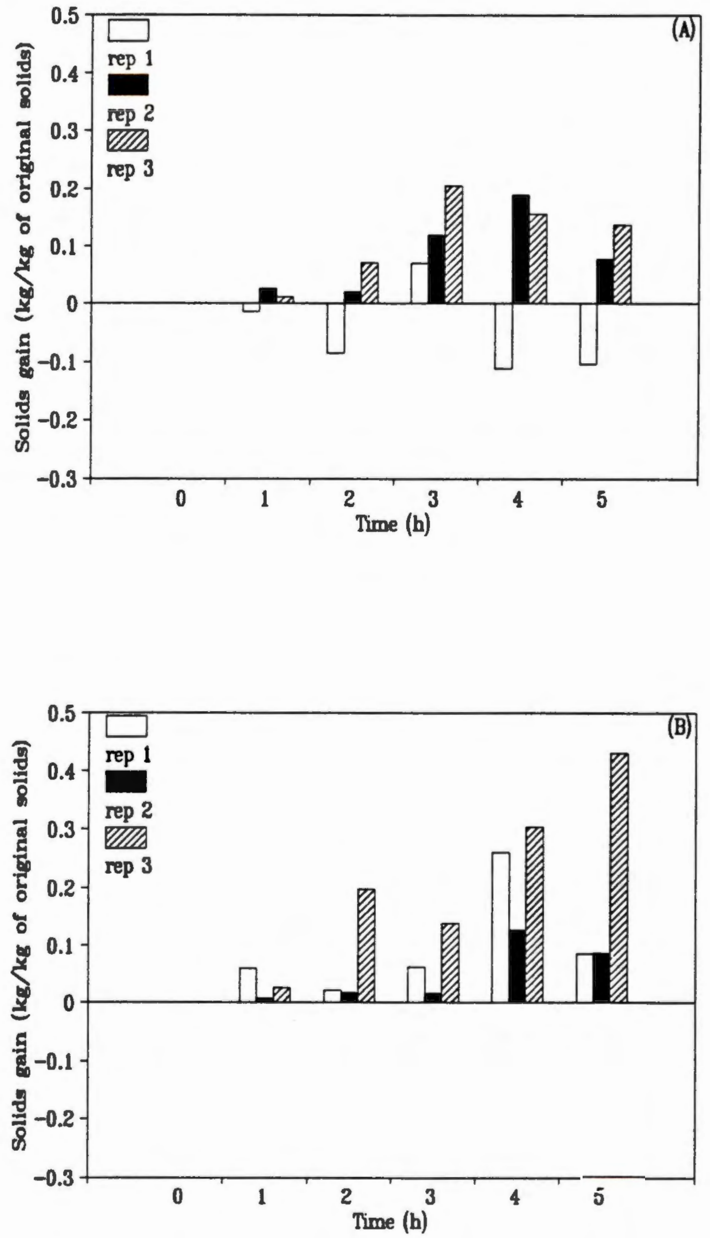
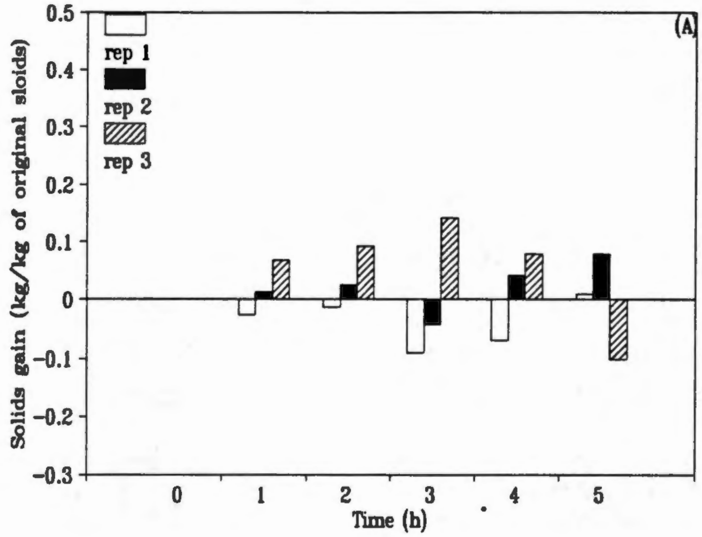


Fig. C2 -- Solids gain by potato strips in contact with 50% corn syrup solutions of 26 DE (A) and 43 DE (B) at 20°C.



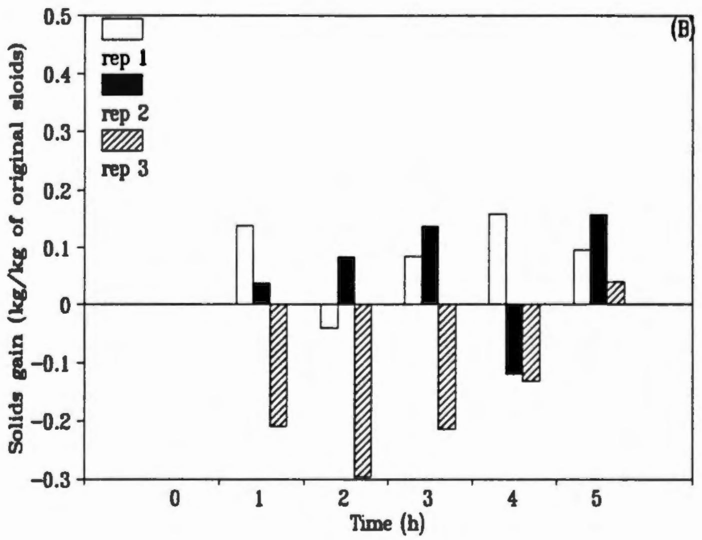
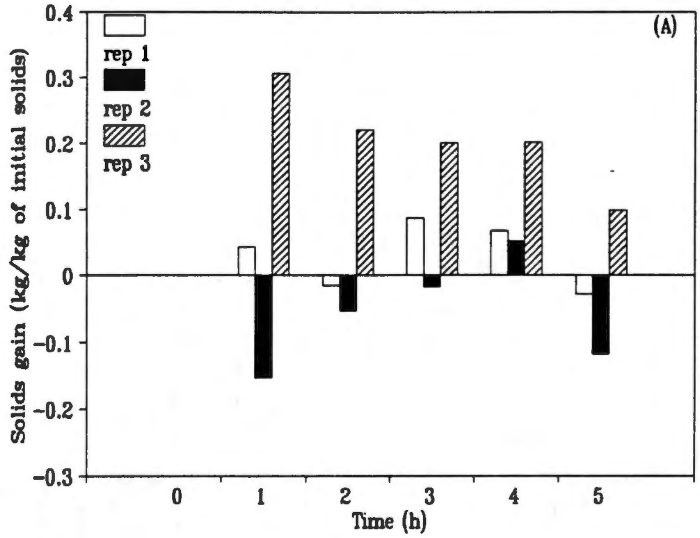


Fig. C3 -- Solids gain by potato strips in contact with 60% corn syrup solutions of 26 DE (A) and 43 DE (B) at 20°C.



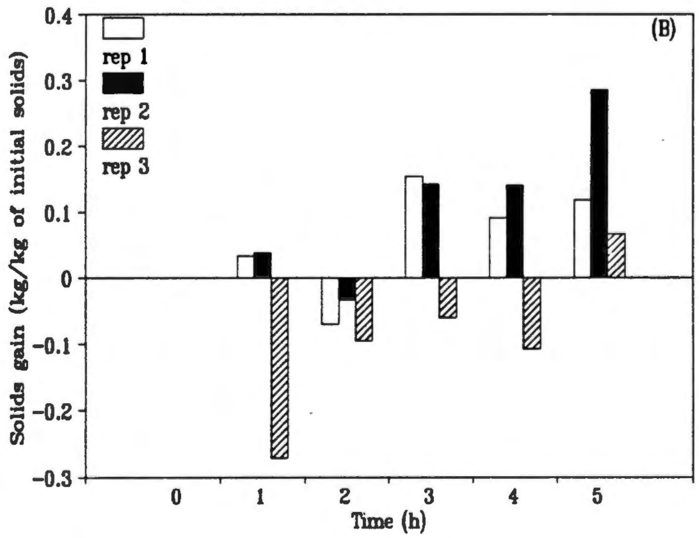
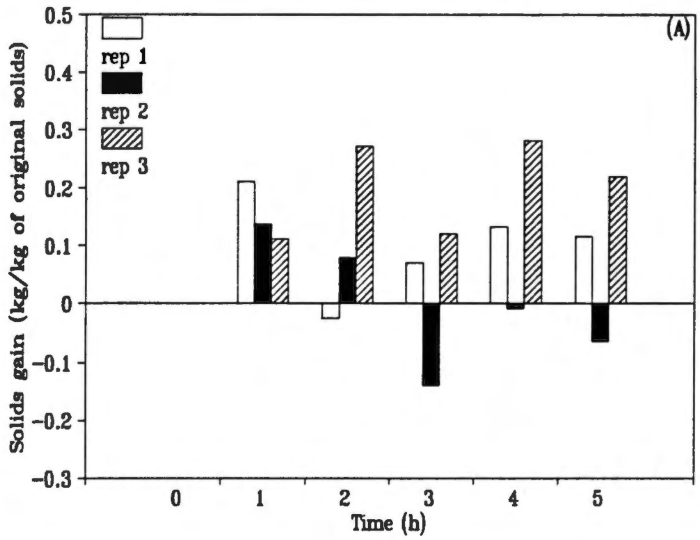


Fig. C4 -- Solids gain by potato strips in contact with 40% corn syrup solutions of 26 DE (A) and 43 DE (B) at 30°C.



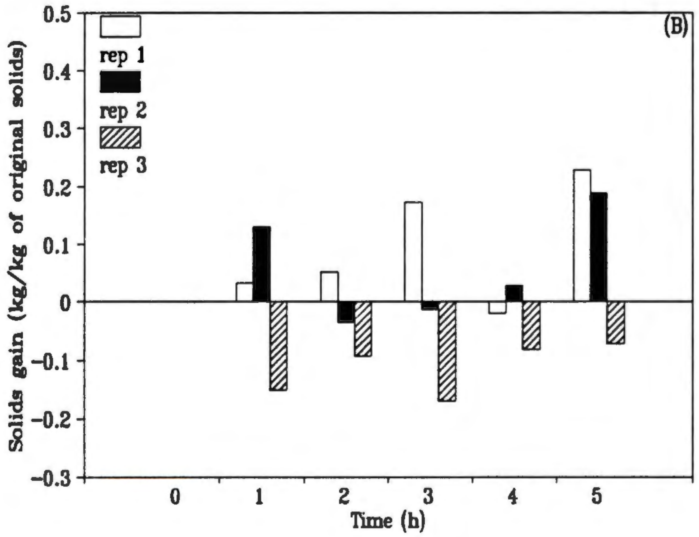


Fig. C5 -- Solids gain by potato strips in contact with 50% corn syrup solutions of 26 DE (A) and 43 DE (B) at 30°C.

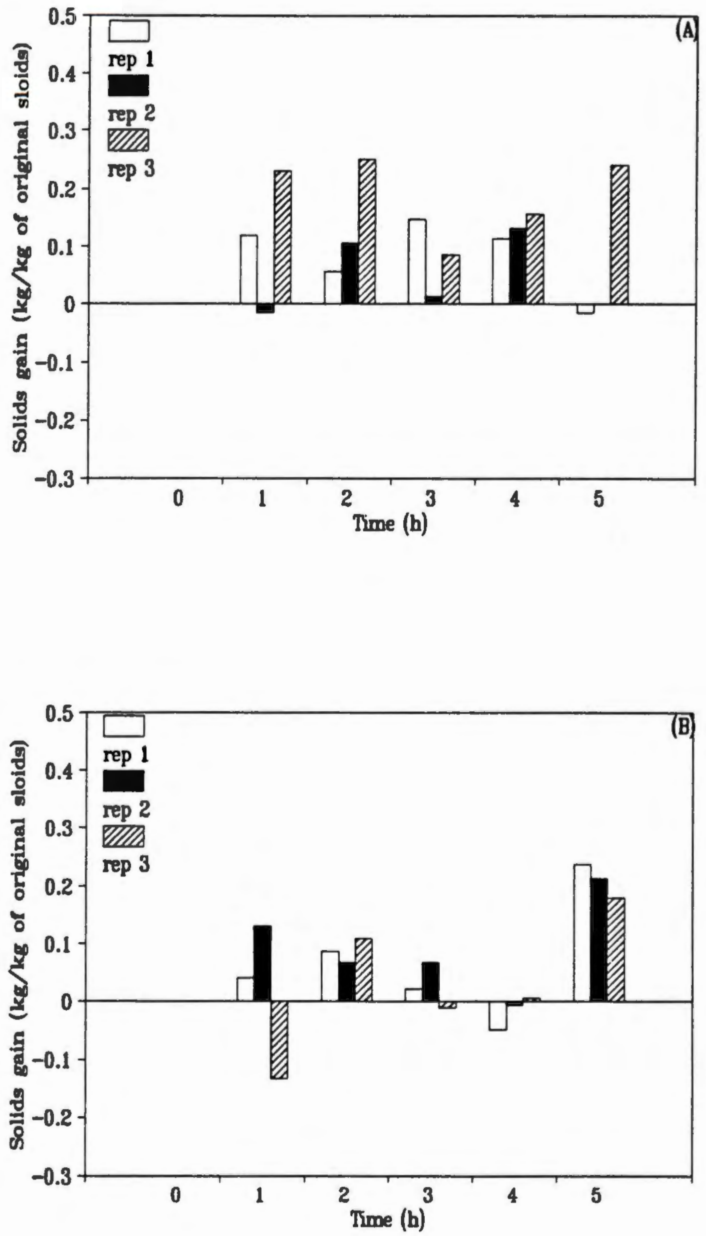
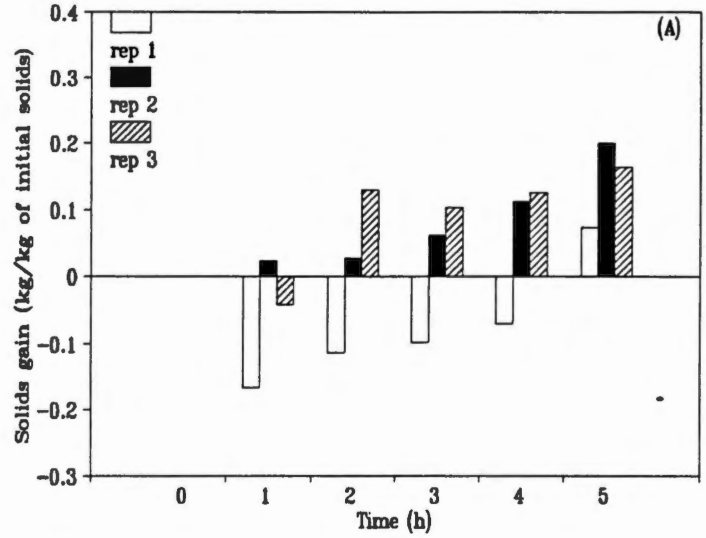


Fig. C6 -- Solids gain by potato strips in contact with 60% corn syrup solutions of 26 DE (A) and 43 DE (B) at 30°C.



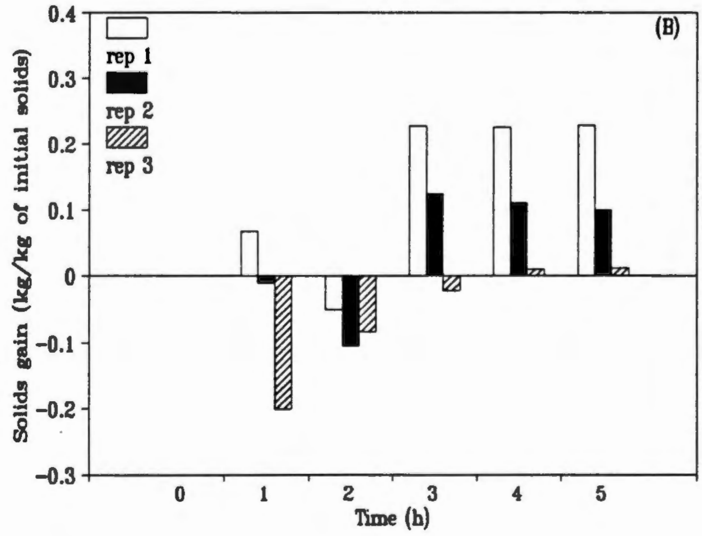


Fig. C7 -- Solids gain by potato strips in contact with 40% corn syrup solutions of 26 DE (A) and 43 DE (B) at 40°C.

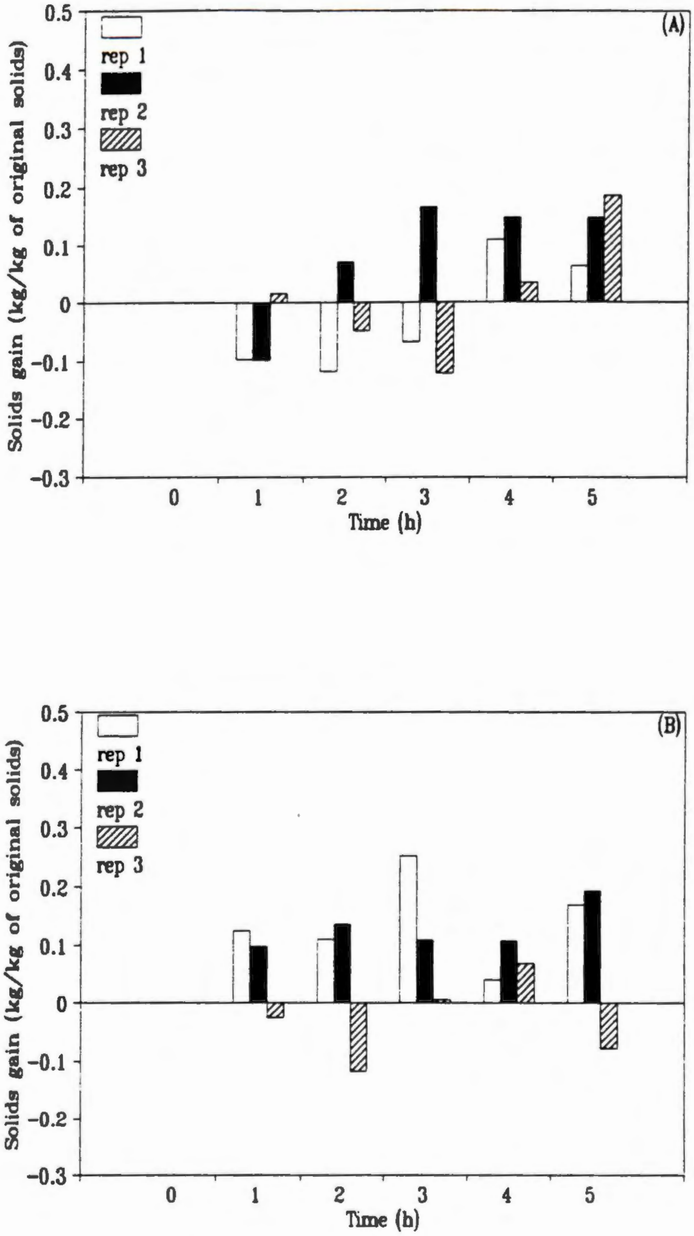
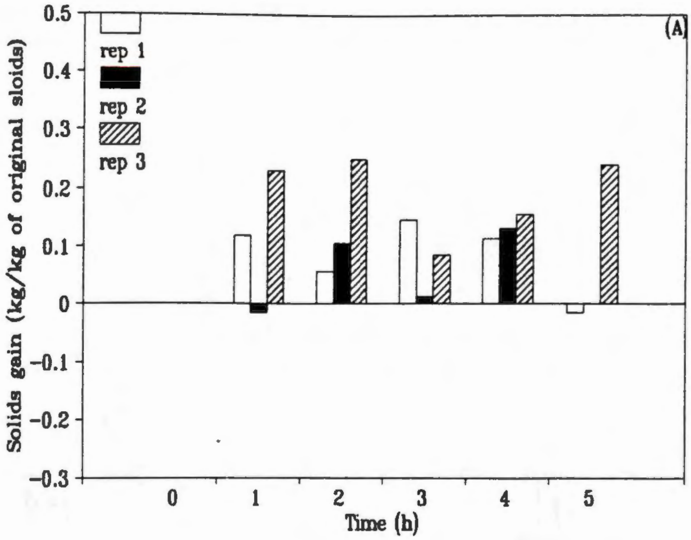


Fig. C8 -- Solids gain by potato strips in contact with 50% corn syrup solutions of 26 DE (A) and 43 DE (B) at 40°C.



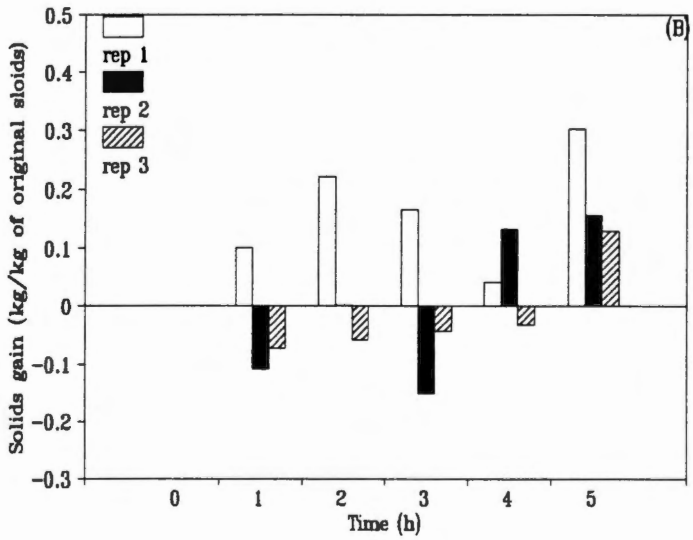


Fig. C9 -- Solids gain by potato strips in contact with 60% corn syrup solutions of 26 DE (A) and 43 DE (B) at 40°C.

APPENDIX D

D1. Frequency table of acceptability (like) of French fried potato by gender of panelists controlling for storage of zero month.

Like[a]	Gender[b] 1	2	Total
1	3	5	8
2	3	10	13
3	17	8	25
4	19	19	38
5	22	16	38
6	29	30	59
7	22	12	34
8	3	4	7
Total	118	104	222

Frequency missing = 2

[a] 8 = like extremely; 7 = like very much; 6 = like moderately; 5 = like slightly; 4 = dislike slightly; 3 = dislike moderately; 2 = dislike very much; 1 = dislike extremely.

[b] 1 = male; 2 = female.

D2. Frequency table of acceptability (like) of French fried potato by gender of panelists controlling for storage of two month.

Like[a]	Gender[b] 1	2	Total
1	1	3	4
2	5	4	9
3	7	5	12
4	14	11	25
5	25	16	41
6	38	18	56
7	24	7	31
8	2	0	2
Total	116	64	180

Frequency Missing = 20

[a] 8 = like extremely; 7 = like very much; 6 = like moderately; 5 = like slightly; 4 = dislike slightly; 3 = dislike moderately; 2 = dislike very much; 1 = dislike extremely.

[b] 1 = male; 2 = female.

D3. Frequency table of potential for purchasing (buy) of French fried potato by frequency of consumption controlling for storage of zero month.

Buy[a]	Frequency[b] 1	2	3	4	Total
1	0	7	19	8	34
2	0	10	42	17	69
3	2	6	43	27	78
4	0	1	17	13	31
5	0	0	7	5	12
Total	2	24	128	70	224

[a] 5 = I would buy this very often; 4 = I would frequently buy this; 3 = I would buy this now and then; 2 = I would hardly ever buy this; 1 = I would never buy this.

[b] 4 = consuming French fries several time a week; 3 = consuming French fries several time a month; 2 = consuming French fries several time a year; 1 = never.

D4. Frequency table of potential for purchasing (buy) of French fried potato by frequency of consumption controlling for storage of two month.

Buy[a]	Frequency[b] 1	2	3	4	Total
1	0	4	9	10	23
2	0	8	28	16	52
3	0	14	43	26	83
4	0	0	22	12	34
5	0	1	5	0	6
Total	0	27	107	64	198

Frequency Missing = 2

[a] 5 = I would buy this very often; 4 = I would frequently buy this; 3 = I would buy this now and then; 2 = I would hardly ever buy this; 1 = I would never buy this.

[b] 4 = consuming French fries several time a week; 3 = consuming French fries several time a month; 2 = consuming French fries several time a year; 1 = never.

D5. Frequency table of acceptability (like) of French fried potato by frequency of consumption controlling for storage of zero month.

Like[a]	Frequency[b] 1	2	3	4	Total
1	0	3	2	3	8
2	0	2	11	1	14
3	0	5	12	8	25
4	0	5	23	10	38
5	0	3	25	10	38
6	2	5	31	22	60
7	0	1	19	14	34
8	0	0	5	2	7
Total	2	24	128	70	224

[a] 8 = like extremely; 7 = like very much; 6 = like moderately; 5 = like slightly; 4 = dislike slightly; 3 = dislike moderately; 2 = dislike very much; 1 = dislike extremely.

[b] 4 = consuming French fries several time a week; 3 = consuming French fries several time a month; 2 = consuming French fries several time a year; 1 = never.

D6. Frequency table of acceptability (like) of French fried potato by frequency of consumption controlling for storage of two month.

Like[a]	Frequency[b] 1	2	3	4	Total
1	0	1	1	2	4
2	0	0	5	4	9
3	0	2	7	5	14
4	0	6	10	12	28
5	0	6	25	13	44
6	0	9	34	19	62
7	0	2	24	9	35
8	0	1	1	0	2
Total	0	27	107	64	198

Frequency Missing = 2

[a] 8 = like extremely; 7 = like very much; 6 = like moderately; 5 = like slightly; 4 = dislike slightly; 3 = dislike moderately; 2 = dislike very much; 1 = dislike extremely.

[b] 4 = consuming French fries several time a week; 3 = consuming French fries several time a month; 2 = consuming French fries several time a year; 1 = never.

APPENDIX E

Table E1 -- Mean moisture content of frozen French fried potato (before and after frying) as affected by osmotic treatment and storage for two months

Factor	Moisture 1[a]	Moisture 2[b]
Replicate		
1	71.268[d]	49.350[d]
2	74.490[d]	49.300[c]
Trearment[c]		
1	80.335[d]	47.498[d]
2	65.422[e]	51.353[d]
Storage (mo)		
0	74.033[d]	51.263[d]
2	71.725[d]	47.588[d]

[a] The moisture content of potato before frying.
[b] The moisture content of potato after frying.
[c] Two treatments:
(1) control (conventionally prepared, frozen potato strips fried at 195°C for 4.5 min).
(2) potato strips osmotically concentrated in 26 DE corn syrup solution of 60% solute concentration at room temperature for 3 h, frozen and fried at 195°C for 1 min.
[d, e] Means in a column within a factor not sharing same superscript are different ($p<0.05$).

Table E2 -- Mean oil content of frozen French fried potato as affected by osmotic treatment and storage for two months

Factor	Oil content (kg/100 kg of moisture free potato)
Treatment[c]	
1	21.80^{a}
2	6.42^{b}
Storage (mo)	
0	14.71^{a}
2	13.51^{a}
Replication	12.74^{b}
1	15.48^{a}
2	

[a, b] Means in a column within a factor not sharing same superscript are different ($p<0.05$).

[c] Two treatments:
(1) control (conventionally prepared, frozen potato strips)
(2) potato strips osmotically concentrated in 26 DE corn syrup solution of 60% solute concentration at room temperature for 3 h, and then frozen.

Table E3 -- Mean Hunter L, "a", and "b" values for French fried potatoes

Factor	L	"a"	"b"
Replication			
1	57.3[a]	3.6[a]	21.7[a]
2	56.8[a]	3.4[a]	20.9[a]
Treatment			
Control	60.9[a]	5.4[a]	21.7[a]
OD[c]	53.2[b]	1.6[b]	20.9[a]
Storage(mo)[d]			
0	58.1[a]	3.3[a]	21.8[a]
2	56.0[a]	3.7[a]	20.8[a]

[a,b] Means in a column within a factor not sharing same superscript are different ($p<0.05$).

[c] The potato strips were dehydrated in 26 DE, 60% corn syrup solution for 3 hours at room temperature.

[d] The dehydrated and the control potatoes were frozen and held at -17°C.

APPENDIX F

Table F1 -- Experimental data for osmotic concentration of potato strips in corn syrup solutions

Conc[a] (%, w/w)	Temp[b] (°C)	Rep[c]	Time (h)	m_θ/m_0[d]	ML[e]	SG[f]
26 DE						
40	20	1	0	1.000	0.000	0.000
			1	0.807	0.281	0.169
			2	0.733	0.351	0.079
			3	0.707	0.376	0.048
			4	0.631	0.460	0.007
			5	0.652	0.417	-0.067
		2	0	1.000	0.000	0.000
			1	0.736	0.299	-0.117
			2	0.695	0.371	-0.028
			3	0.628	0.449	-0.048
			4	0.628	0.474	0.060
			5	0.596	0.523	0.099
		3	0	1.000	0.000	0.000
			1	0.828	0.242	0.118
			2	0.743	0.368	0.202
			3	0.672	0.438	0.130
			4	0.654	0.460	0.130
			5	0.687	0.446	0.238
40	30	1	0	1.000	0.000	0.000
			1	0.768	0.296	0.043
			2	0.737	0.320	-0.016
			3	0.732	0.350	0.088
			4	0.629	0.472	0.067
			5	0.606	0.479	-0.028
		2	0	1.000	0.000	0.000
			1	0.782	0.235	-0.153
			2	0.712	0.349	-0.053
			3	0.700	0.373	-0.018
			4	0.679	0.418	0.053
			5	0.654	0.405	-0.118

Table F1 (Continued)

Conc[a] (%, w/w)	Temp[b] (°C)	Rep[c]	Time (h)	m_θ/m_0[d]	ML[e]	SG[f]
40	30	3	0	1.000	0.000	0.000
			1	0.816	0.302	0.307
			2	0.760	0.350	0.220
			3	0.703	0.417	0.202
			4	0.665	0.464	0.203
			5	0.661	0.445	0.099
40	40	1	0	1.000	0.000	0.000
			1	0.796	0.214	-0.167
			2	0.605	0.472	-0.114
			3	0.533	0.569	-0.098
			4	0.476	0.648	-0.070
			5	0.524	0.627	0.074
		2	0	1.000	0.000	0.000
			1	0.776	0.282	0.024
			2	0.717	0.356	0.027
			3	0.708	0.375	0.061
			4	0.623	0.491	0.112
			5	0.644	0.487	0.201
		3	0	1.000	0.000	0.000
			1	0.779	0.270	-0.041
			2	0.732	0.375	0.130
			3	0.661	0.458	0.104
			4	0.648	0.480	0.126
			5	0.650	0.488	0.164
50	20	1	0	1.000	0.000	0.000
			1	0.794	0.252	-0.014
			2	0.662	0.399	-0.085
			3	0.669	0.428	0.070
			4	0.604	0.465	-0.111
			5	0.597	0.476	-0.105

Table F1 (Continued)

Conc[a] (%, w/w)	Temp[b] (^oC)	Rep[c]	Time (h)	m_θ/m_0[d]	ML[e]	SG[f]
50	20	2	0	1.000	0.000	0.000
			1	0.705	0.371	0.026
			2	0.607	0.491	0.020
			3	0.587	0.539	0.118
			4	0.572	0.574	0.190
			5	0.522	0.611	0.078
		3	0	1.000	0.000	0.000
			1	0.775	0.282	0.011
			2	0.636	0.469	0.072
			3	0.645	0.490	0.205
			4	0.613	0.518	0.155
			5	0.588	0.544	0.137
50	30	1	0	1.000	0.000	0.000
			1	0.720	0.393	0.211
			2	0.619	0.463	-0.026
			3	0.611	0.495	0.070
			4	0.513	0.631	0.133
			5	0.515	0.623	0.116
		2	0	1.000	0.000	0.000
			1	0.745	0.356	0.137
			2	0.670	0.435	0.078
			3	0.608	0.456	-0.141
			4	0.620	0.477	-0.008
			5	0.567	0.528	-0.064
		3	0	1.000	0.000	0.000
			1	0.755	0.330	0.111
			2	0.681	0.461	0.272
			3	0.612	0.511	0.120
			4	0.631	0.525	0.282
			5	0.594	0.556	0.220

Table F1 (Continued)

Conc[a] (%, w/w)	Temp[b] (°C)	Rep[c]	Time (h)	m_θ/m_0[d]	ML[e]	SG[f]
50	40	1	0	1.000	0.000	0.000
			1	0.771	0.265	-0.098
			2	0.523	0.576	-0.119
			3	0.482	0.642	-0.068
			4	0.468	0.708	0.108
			5	0.432	0.741	0.063
		2	0	1.000	0.000	0.000
			1	0.701	0.346	-0.099
			2	0.654	0.444	0.072
			3	0.638	0.486	0.166
			4	0.562	0.575	0.148
			5	0.524	0.622	0.147
		3	0	1.000	0.000	0.000
			1	0.735	0.341	0.016
			2	0.635	0.451	-0.047
			3	0.538	0.553	-0.121
			4	0.553	0.577	0.035
			5	0.566	0.600	0.185
60	20	1	0	1.000	0.000	0.000
			1	0.784	0.261	-0.027
			2	0.681	0.394	-0.012
			3	0.613	0.459	-0.090
			4	0.619	0.457	-0.070
			5	0.605	0.493	0.010
		2				
			1	0.701	0.372	0.013
			2	0.596	0.506	0.025
			3	0.529	0.572	-0.043
			4	0.513	0.612	0.042
			5	0.490	0.650	0.078

Table F1 (Continued)

Conc[a] (%, w/w)	Temp[b] (°C)	Rep[c]	Time (h)	m_θ/m_0[d]	ML[e]	SG[f]
60	20	3	0	1.000	0.000	0.000
			1	0.749	0.328	0.067
			2	0.643	0.465	0.092
			3	0.607	0.522	0.142
			4	0.575	0.546	0.079
			5	0.544	0.541	-0.102
60	30	1	1	0.693	0.405	0.118
			2	0.611	0.492	0.055
			3	0.571	0.562	0.147
			4	0.516	0.622	0.113
			5	0.453	0.669	-0.016
		2	0	1.000	0.000	0.000
			1	0.692	0.384	-0.015
			2	0.666	0.448	0.106
			3	0.597	0.511	0.013
			4	0.584	0.557	0.131
			5	0.535	0.586	0.001
		3	0	1.000	0.000	0.000
			1	0.749	0.367	0.231
			2	0.670	0.469	0.251
			3	0.578	0.544	0.086
			4	0.544	0.603	0.155
			5	0.566	0.596	0.241
60	40	1	0	1.000	0.000	0.000
			1	0.757	0.290	-0.054
			2	0.492	0.629	-0.069
			3	0.438	0.695	-0.080
			4	0.429	0.724	-0.012
			5	0.426	0.751	0.071

Table F1 (Continued)

Conc[a] (%, w/w)	Temp[b] (°C)	Rep[c]	Time (h)	m_θ/m_0[d]	ML[e]	SG[f]
60	40	2	0	1.000	0.000	0.000
			1	0.713	0.388	0.143
			2	0.624	0.525	0.258
			3	0.587	0.550	0.169
			4	0.557	0.601	0.230
			5	0.502	0.759	0.613
		3	0	1.000	0.000	0.000
			1	0.720	0.368	0.047
			2	0.642	0.541	0.324
			3	0.562	0.580	0.091
			4	0.535	0.614	0.092
			5	0.573	0.606	0.242
43 DE						
40	20	1	0	1.000	0.000	0.000
			1	0.725	0.384	0.170
			2	0.664	0.456	0.156
			3	0.620	0.503	0.121
			4	0.535	0.578	-0.002
			5	0.559	0.583	0.140
		2	0	1.000	0.000	0.000
			1	0.753	0.300	-0.043
			2	0.677	0.397	-0.040
			3	0.600	0.483	-0.083
			4	0.602	0.519	0.062
			5	0.588	0.557	0.139
		3	0	1.000	0.000	0.000
			1	0.728	0.308	-0.093
			2	0.653	0.466	0.235
			3	0.601	0.519	0.187
			4	0.568	0.548	0.133
			5	0.601	0.554	0.361

Table F1 (Continued)

Conc[a] (%, w/w)	Temp[b] (°C)	Rep[c]	Time (h)	m_θ/m_0[d]	ML[e]	SG[f]
40	30	1	0	1.000	0.000	0.000
			1	0.735	0.343	0.033
			2	0.652	0.420	-0.071
			3	0.645	0.488	0.155
			4	0.580	0.555	0.091
			5	0.561	0.585	0.119
		2	0	1.000	0.000	0.000
			1	0.756	0.315	0.039
			2	0.623	0.463	-0.033
			3	0.606	0.529	0.144
			4	0.583	0.556	0.141
			5	0.581	0.595	0.285
		3	0	1.000	0.000	0.000
			1	0.657	0.763	-0.271
			2	0.679	0.705	-0.096
			3	0.647	0.694	-0.060
			4	0.608	0.709	-0.108
			5	0.623	0.652	0.066
40	40	1	0	1.000	0.000	0.000
			1	0.725	0.359	0.068
			2	0.577	0.514	-0.051
			3	0.584	0.573	0.227
			4	0.546	0.620	0.225
			5	0.522	0.650	0.229
		2	0	1.000	0.000	0.000
			1	0.666	0.415	-0.011
			2	0.580	0.499	-0.106
			3	0.559	0.582	0.124
			4	0.553	0.587	0.111
			5	0.530	0.613	0.100

Table F1 (Continued)

Conc[a] (%, w/w)	Temp[b] (°C)	Rep[c]	Time (h)	m_θ/m_0[d]	ML[e]	SG[f]
40	40	3	0	1.000	0.000	0.000
			1	0.687	0.740	0.995
			2	0.660	0.702	0.769
			3	0.592	0.681	0.430
			4	0.588	0.671	0.382
			5	0.565	0.670	0.285
50	20	1	0	1.000	0.000	0.000
			1	0.706	0.380	0.060
			2	0.619	0.479	0.021
			3	0.605	0.506	0.062
			4	0.588	0.577	0.260
			5	0.513	0.627	0.086
		2	0	1.000	0.000	0.000
			1	0.770	0.293	0.008
			2	0.672	0.419	0.017
			3	0.610	0.497	0.016
			4	0.587	0.554	0.127
			5	0.557	0.582	0.087
		3	0	1.000	0.000	0.000
			1	0.681	0.390	0.026
			2	0.625	0.491	0.196
			3	0.566	0.551	0.138
			4	0.603	0.541	0.305
			5	0.586	0.587	0.429
50	30	1	0	1.000	0.000	0.000
			1	0.713	0.372	0.034
			2	0.630	0.480	0.052
			3	0.590	0.563	0.172
			4	0.511	0.612	-0.020
			5	0.547	0.631	0.227

Table F1. (Continued).

Conc[a] (%, w/w)	Temp[b] (°C)	Rep[c]	Time (h)	m_θ/m_0[d]	ML[e]	SG[f]
50	30	2	0	1.000	0.000	0.000
			1	0.712	0.393	0.130
			2	0.590	0.504	-0.035
			3	0.525	0.590	-0.012
			4	0.523	0.604	0.029
			5	0.544	0.617	0.187
		3	0	1.000	0.000	0.000
			1	0.684	0.370	-0.152
			2	0.641	0.446	-0.093
			3	0.578	0.504	-0.170
			4	0.563	0.553	-0.082
			5	0.573	0.543	-0.072
50	40	1	0	1.000	0.000	0.000
			1	0.699	0.405	0.124
			2	0.569	0.563	0.111
			3	0.566	0.601	0.253
			4	0.474	0.664	0.040
			5	0.478	0.691	0.170
		2	0	1.000	0.000	0.000
			1	0.663	0.446	0.097
			2	0.578	0.562	0.135
			3	0.531	0.614	0.108
			4	0.499	0.654	0.107
			5	0.497	0.677	0.192
		3	0	1.000	0.000	0.000
			1	0.738	0.339	-0.026
			2	0.627	0.456	-0.117
			3	0.568	0.574	0.006
			4	0.526	0.650	0.068
			5	0.508	0.627	-0.079

Table F1 (Continued)

Conc[a] (%, w/w)	Temp[b] (^oC)	Rep[c]	Time (h)	m_θ/m_0[d]	ML[e]	SG[f]
60	20	1	0	1.000	0.000	0.000
			1	0.688	0.422	0.139
			2	0.571	0.523	-0.041
			3	0.547	0.584	0.085
			4	0.534	0.619	0.158
			5	0.484	0.665	0.096
		2	0	1.000	0.000	0.000
			1	0.756	0.319	0.038
			2	0.657	0.455	0.083
			3	0.591	0.552	0.137
			4	0.545	0.543	-0.121
			5	0.525	0.641	0.157
		3	0	1.000	0.000	0.000
			1	0.700	0.390	-0.209
			2	0.591	0.496	-0.297
			3	0.571	0.545	-0.214
			4	0.564	0.577	-0.132
			5	0.588	0.600	0.038
60	30	1	0	1.000	0.000	0.000
			1	0.717	0.368	0.040
			2	0.611	0.514	0.087
			3	0.530	0.599	0.022
			4	0.478	0.646	-0.048
			5	0.514	0.675	0.237
		2	0	1.000	0.000	0.000
			1	0.721	0.382	0.129
			2	0.576	0.546	0.067
			3	0.529	0.606	0.067
			4	0.493	0.632	-0.006
			5	0.498	0.681	0.213

Table F1 (Continued)

Conc[a] (%, w/w)	Temp[b] (°C)	Rep[c]	Time (h)	m_θ/m_0 [d]	ML[e]	SG[f]
60	30	3	0	1.000	0.000	0.000
			1	0.682	0.379	-0.133
			2	0.747	0.371	0.108
			3	0.607	0.518	-0.011
			4	0.576	0.564	0.006
			5	0.570	0.628	0.179
60	40	1	0	1.000	0.000	0.000
			1	0.697	0.401	0.101
			2	0.560	0.602	0.222
			3	0.517	0.641	0.166
			4	0.454	0.690	0.042
			5	0.479	0.722	0.304
		2	0	1.000	0.000	0.000
			1	0.648	0.413	-0.109
			2	0.530	0.589	0.002
			3	0.461	0.636	-0.151
			4	0.492	0.669	0.133
			5	0.449	0.728	0.156
		3	0	1.000	0.000	0.000
			1	0.696	0.379	-0.073
			2	0.605	0.504	-0.058
			3	0.536	0.601	-0.043
			4	0.486	0.671	-0.032
			5	0.530	0.665	0.128

[a] Concentration (%, w/w).
[b] Temperature.
[c] Replication.
[d] m_0 and m_θ are mass of potato at time zero and time theta, respectively. Raw data of original moisture content are listed in Table F2 (Appendix F).
[e] ML: moisture loss (fraction of original).
[f] SG: solids gain (kg solids taken up/kg of solids originally present).

Table F2 -- Moisture content of potatoes before osmotic concentration in corn syrup solutions (experimental data)

Concentration (%, w/w)	Temperature (oC)	Moisture content (mass fraction) Rep1	Rep2	Rep3
26 DE				
40	20	0.805	0.808	0.806
	30	0.812	0.795	0.806
	40	0.785	0.810	0.788
50	20	0.805	0.808	0.806
	30	0.812	0.795	0.806
	40	0.785	0.810	0.788
60	20	0.805	0.808	0.806
	30	0.812	0.795	0.806
	40	0.785	0.810	0.788
43 DE				
40	20	0.804	0.792	0.830
	30	0.792	0.800	0.755
	40	0.804	0.800	0.755
50	20	0.804	0.792	0.830
	30	0.792	0.800	0.755
	40	0.804	0.800	0.755
60	20	0.804	0.792	0.830
	30	0.792	0.800	0.755
	40	0.804	0.800	0.755

Table F3 -- Experimental data on quality attributes studies of fresh (control) and osmotically concentrated (OD), frozen, French fried potatoes

Replication	Treatment	Storage (mo)	Oil content[a]	Moisture content1[b]	Moisture content2[c]
1	Control	0	21.07	81.38	52.13
1	OD	0	6.72	81.36	46.98
1	Control	0	18.49	79.64	46.62
1	OD	0	4.68	78.96	44.26
2	Control	2	24.11	61.35	52.96
2	OD	2	6.93	72.04	52.98
2	Control	2	23.51	62.70	46.49
2	OD	2	7.35	65.60	52.98

[a] kg oil/100 kg of moisture free potatoes.
[b] Moisture content before frying (%, w.b).
[c] Moisture content after frying (%, w.b).

Table F4 -- Experimental data on quality attributes studies of fresh (control) and osmotically concentrated (OD), frozen, French fried potatoes

		Storage	Hardness		Color	
Rep[a]	Trt[b]	(mo)	(kg)	L	"a"	"b"
1	Control	0	92.0	62.65	1.30	22.25
1	OD	0	83.5	54.10	5.13	21.60
1	Control	2	87.7	59.55	2.10	23.05
1	OD	2	84.0	52.75	5.60	20.00
2	Control	0	92.5	64.15	1.40	21.95
2	OD	0	68.5	51.55	5.45	21.50
2	Control	2	84.5	57.15	1.55	19.70
2	OD	2	59.5	54.35	-5.25	20.40

[a] Replication.
[b] Treatment.

VITA

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