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REFRIGERATED POTATO STRIPS PRODUCTION

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by

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ABSTRACT

The demand for fresh-cut produce has been increasing because it is nutritious, ready-to-eat or -use, convenient with minimum preparation time and fresh-like with a shelf-life up to two weeks. Chemicals, including sulfite- and chlorine-based agents, are commonly used in the fresh-cut potato industry to prevent browning and to sanitize produce. Sulfites are allowed for fresh potatoes because cooking evaporates sulfur dioxide which is considered the offending component in sulfite-sensitivity. Nevertheless, there is a concern about these compounds which can provoke allergic reactions and produce carcinogens. Frozen potato strips, although not fresh-like, are preferred in deep-fat frying because fresh and fresh-cut potato strips become soggy, limp, greasy and too dark. In this study, alternative processing and packaging techniques were investigated to produce safe and high quality refrigerated potato strips with a shelf-life up to four weeks, to be used as an alternative to fresh-cut or frozen potato strips for French frying.

The effects of processing conditions —blanching time, ascorbic acid (AA) and calcium chloride (CaCl_2) concentrations and potato variety— on color and textural quality of refrigerated potato strips were investigated. The highest peak force was determined in potato fries blanched at low temperature (60°C) for 30 min and then blanched at high temperature ($\sim 98^\circ\text{C}$) for 5 min. However, there was no significant difference in peak force of potato fries blanched at low temperature for 30 or 20 min followed by high temperature blanching for 10 or 5 min. Changes in blanching time did not affect the lightness of potato fries. Increasing CaCl_2 concentration caused a significant increase in peak force of potato strips. Ascorbic acid did not affect color. The highest

peak force was obtained in potato fries prepared from the Russet Burbank variety. The results indicate that blanching the Russet Burbank variety of potato strips at low temperature (60°C) in 0.5% CaCl₂ solution for 20 or 30 min followed by blanching at high temperature (~98°C) in boiling water for 5 or 10 min was effective in potato strips processing to improve color and textural quality. However, optimal quality varies based on customer preferences.

Moreover, hot water blanching is also necessary for surface pasteurization of potato strips. However, microbial recontamination and resulting growth will occur unless a proper environment is provided during packaging. Near-aseptic packaging was found to be an alternative non-chemical method to extend shelf-life of blanched potato strips. In near-aseptic packaging of potato strips, blanched and cooled strips are packaged in a near-aseptic environment in which the packaging chamber and packaging materials are pasteurized with steam at atmospheric pressure for 30 min, then cooled to room temperature and continuously pressurized with filter sterilized air. In this part of the study, the effect of low (60°C) and high (~98°C) temperature blanching time and storage time on microbial, color and textural quality of near-aseptically packaged refrigerated potato strips were examined. Microbial spoilage was observed for all treatments which received a high temperature blanch of only one minute. No microbial growth was observed within 28 days of refrigerated storage for strips treated for either 10- or 20-min in low temperature blanch followed by 5- or 10-min in high temperature blanch. Near-aseptically packaged refrigerated potato fries were lighter in color ($P < 0.05$) than unprocessed fries (neither blanched nor near-aseptically packaged) and less color difference ($P < 0.05$) was observed in near-aseptic potato fries compared to unprocessed

fries. Near-aseptic potato fries were higher in peak force ($P < 0.05$) compared to unprocessed fries. No significant changes were observed in the quality of near-aseptically packaged refrigerated potato strips during 28 days of storage at 7°C.

Gaseous ozone, a strong antimicrobial agent, was studied as an in-package treatment of blanched potato strips to extend shelf-life. Potato strips were subjected to a batch ozone treatment for 20 s or a continuous ozone treatment for 5, 15 or 30 min by injecting ozone gas into the package. Microbial growth was observed the following day for bags with no ozone treatments. Continuous ozone treatment was effective in extending shelf-life of refrigerated potato strips compared to batch ozone treatment. No microbial growth was observed in 30- and 15-min continuous ozone treated strips after 28 and 21 days storage, respectively. There was no significant difference between the color of blanched strips and ozone treated blanched strips.

Finally, using the best treatments for the earlier experiments, the effects of near-aseptic packaging and in-package chemical treatments with gaseous ozone, sodium metabisulfite (SM) solution and FIT Fruit and Vegetable Wash™ solution on 2-step blanched potato strips were investigated. There was no microbial growth on any of the potato strips during 28 days of refrigerated storage. In SM treated strips, lighter color ($P < 0.05$) and less color difference ($P < 0.05$) were observed after frying compared to other treatments. Near-aseptic packaging was found to be an effective non-chemical alternative because there was no significant difference in before-frying color, textural quality and oil content compared to SM treatment which is currently the industry practice. FIT was found to be the most effective chemical treatment because the FIT significantly increased after-frying peak force of fries. Gaseous ozone treatment significantly decreased the color

quality of potato strips. There was no significant difference in the oil content of near-aseptically packaged potato fries, in package chemically treated potato fries and unprocessed fries.

Overall, the research results indicate that two-step blanching is necessary in improving color and textural quality of potato strips. Near-aseptic packaging as a non-chemical treatment and in-package FIT treatment are the better alternatives for blanched potato strips to extend shelf-life and maintain quality.

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Dedicated to My Parents

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Chapter 1

Introduction

The potato is one of the most widely cultivated vegetables in the world. One-third of the world's potatoes are cultivated by China and India (IYP, 2007). The United States is fourth in potato production with approximately 20 million tonnes per year (ERS-USDA, 2004). Most potatoes in the U.S. are consumed as frozen potato fries, potato chips and dehydrated potato products. Twenty eight percent are consumed fresh (NPC, 2007). The potato ranks first in fresh vegetable consumption. Consumer demand for fresh fruits and vegetables increased over the past 20 years in the U.S. Improvement in domestic production, product convenience and new technological improvements are the factors that affect fresh fruits and vegetable consumption. On the other hand, increasing income and interest in sustaining a healthier lifestyle are other factors in increasing utilization (Pollock, 2001).

Fresh-cut fruits and vegetables are convenient alternatives to intact fresh products. Fresh-cut produce is defined as physically altered from its original form but remaining in a fresh state (Lamikanra, 2002). Chemical preservation techniques are used to maintain fresh-like character and extend the shelf-life up to two weeks. In the fresh-cut potato industry, chemicals such as sulfite- and chlorine-based agents are commonly used to prevent browning and to sanitize produce (Beltran et al., 2005). Application of these compounds can provoke allergic reactions (Peroni and Boner, 1995) and produce carcinogens (Fawell, 2000). However, sulfites are allowed to be used for fresh potatoes

(FDA, 1994) because they are consumed cooked, and sulfur dioxide evaporates during the cooking process. Nevertheless, in deep-fat frying, frozen potato strips are preferred over fresh and fresh-cut potato strips which become soggy, limp, greasy and too dark (Talbert and Smith, 1987).

Blanching is a mild thermal treatment used in canning and freezing. In the frozen potato industry, two or three step blanching is used to improve final product quality. Two-step water blanching, low temperature (50-70°C) followed by high temperature (80-100°C) blanching, increases firmness and inactivates undesired enzymes (Abu-Ghannam and Crowley, 2006; Loon, 2005; Canet and Hill, 1987). Low temperature blanching minimizes texture degradation by activating pectin methyl-esterase enzymes (Nourian and Ramaswamy, 2003; Aguilar et al., 1997). High temperature blanching improves color by inactivating phenolase enzyme (Canet and Hill, 1987; Agblor and Scanlon, 2000). Hot water blanching provides more uniform color in fried products by leaching reducing sugars (Talbert and Smith, 1987). Blanching is also used in surface pasteurization of fruits and vegetables. Immersion in hot water reduces targeted microbial populations up to 5 log₁₀ CFU/g by providing excellent heat transfer through the food surface (Annous et al., 2004; Pao and Davis, 1999).

Ozone is preferred over traditional antimicrobial agents because of its effective antimicrobial property and lack of residual substances (Guzel-Seydim et al., 2004). Ozone has been granted as GRAS status as an antimicrobial agent used for food treatment, storage and processing by the U.S. Food and Drug Administration (21 CFR 173.368). Gaseous ozone treatment is more effective than aqueous ozone. In studies, gaseous ozone was used to treat berries (Bialka and Demirci, 2007), dried figs (Akbas

and Ozdemir, 2008) and spinach leaves (Klockow and Keener, 2009). Significant reduction in microbial populations was observed in ozone treated samples. Ozone gas was also used to prevent fungal decay and rot on fresh produce such as bananas, citrus fruits, berries and potatoes (Sapers et al., 2006).

FIT Fruit and Vegetable Wash™ (Procter and Gamble Co., Cincinnati, OH) is an antimicrobial which consists of GRAS components levulinic acid (FDA, 2004) (21 CFR 172.515) and sodium dodecyl sulfate (SDS) (FDA, 1978) (21 CFR 172.822). As a surfactant, SDS enhances the antimicrobial activity of levulinic acid. FIT can reduce the population of *Escherichia coli* and *Salmonella* significantly in less than a minute. Zhao et al. (2009), inventors of the formulation, observed greater than 6.7 log₁₀ CFU/g reductions of both *Salmonella* and *E. coli* O157:H7 populations on lettuce with 3% levulinic acid and 1% SDS in less than 20 s. However, chemical and thermal treatments are not sufficient to extend shelf-life until cut produce is packaged in an environment free of spoilage microorganisms.

This study addressed the production of refrigerated potato strips intended for frying. The overall objective was to determine processing and packaging techniques to achieve a safe and high quality product with a four week minimum shelf-life.

Chapter 2

Literature Review

2.1. Potato

Potatoes (*Solanum tuberosum*) were first cultivated around 200 B.C. in Peru by Inca Indians. They were used for many purposes including healing broken bones, helping digestion, preventing rheumatism and measuring time by correlating cooking period (NPC, 2007). The first European to discover the potato was Castellanos. Although European consumers were against the potato at the beginning, they accepted it later because of its long shelf-life and high nutrient values. The first potatoes arrived in North America in 1691 (Bosse and Boland, 2006).

Today, the potato is probably the most widely cultivated vegetables in the world. It is a highly nutritious food which consists of 80% water and 20% dry matter (Salunkhe et al., 1991). Potatoes also contain vitamins including niacin, riboflavin, thiamin and vitamin C, and minerals such as calcium, iron, magnesium, phosphorus, potassium, sodium and sulfur. Potatoes are rich in antioxidants which neutralize the negative effects of free radicals and reduce the risk of high blood pressure (Bosse and Boland, 2006).

Potatoes, along with tomatoes, peppers and eggplants, belong to the family *Solanaceae*. The potato plant consists of leaves, stems and tubers or underground stems. The potato tuber composition varies depending on the variety and growing conditions (Salunkhe et al., 1991). Variety is an important parameter that affects the yield, dry

matter content and quality of potatoes. Mostly, high specific gravity and long storage life potatoes are preferred in frozen potato and potato chips processing. The Russet Burbank is the number one potato variety used for frozen potato fries production because it is high in dry matter, has a long tuber type and has high antioxidant activity. The Superior variety is high in yield with minimum skinning and adequate for potato chips. The Norwis, a good long-term storage potato, is the standard for excellent baking and processing quality (PAA, 2007). The Keuka Gold is also another variety with a pale yellow flesh and scurfy skin. It is rich in flavor and very high in yields of large round tubers, good for mashing. The Reba variety tubers are large with white skin and flesh and high yields. They have excellent flavor and are mainly used in baked and mashed potato processing (NYSAES, 2008).

2.2. Potato Production and Consumption

Until the 1990s, most potatoes were produced and consumed in Europe, North America and countries of the former Soviet Union. Because of demand in Asia, Africa and Latin America, potato production increased in developing countries (IYP, 2008). In 2005, potato production in developing countries exceeded production in developed countries. According to Food and Agriculture Organization (2007) statistics, China is the world's biggest potato producer with 72 million tonnes per year. Russia and India rank in second and third place with 36.7 and 26.2 million tonnes per year, respectively. The United States is the fourth largest potato producer in the world. Potatoes are grown commercially in 36 states. The top ten potato producing states are listed in the Table 2.1.

Table 2.1. Annual potato production in the top ten states of the United States. *

Top Ten Potato Producing States	Production (million tonnes)
Idaho	5.35
Washington	4.31
Wisconsin	1.27
Colorado	1.04
Oregon	0.99
North Dakota	0.95
Minnesota	0.81
Maine	0.68
Michigan	0.63
Nebraska	0.36

* NASS-USDA, 2005

Nearly 80 percent of the U.S. consumes some form of potatoes, mainly as frozen potato fries, fresh potatoes, potato chips, dehydrated potato products and canned potatoes, within every four days (NPC, 2007) (Figure 2.1). Based on the Economic Research Service (ERS-USDA, 2007), U.S. per capita annual consumption is 57.2 kg. Frozen potatoes, frozen fries, tater tots, spiral fries, homefries, wedges and frozen whole potatoes, are the most consumed with 24 kg per person per year. Fresh, chips, dehydrated and canned potatoes are consumed at a rate of 20, 7.2, 5.9 and 0.5 kg per person, respectively.

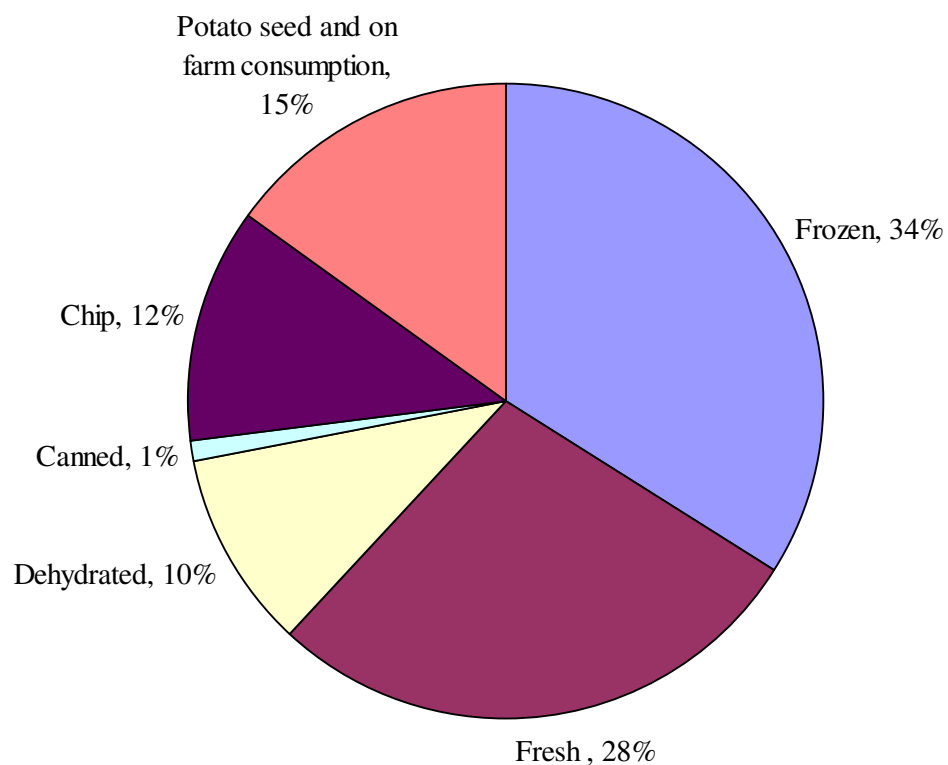


Figure 2.1. Potato utilization in the U.S. (NPC, 2007).

2.3. Commercial Potato Processing and Products

Consumption of potatoes has increased in the United States since 1980 (Smith et al., 1997) and 57% of potatoes are consumed as processed (NPC, 2007). Potatoes are processed into frozen potato fries, potato chips, dehydrated, canned, potato starch and flour. Processing of frozen potato fries and potato chips are discussed here.

2.3.1. Frozen Potato Fries

A wide variety of frozen potato products are prepared for institutional and home uses. Frozen potato products have uniform quality from one season to another and are simple to store. In addition, frozen products reduce labor and time in preparation for institutional serving. Frozen potato fries are preferred for home use because freshly cut potato fries are usually soggy, limp, greasy and too dark (Talbert and Smith, 1987).

In frozen potato fries processing (Figure 2.2), potatoes are washed, peeled, sorted and cut into strips. Strip size is essential because it impacts the color, texture and oil content of potato fries (Tajner-Czopek et. al., 2008; Krokida et al., 2000b).

Strips are hot water blanched before frying to leach out reducing sugars and to destroy enzyme activity. Hot water blanching provides more uniform color of fried products, reduces fat absorption through gelatinization of the starch, reduces frying time and improves the texture of the final product (Talbert and Smith, 1987). Blanching can be done with hot water or steam, but the former is preferred because of increased leaching of sugars. Two or three step, compared to single step, blanching, is also preferred to improve final product quality. Two-step water blanching, a combination of low temperature (50-70°C) followed by high temperature (80-100°C) blanching, increases firmness and inactivates undesired enzymes (Abu-Ghannam and Crowley, 2006; Loon, 2005). Low temperature blanching activates the pectin methyl esterase enzyme thereby improving texture and reducing oil absorption by decreasing the porosity of potato strips (Aguilar et al., 1997). High temperature blanching improves the color by inactivating phenolase enzyme (Agblor and Scanlon, 2000). Sodium acid pyrophosphate is used in

blanching water to create more crisp and rigid texture (Talbert and Smith, 1987), to prevent after-cooking darkening (Smith et al., 1997; Salunkhe et al., 1991) and to minimize enzymatic browning (Moyano et al., 2007).

Drying is required to remove excess water from the strips and, thereby, to increase strip solidity (Smith et al., 1997; Talbert and Smith, 1987) and to decrease oil content of fried potatoes (Tajner-Czopek et al., 2008).

The strips are par-fried (partially fried) in vegetable oil at 177-190°C for less than one minute (Smith et al., 1997). Par-frying prevents cohesion of potato strips by removing surface water, breaks up any enzyme activity at the surface of strips (Talbert and Smith, 1987) and prevents moisture redistribution in the strips (Agblor and Scanlon, 2000). Excess oil is removed from the strips by passing through a vibrating screen (Talbert and Smith, 1987).

Potato strips are kept in coolers until final freezing at -11°C. Freezing of potato strips prevent breakage of them after packing (Smith et al., 1997) and otherwise preserves quality.

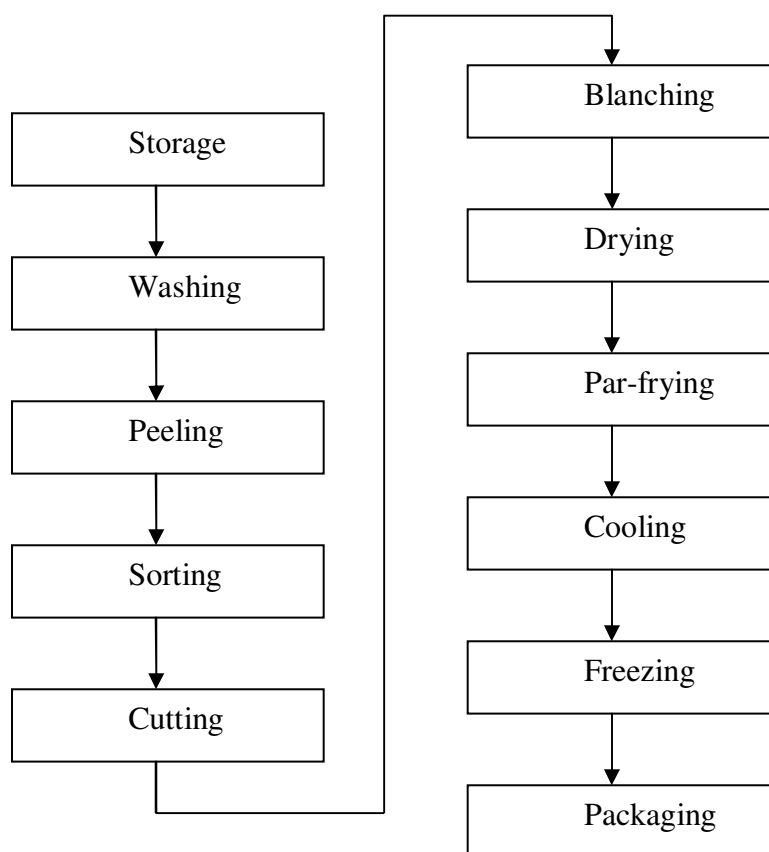


Figure 2.2. Steps in frozen potato fries production.

2.3.2. Potato Chips

A potato chip processing procedure widely used in the industry is described in Figure 2.3. Potatoes are washed, abrasively peeled and cut into slices. Slices are washed in rotating reels with water under high pressure to remove excess starch and thereby reduce cohesiveness. Slices are immersed in hot water or solutions such as sodium bisulfate, sodium citrate, citric acid or phosphoric acid to prevent browning (Talbert and

Smith, 1987; Salunkhe et al., 1991). The temperature of the hot water or solution must be between 65 and 93°C and the approximate holding time must be 1 min or more (Talbut and Smith, 1987). Washing is followed by a partial drying in a tunnel with infrared or microwave heat to remove excess moisture (Salunkhe et al., 1991). Potato chips are fried in vegetable oil between 165 and 177°C for approximately 4 min. Salt or coatings can be used based on the desired flavor and then chips are packaged (Beelman, 2004).

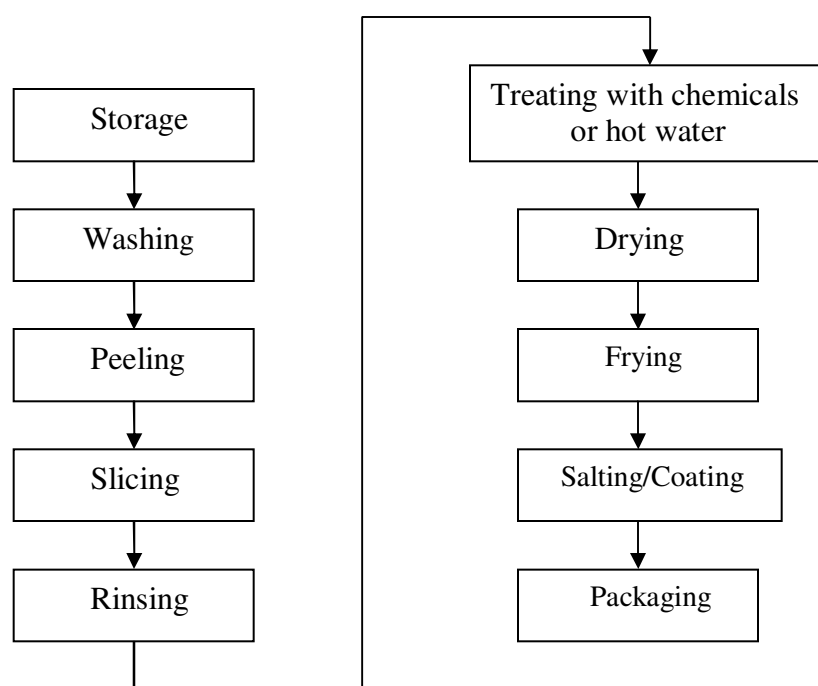


Figure 2.3. Steps in potato chips production.

2.4. Fresh-cut Potatoes

Fresh-cut fruits and vegetables are one of the fastest growing categories in the food industry. Since they are fresh, healthy and convenient, fresh-cut products are experiencing greater demand. In the United States, fresh-cut produce sales rapidly increased from \$3.3 billion in 1994 to \$11 billion in 2000. Sales continue to increase with an annual growth rate between 10 and 20% (ARS-USDA, 2005). Generally, fresh-cut fruits and vegetables are ready-to-eat or -use and fresh-like with a shelf-life up to two weeks. Fresh-cut fruits and vegetables fit into the fast food mentality of Americans.

Minimal processing is a technology used in fresh-cut produce production. There are several definitions for minimal processing. Briefly, minimal processing consists of the least possible treatments that extend shelf-life and improve safety of the food product without changing the fresh quality (Ohlsson and Bengtsson, 2002). Minimal processing involves unit operations such as washing, sorting, peeling and cutting, preservation methods, packaging in modified atmosphere environment and storing at refrigeration temperature. Processing damages plant tissues. Respiration rate and ethylene (plant growth hormone) production increases in wounded tissue which decreases the shelf-life (Rahman, 2007). In addition, tissue damage increases the risk of microbial growth since the natural defenses of the cells are reduced, and damaged cells leak out nutrients that are then easily accessed by microorganisms (USDA, 2007). Therefore, modified atmosphere packaging is preferred for minimally processed fruits and vegetables stored at refrigeration temperature (Rahman, 2007). Modified atmosphere packaging does not improve the quality but delays deterioration of product, so initial product quality in

addition to the packaging material, gas mixture and refrigeration conditions is important for maintaining high quality over the shelf-life (Martinez-Ferrer et al., 2002).

Average shelf-life for fresh-cut fruits and vegetables varies from 10 to 14 days. Gunes and Lee (1997) were able to extend the shelf-life of minimally processed potatoes nearly three weeks with anti-browning agents (0.5% L-cysteine and 2% citric acid) and modified atmosphere packaging under refrigerated conditions. Erturk and Picha (2006) were able to reduce microbial population on fresh-cut sweet potatoes by treating with 200 ppm chlorine at 1°C and achieve 14 days refrigerated storage. Waimaleongora-Ek et al. (2008) were able to improve quality of fresh-cut sweet potatoes by coating with a derivative of a natural carbohydrate polymer, chitosan, to achieve 17 days of shelf-life.

2.5. Factors Influencing Processing Quality of Potatoes

2.5.1. Storage

Ventilation, temperature and relative humidity of the storage are important parameters that affect the quality of potatoes. Excessive moisture loss, rot development, sprout growth and sugar accumulation are prevented with good storage (Talbert and Smith, 1987). Additionally, good storage provides a year-around supply of tubers.

A potato consists of 80% water, 18% carbohydrates, 2% protein, minerals, vitamins, amino acids and phenolics. Starch, the main carbohydrate, constitutes about 70% of the total carbohydrates. Sucrose, glucose and fructose are the major sugars of the

potato tuber (Salunkhe et al., 1991). Sucrose occurs in the leaves of the potato plant during photosynthesis. Then, it passes to the tuber under the ground where it is converted to starch (Beelman, 2004). In the food processing industry, tubers are stored at 10°C to prevent reducing sugar accumulation and excessive sprouting. However, sprout inhibitors such as maleic hydrazide (MH-30) and chloroisopropyl carbamate (CIPC) are widely used to prevent sprouting during storage (Salunkhe et al., 1991).

When the potato tubers are kept at lower temperature (~5°C), starch is converted to sugar by phosphorylase enzyme, and results in dark-colored fried products. After reconditioning at high temperature (20-25°C), sugars are converted back to starch by the enzyme starch synthetase (Salunkhe et al., 1991).

Storage conditions also affect the specific gravity of the tuber. Higher specific gravity is needed in potato chips, frozen potato fries and dehydrated potato processing. Storing at 10°C helps to retain the original specific gravity of the tuber (Talbert and Smith, 1987).

During respiration, sugars are converted to carbon dioxide, water and energy. Temperature and atmospheric condition of the storage environment affect the respiration rate of the tubers. Respiration rate increases at high temperatures which results in weight loss of tubers (Voss et al., 2007) and thereby gives low specific gravity.

2.5.2. Specific Gravity and Dry Matter Content

Specific gravity and dry matter content are important and related parameters for the quality of processed potatoes. Dry matter content of potatoes varies from 15 to 24%

(Table 2.2). The dry matter content of potatoes is directly correlated with its starch content (Smith et al., 1997).

Table 2.2. Characteristics of the three major potato types used in processing in North America. *

Processing Characteristic	Potato Type		
	Red	Russet	White
Appearance:			
Flesh of meat	White	White	White
Skin color	Red	Brown	White/tan
Skin texture	Smooth	Rough/netted	Smooth
Tuber shape	Round	Long	Round/oblong
Quality:			
Main use	Boiled/salad	Strips/baked	Chips
Key appearance	Redness	Longness	Roundness
Specific gravity	Low	Medium	High
Dry matter (%)	15-19	17-21	18-24
Starch (%)	10-13	12-15	13-18
Glucose at harvest	High	Medium	Low
Fry color	Brown	Tan/white	White
Cooked texture	Pasty/waxy	Mealy/flakey	Grainy/dry
Taste	Slightly sweet	Bland/soft	Bland/dry

* Smith et al., 1997

Potatoes for the manufacture of chips, frozen strips and dehydrated products should have high dry matter content. Higher dry matter content improves the texture, appearance and color of potato chips and frozen potato strips (Salunkhe et al., 1991). The

specific gravity varies between 1.050 and 1.109 for commercially grown potatoes. In potato fries processing, specific gravity of a potato mostly varies from 1.080 to 1.099 for the best texture and appearance (Table 2.3). Crispiness, flavor and tenderness of potato fry increase, whereas mealiness and oiliness decrease with high specific gravity. A low specific gravity potato strip requires longer blanching time to produce desirable fry color, and it assumes poor texture after frying (Smith et al., 1997).

Table 2.3. Influence of specific gravity and dry matter on texture and processing uses of potatoes. *

Tuber Specific Gravity	Tuber Dry Matter Content	Product Texture	Processing Uses
1.050-1.059	15.5-17.3%	Soggy	Excellent salad
1.060-1.069	17.4-19.1%	Pasty	Excellent canning Excellent boiling Good salad
1.070-1.079	19.2-21.1%	Waxy	Good canning Excellent mashing Good boiling Fair canning Fair French frying Fair chipping
1.080-1.089	21.2-22.9%	Mealy	Excellent baking Excellent French frying Good chipping
1.090-1.099	23.0-24.8%	Dry	Excellent chipping Good French frying Fair baking
1.100-1.109	24.9-26.6%	Very Dry	Fair/good chipping

* Smith et al., 1997

2.6. Quality of Potato Strips

The priority of quality parameters changes according to consumer and manufacturer interests. Color, texture and oil content are common parameters that affect quality of potato fries. Microbiological quality is also essential for the shelf-life of fresh-cut potato strips.

2.6.1. Color

Color is an important quality parameter for the acceptability of any food product. Enzymatic browning occurs when the cut or peeled surfaces of fresh potatoes are exposed to air. Phenolase enzyme catalyzes oxidation of phenolic compounds (chlorogenic acid and amino acid tyrosine) in the presence of oxygen. The ultimate product of tyrosine is dark brown colored melanin (Figure 2.4) (Salunkhe et al., 1991; Sun, 2006). Hydroxylation and oxidation reactions are involved in the phenolase catalytic reaction; the other reactions are, or can be, non-enzymatic (Kitts, 2007).

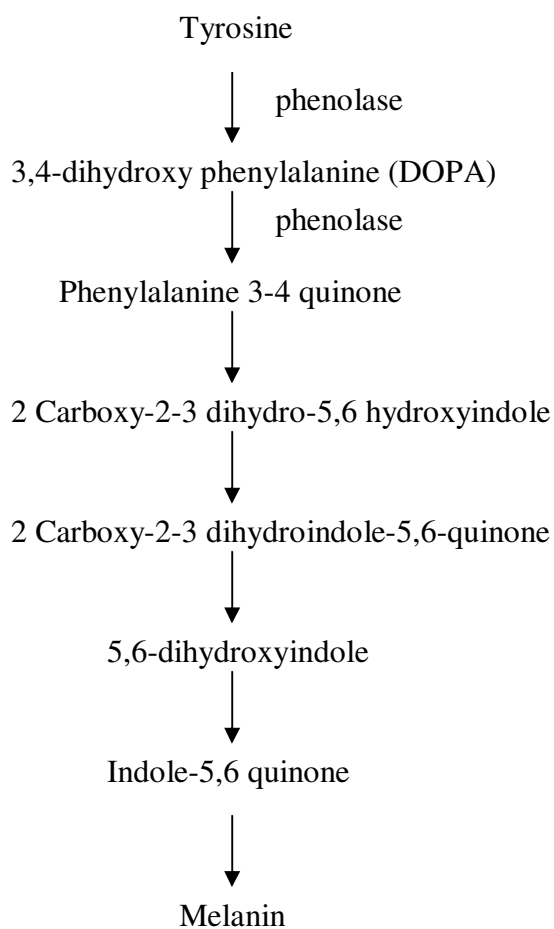


Figure 2.4. Scheme of oxidation of tyrosine by phenolase and the formation of melanin pigments (Salunkhe et al., 1991).

Chemical reactions between the reducing sugars (mainly D-glucose) and amino acids conclude with undesirable color and flavor at high temperatures (170-195°C) (Smith et al., 1997). Browning occurs when the carbonyl group of a reducing sugar (aldose) condenses with a free amino group of an amino acid that is part of a protein chain. This is called Maillard reaction (Figure 2.5). It is defined as a non-enzymatic browning reaction to differentiate it from enzymatic browning. Non-reducing sugar (e.g.

sucrose) does not affect the color of potato strips (Beelman, 2004; Fennema, 1996). The acceptable upper limit of reducing sugar to prevent a Maillard reaction is 0.10% on a fresh weight basis, but that value can change based on the cooking method (Salunkhe et al., 1991).

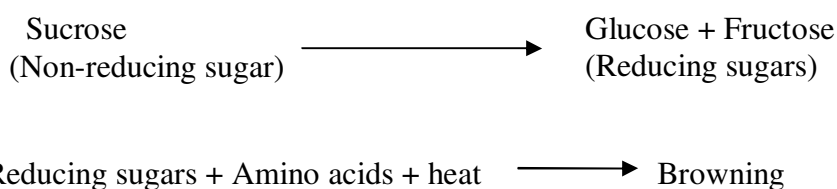


Figure 2.5. Maillard reaction (Beelman, 2004).

Like the Maillard reaction, caramelization and ascorbic acid oxidation are forms of non-enzymatic browning. Caramelization occurs in the absence of nitrogen containing compounds because of heating of carbohydrates and reducing sugars (Fennema, 1996). Technically, sucrose does not caramelize only because it first decomposes into glucose and fructose which then can caramelize.

Blanching is the most commonly used process to inactivate enzymes in fruits and vegetables, used for canning and freezing. Blanching temperature varies between 70-105°C (Marshall et al., 2000). Generally, water blanching at 60-82°C is used in potato processing (Talbert and Smith, 1987). The polyphenol oxidase which causes potato browning is quickly inactivated at approximately 100°C (Marshall et al., 2000). Optimum

blanching time changes depends on the size of the product. High-temperature, short-time water blanching gives a light color but decreases textural quality (Agblor and Scanlon, 2000). As described earlier, two step blanching is commonly used in frozen potato fries processing, (Abu-Ghannam and Crowley, 2006; Loon, 2005), and water blanching is preferred over steam blanching, because water blanching prevents non-enzymatic browning by leaching reducing sugar.

Preservatives are also used in improving color quality. In the fresh-cut industry, treating with preservatives is preferred instead of blanching because heat treatment affects product freshness (Wiley, 1994). Some of the browning inhibitors used for potato products are erythorbic-citric acid (Cacace et al., 2002), citric acid, and sodium acid pyrophosphate (Smith et al., 1997; Krochta et al., 1994). Ascorbic acid reduces o-quinones, avoiding the formation of browning compounds during the polyphenoloxidase reactions to phenol compounds (Mcevely et al., 1992). In addition, refrigeration and freezing inhibits the polyphenol oxidase enzyme activity but it does not inactivate the enzyme. Polyphenol oxidase enzyme is inhibited below 7°C (Marshall et al., 2000).

Color is a 3-dimensional characteristic. Humans have three types of light sensing capabilities: red, green and blue. The International Committee on Illumination (Commission Internationale d'Eclairage, or CIE) represents color with X, Y and Z numerical values of color (Moreira et al., 1999). Today, L*a*b* color space which is computed via simple formulas from X, Y and Z, is used to define color changes of a product in the food industry. This uniform color space was adopted by CIE in 1976. In this color space, L* is the lightness which ranges from 0 to 100, and chromatic components of a* (from green to red) and b* (from blue to yellow) range from -60 to 60.

ΔE indicates the size of the color difference which is calculated with Equation 2.1 (Konica Minolta, 1998; Nourian and Ramaswamy, 2003). Delta (Δ) shows the difference between the processed and reference values. Generally a calibration plate is used as a standard reference value.

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (2.1)$$

2.6.2. Texture

Texture is one of the most important quality parameter in potato processing. Firmness is the attribute most often used to describe the texture quality of vegetables. Maintaining firm texture during storage indicates freshness of fresh-cut potato strips. Not only firmness during storage but also crispiness after frying is important for the textural quality of potato strips. Potato fries with a crispy outside, and a soft and steamy inside define a desired after-frying textural quality.

Pectin, cellulose and hemicellulose form the rigid structure of raw potatoes. Pectin is the major component in a potato since it holds the intercellular structure together and contributes to the mechanical strength of the cell wall. Pectin is more easily leached than other cell wall polymers (Abu-Ghannam and Crowley, 2006). Low temperature (50-70°C) blanching minimizes texture degradation because the pectin methyl esterase enzyme becomes active. Pectin methyl-esterase hydrolyzes methyl ester bonds in pectin molecules and frees carboxylate groups. The free carboxylate groups form cross-links between pectin polymers through salt-bridge formation with divalent cations such as Ca^{2+}

and Mg^{2+} naturally present in the tissues or added to the blanching water (Nourian and Ramaswamy, 2003). Pectin methyl-esterase activity in blanched potatoes varies based on the temperature distribution in the potato tissue (González-Martínez et al., 2004). Pectin methyl esterase is very active in the temperature range of 50 to 70°C, but is rapidly inactivated above 70°C (Andersson et al., 1994; Nourian and Ramaswamy, 2003; Ni et al., 2005). Aguilar et al. (1997) found that the best texture and least oil absorption occurred for potato strips (5x5 mm) blanched at 55°C for 45 min and 65°C for 30 min, respectively. Abu-Ghannam and Crowley (2006) reported that pre-treatment by water blanching at 65°C followed by treatment at 95-100°C gave the better texture compared to without pre-treatment, for whole new potatoes. Canet and Hill (1987) applied different blanching techniques to frozen potatoes. The firmest texture was obtained in stepwise blanching by pretreatment at 70°C for 10 min followed by water cooling and conventional blanching at 97°C for 2 min.

Besides the blanching, thermal processes such as pre-drying and frying cause water losses which increase dry matter content and thereby affect the texture of the finished product (Table 2.4) (Lisińska and Golubowska, 2005). Furthermore, frying oil type and temperature are essential factors that impact the final texture.

Table 2.4. Content of dry matter in potato tubers during French fry processing. *

Processing Step	Dry Matter (%)
Potato not peeled	21.0
Potato after peeling	22.0
Potato after cutting	20.7
Strips after blanching	21.2
Strips after pre-drying	24.8
French fries after frying	55.3

* Lisińska and Golubowska, 2005

Chemicals may be used in blanching water to improve the firmness of potato strips. Calcium chloride, magnesium chloride and calcium citrate, were tested on both high and low specific gravity potatoes. The most effective chemical was calcium chloride (0.5%) for French fries (Jaswal, 1970). Calcium chloride has a significant effect on the shelf-life of various fruits and vegetables. Calcium chloride extends storage life, reduces the oil consumption and the darkening, and improves the nutritional value by increasing calcium content (Mishra, 2002).

Szczesniak (1998) defines texture as “the sensory and functional manifestation of the structural and mechanical properties of foods, detected through the senses of vision, hearing, touch and kinesthetics.” Although sensory methods determine the textural characteristics of food product based on the consumer opinion, instrumental methods are preferred by producers due to complexity of sensory analysis. Crispiness is a major textural property of French fries but structural heterogeneity of potato tubers causes variation in instrumental texture data (Miranda and Aguilera, 2006). In the literature,

several methods have been used to determine textural property of potato fries. Walter et al. (2002) compared instrumental texture profile analysis, puncture, bending and Kramer shear against each other but, unfortunately, not against sensory measurements. The Kramer shear test indicated low coefficient of variation compared to puncture and bending tests. Lima and Singh (2001) compared the mechanical properties of potato fries by using puncture and three-point bending cells. Maximum peak force was determined as a best parameter to differentiate treatments. Puncture force and flexural strength increased by increasing frying time and temperature. Sanz et al. (2007) determined the effect of pre-frying and final frying times on crispiness of French fries by fracture and acoustic measurements. In their study, biting with front teeth was simulated by using a wedge-shaped aluminum probe. During fracturing, sound was recorded with an acoustic sensor. Increasing pre-frying time and final frying time increased the number of large peak force and number of sound events which indicated higher crispiness. Loon et al. (2007) tested crispiness of French fries by mechanical testing with a wedge-shaped probe and sensory evaluation. This is one of the few studies found in which sensory measurements were compared against instrumental measurements. Good correlation was observed between mechanical testing and sensory evaluation of French fries crispiness. However, there is not any standard method to determine crispiness of potato fries.

2.6.3. Oil Content

Deep-fat frying involves convection heat transfer from surrounding oil to the surface of the potato fry and conduction heat transfer from surface to the interior of the

particle. The process is especially complex because of the mass transfer and phase change heat transfer that occurs as liquid water moves from inside the potato and is evaporated to steam which finally rises from the oil surface. Frying conditions alter the structure of potato fries, for instance, increasing frying temperature increases the porosity (Krokida et al., 2000a) and the oil content of French fries (Krokida et al., 2000b).

Oil content is one of the important quality attributes of fried products because high oil content results in an oily and a tasteless product. The frying temperature should be determined based on the best quality of final product, and for new product development, 177°C can be a good starting temperature (Dunford, 2004). As shown in Table 2.5., oil content of product is governed by frying temperature and time (Moreira et al., 1999).

Table 2.5. Effect of frying conditions on oil uptake of potato chips and French fries

Product	Frying Temperature (°C)	Frying Time (s)	Moisture Content (% w.b.)	Oil Content (% w.b.)	OC/MR**
Potato Chips	145	60	66.5	3.0	0.05
	145	300	14.7	31.8	0.16
	165	60	58.0	11.8	0.15
	165	300	4.9	35.9	0.15
	185	60	37.7	14.1	0.09
	185	300	0.7	36.2	0.14
French Fries	182	120	58.7	9.6	0.33
	182	135	50.0	12.1	0.24
	182	150	46.2	13.9	0.24
	182	165	44.5	15.7	0.25

* Moreira et al., 1999

** OC/MR: oil content/moisture removed

Potato variety, product shape and processing techniques are some of the factors that affect the oil absorption in French fries. It was found that with Russet Burbank and Agria varieties of straight cut, frozen French fries oil contents were 10.2% and 7.1%, respectively (O'Connor et al., 2001).

Low temperature, long-time blanching of a potato strip decreases the porosity and thereby reduces the oil absorption (Aguilar et al., 1997). Oil content of common deep-fat fried products is provided in Table 2.6.

Table 2.6. Deep-Fat Fried Products in the U.S. *

Product	Oil Content (%)
Potato Chips	33-38
Tortilla Chips	23-30
Corn Chips	30-38
Expanded Snack Products	20-40
Roasted Nuts	5-6
French Fries	10-15
Doughnuts	20-25
Frozen Food (fish, chicken, pancakes)	10-15

* Moreira et al., 1999

Smoke point is an important oil parameter for deep-fat frying. Flavor and odor are initial signs of oil degradation. After that, oil begins to smoke. The smoke point, seen as a bluish smoke, is the temperature at which an oil or fat begins to break down (Stauffer, 1996). The triglycerides break down into free fatty acids and glycerol then glycerol is converted to acrolein (Figure 2.6) which causes smoke (Moreira et al., 1999). The smoke points of fats and oils depend on content of free fatty acids and glycerol.

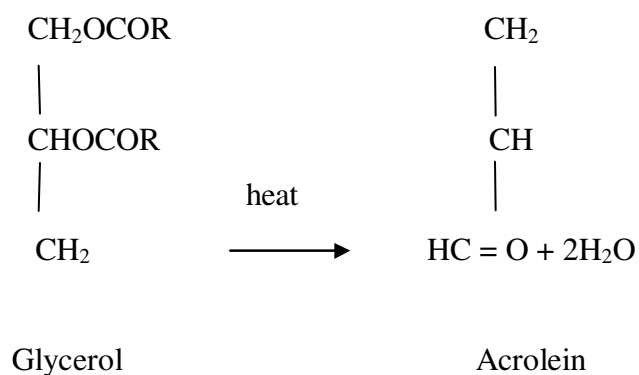
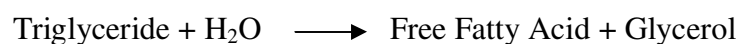


Figure 2.6. Presence of smoke component acrolein (Moreira et al., 1999).

Fats with a smoke point higher than 200°C are suitable for deep-fat frying. Example oils are corn, grapeseed, peanut and safflower (Moreira et al., 1999). Although olive oil is healthy, it is not used for deep fat frying since its smoke point is about 190°C.

The methods used for oil content determination are classified as extraction, refractometric, hydraulic press and NIR spectroscopy. The most common method is extraction. Petroleum ether, diethyl ether, and hexane are solvents used in extraction methods (Moreira et al., 1999). Generally, the Soxhlet extraction technique is used in oil content determination of potato fries and chips (O'Connor et al., 2001; Bouchon and Pyle, 2004 and Loon, 2005). In Soxhlet extraction, the sample is dried, ground into small particles and placed in a porous cellulose thimble. The thimble is placed in an extraction chamber which is located on the flask containing the solvent and below a condenser. The

flask is heated and the solvent evaporates up into the condenser. Evaporated solvent is converted into a liquid, passes through the extraction chamber containing the sample and carries the extracted analytes into bulk liquid. This cycle is repeated many times for hours or days. Finally, the solvent in the flask is evaporated and the mass of the remaining lipid is measured. The percentage of lipid in the initial sample is calculated.

2.6.4. Microbiological Quality

Generally, shelf-life of frozen potato fries is approximately one year because no microbial growth occurs at freezing temperatures. However, shelf-life for fresh-cut produce reaches up to 14 days in refrigerated storage. Psychrotrophic bacteria can grow under refrigeration, although slowly (Hui, 2006), but grow optimally above refrigeration temperature (Kraft, 1992). A number of yeasts and molds can grow at refrigeration temperatures as well. Shelf-life of the product varies based on the mechanism of product deterioration, expected quality of the food in the package, the environmental conditions during distribution and storage and the barrier properties of the packaging materials (Moreira et al., 1999). Based on the product, specific or combinations of preservation techniques help in decreasing microbial load and improving shelf-life (Wiley, 1994).

2.7. Preservation Techniques for Refrigerated Food Products

Preservation techniques, surface pasteurization or chemical treatments, are commonly used to decrease microbial load in refrigerated fruits and vegetables.

However, packaging is also important to maintain an environment free of microorganisms during the storage.

2.7.1 Surface Pasteurization

Surface pasteurization, steam or water, is more effective and acceptable method in sanitizing produce compared to chemical washes. However, it has limited use in the fresh-cut industry because thermal treatments generally affect the freshness of produce. Steam and hot water surface pasteurization is a promising technology for refrigerated produce because it reduces spoilage microorganisms on the surface of fruits and vegetables. Nevertheless, steam is mostly used for surface pasteurization of meat and poultry products rather than fruits and vegetables (Sapers et al., 2006).

Immersion in hot water inactivates bacteria by providing excellent heat transfer through the food surface. Annous et al. (2004) were able to reduce *Salmonella* population by $\geq 5 \log_{10}$ CFU/cm² on cantaloupe surfaces by commercial-scale hot water immersion at 76°C for 3 min. Pao and Davis (1999) were able to reduce *E. coli* populations on orange surfaces up to 5 log₁₀ CFU/g by hot water immersion either at 70°C for 2 min or 80°C for 1 min. Fleischman et al. (2001) reported that no *E. coli* populations were found on the surfaces of whole apples after surface pasteurization in water at 95°C for 60 s.

2.7.2. Chemical Preservation Techniques

Chemical preservation technique is widely used for fresh-cut produce to keep fresh-quality of product over a long shelf-life. There are several washing agents used in the food industry to reduce microbial contamination.

2.7.2.1. Chlorine

Chlorine is the most widely used sanitizing agent for fresh produce. The U.S. Food and Drug Administration (FDA, 1999) specified a use level of chlorine at no more than 0.2 % for fruits and vegetable wash (21 CFR 173.315). Chlorine is easy to apply, inexpensive and effective on all microorganisms. However, chlorine is corrosive to metals and reaction products may be hazardous. It is a potential carcinogen due to its reaction products with organic constituents of the food. It reduces microbial population up to 2 logs (Sapers et al., 2006). Akbas and Olmez (2007) were able to reduce mesophilic and psychrotrophic bacteria populations on lettuce by 1.7 and 2.0 log₁₀ CFU/g respectively with dipping in 100 mg/L chlorine solution.

2.7.2.2. Ozone

Ozone is a highly reactive antimicrobial with no residual effect (>100 times more reactive than chlorine). It is becoming popular because of its effective antimicrobial property and lack of residual substances. According to FDA (2001) “Ozone may be

safely used in the treatment, storage, and processing of foods, including meat and poultry”. It is a GRAS status antimicrobial agent used for preservation in contact with food in gaseous or aqueous phase based on current industry standards. In addition, ozone is used for treatment of raw agricultural commodities. It is applied either on food or in water to treat food (21 CFR 173.368).

The corona discharge method is usually used for commercial ozone generation. Ozone is generated by passing oxygen molecules or air through an electrical charge. Oxygen molecules (O_2) are separated into highly reactive oxygen atoms (O). The unstable ozone molecule (O_3) forms when free oxygen atom combines with oxygen molecule (O_2) (Guzel-Seydim et al., 2004). Since ozone has a high oxidation potential, it oxidizes and penetrates bacterial cell walls. Ozone oxidizes essential components such as enzymes, proteins, DNA. Then, the cell is separated into pieces and destroyed which is called lysis (Lenntech, 2008). Gaseous ozone treatments are generally more effective than aqueous ozone treatments. Bialka and Demirci (2007) were able to reduce *Salmonella* and *E. coli* O157:H7 on strawberries by 2.60 and 2.96 \log_{10} CFU/g, respectively, using gaseous treatments. Akbas and Ozdemir (2008) were able to reduce *B. cereus* in dried figs up to 2 \log_{10} CFU/g with gaseous ozone. In both studies, there were no significant changes in color after ozone treatments. Klockow and Keener (2009) analyzed the effectiveness of ‘in-package’ gaseous ozone generation and treatment on spinach leaves. They were able to reduce *E. coli* O157:H7 in spinach by 3-5 \log_{10} CFU/leaf after 24 hours storage. Gaseous ozone also prevented fungal decay and rot on fruits and vegetables such as bananas, citrus fruits, berries, potatoes, and extended shelf-life (Sapers et al., 2006).

2.7.2.3. Sulfites

Sulfite salts such as sodium metabisulfite are also widely used for preservation of food products in the industry due to low cost of sulfites. However, there are regulatory restrictions preventing sulfites from being used in meats, other foods recognized as sources of thiamine and fruits and vegetables which are consumed fresh, due to adverse affects on human health (FDA, 1994). Application of these compounds can provoke allergic reactions (Peroni and Boner, 1995) and produce carcinogens (Fawell, 2000). In fresh-cut potato industry, chemicals such as sulfites and chlorine based agents are commonly used to prevent browning and to sanitize produce. Beltran et al. (2005) were able to reduce anaerobic microorganisms by 0.6 and 0.7 logs in fresh-cut potato strips with dipping into sodium sulfite and hypochlorite solutions for 3 min, respectively. In the case of deep-fat frying, sulfites are allowed because the sulfite is lost by evaporation during the frying process (Petri et al., 2008).

2.7.2.4. FIT Wash

FIT Fruit and Vegetable Wash (Procter and Gamble Co., Cincinnati, Ohio) is marketed as an effective antimicrobial. The original FIT formulation consists of oleic acid, glycerol, ethyl alcohol, potassium hydrate, sodium bicarbonate, citric acid and grapefruit oil. Beuchat et al., (2001a) were able to reduce *Salmonella* and *Escherichia coli* O157:H7 populations ranged from 1.7 to 2.3 log₁₀ CFU/g and 1.7 to 5.4 log₁₀ CFU/g respectively with 30 min FIT treatment. Beuchat et al. (2001b) were also able to decrease *Salmonella* and *Listeria monocytogenes* populations 6.83 log₁₀ CFU/g and 4.96 log₁₀

CFU/g, respectively on ripe tomatoes by using FIT. Besides the microbial pathogens, FIT was 98% more effective compared to water for removing pesticides from fruits (Krieger et al., 2003).

Zhao et al. (2009) invented what became the new formula FIT Fruit and Vegetable Wash™ which can kill significant numbers of *Escherichia coli* and *Salmonella* in less than a minute. The new formulation consists of two components; levulinic acid and sodium dodecyl sulfate (SDS). Levulinic acid (FDA, 2004) (21 CFR 172.515) and sodium dodecyl sulfate (1978) (21 CFR 172.822) are generally recognized as safe by FDA. SDS is a surfactant which acts to enhance the antimicrobial activity of levulinic acid. Zhao et al. (2009) were able to reduce both *Salmonella* and *E. coli* O157:H7 populations on lettuce greater than 6.7 log₁₀ CFU/g by using 3% levulinic acid and 1% SDS for less than 20 s. They also achieved reductions in *Salmonella* and aerobic bacterial populations on chicken wings more than 5 log₁₀ CFU/g by using 3% levulinic acid and 2% SDS combination for 1 min. It is not public information what are the concentrations of levulinic acid and SDS in the new FIT formulation or if these are the only ingredients.

2.7.3 Packaging Techniques

2.7.3.1. Modified Atmosphere Packaging

In the fresh-cut industry, modified atmosphere packaging (MAP) is widely used to improve product image, slow undesirable quality changes and extend shelf-life.

Mixtures of CO₂, O₂ and N₂ are used as the environment inside the packaging material.

Optimal gases and their concentrations are different for different products (Farber and Dodds, 1995). However, generally O₂ levels are decreased below and CO₂ levels are increased above atmospheric levels to improve microbial quality by reducing respiration rate (Sapers et al., 2006). Furthermore, antimicrobial activity of CO₂ inhibits microbial growth (Daniels et al., 1985). MAP increases the shelf-life and helps to maintain the quality of produce during the storage however temperature control is required for product safety (Phillips, 1996).

Barrier properties, machine capability, sealing reliability and good visibility of the product are factors that need to be considered in film selection for packaging (Phillips, 1996). Gas permeability of the film is necessary to maintain desired gas concentration inside the package. The ratio of CO₂ to O₂ permeation coefficients between 4 and 8 allows greater diffusion of CO₂ compared to O₂ (Alique, 2003). Polyethylene is one of the polymers commonly used in MAP film which provides hermetic sealing, good visibility and easy sealing (Phillips, 1996).

2.7.3.2. Vacuum Packaging

Vacuum packaging is another technique to reduce oxygen around the food. The product is sealed into a low gas permeability evacuated package. However, vacuum packaging is not preferred for fresh-cut produce because it would create anaerobic conditions leading to growth of anaerobic pathogens such as *C. botulinum* (Farber, 1991; Hotchkiss and Banko, 1992).

2.7.3.3. Aseptic Packaging

According to the FDA (2009) “Aseptic processing and packaging means the filling of a commercially sterilized cooled product into presterilized containers, followed by aseptic hermetical sealing, with a presterilized closure, in an atmosphere free of microorganisms” (21 CFR 113.3). It is a cost-effective and high-quality distribution method. The common target organism for sterilization is *Clostridium botulinum* with a z-value 10°C. Lethality must be achieved at the slowest heating point of the food product and packaging materials in sterilization process. Lethality (L) is a lethal effect of temperature on microorganisms and is predicted using Equation 2.2 (Singh and Heldman, (2001).

$$L=10^{(T-T_{ref})/z} dt \quad (2.2)$$

where T= product temperature, T_{ref} = reference temperature, z= thermal resistance constant and t= time.

Aseptic processing and packaging improves quality by avoiding overcooking during sterilization, provides packaging alternatives and reduces energy and water consumption. However, aseptic packaging is mechanically complex and not practical for low acid foods with particles (Walker, 2008). Besides, aseptic packaging is not preferred in fresh-cut industry because sterilization of food product by thermal treatments damages the fresh-like property of food.

However, near-aseptic conditions are used in refrigerated products to extend shelf-life. Mild thermal process such as pasteurization, sufficient to kill pathogens, is given to food. Pasteurization conditions may vary according to nature of the food. Then,

the pasteurized product is handled and filled in ultraclean conditions and packaged into sterilized bags (Sun, 2006).

Chapter 3

Effects of Processing Conditions on Quality of Refrigerated Potato Strips

Abstract

The effects of processing conditions on color and textural quality of refrigerated potato strips were investigated. To determine effect of blanching time, potato strips were blanched at low temperature (60°C) in 0.25% ascorbic acid (AA) and 0.5% CaCl₂ solution for 10, 20 or 30 min then blanched at high temperature (~98°C) in boiling water for 5, 10 or 15 min and stored for one day at refrigerated temperature. Texture and color analysis were applied after frying. The highest peak force was determined in potato fries blanched at low temperature for 30 min and then blanched at high temperature for 5 min. Changes in blanching times did not significantly affect the lightness. To determine effect of AA and CaCl₂, potato strips were blanched at low temperature for 20 min in 0.125 or 0.25% AA and 0, 0.25 or 0.5% CaCl₂ solution then blanched at high temperature for 10 min and stored for one day at refrigerated temperature. Texture and color analysis were applied before frying. Peak force of potato strips was significantly increased by increasing CaCl₂ concentration. Ascorbic acid did not affect the color quality. To determine effect of potato variety, Russet Burbank, Keuka Gold, Reba and Norwis varieties of potato strips were blanched at low temperature in 0.5% CaCl₂ solution for 20 min then at high temperature in boiling water for 10 min and stored one day at refrigerated storage. Texture and color analysis were applied after frying. The highest

peak force was obtained for the Russet Burbank variety. Less color difference was determined in potato fries prepared from Reba compared to Russet Burbank, Keuka Gold and Norwis. The results indicate that blanching Russet Burbank variety of potato strips at 60°C in 0.5% CaCl₂ solution for 20 or 30 min followed by blanching in boiling water for 5 or 10 min can be an effective process to produce high quality potato strips.

3.1. Introduction

Potato consumption has been increasing in the United States since 1980 (Smith et al., 1997). Nearly 80 percent of the U.S. consumes some form of potatoes within every four days. Potatoes are consumed as frozen, fresh, chips, dehydrated and canned at 34, 28, 12, 10 and 1%, respectively (NPC, 2007). A wide variety of frozen potato products are prepared for institutional and home uses because frozen products reduce labor and time in preparation. Frozen potato fries are preferred for deep-fat frying because freshly cut potato fries are usually soggy, limp, greasy and too dark (Talbert and Smith, 1987). However, U.S. demand for fresh-cut vegetables has increased because they are fresh, healthy and convenient. In the fresh-cut industry, treating with preservatives is preferred instead of thermal treatments because heat treatment might affect the freshness of products (Wiley, 1994). Some of the browning inhibitors used for fresh potato products are erythorbic-citric acid (Cacace et al., 2002), ascorbic acid (Mcevely et al., 1992), citric acid and sodium acid pyrophosphate (Smith et al., 1997; Krochta et al., 1994). Chemicals such as sulfites and chlorine based agents are commonly used to prevent browning and to sanitize produce (Beltran et al., 2005). However, sulfites can cause allergic reactions

(Peroni and Boner, 1995) and chlorine can produce carcinogens (Fawell, 2000). Although the FDA (1994) does not allow sulfites in fresh-cut products, they are allowed for potatoes intended for frying because the frying process evaporates sulfites (Petri et al., 2008).

Blanching is the most commonly used process to inactivate enzymes in fruits and vegetables used for canning and freezing. It can be an alternative to chemical treatments for refrigerated potato strips to improve quality and provide sanitation. Two-step, low temperature followed by high temperature, water blanching is preferred to improve final product quality (Abu-Ghannam and Crowley, 2006; Loon, 2005).

Low temperature (50-70°C) water blanching minimizes texture degradation, because the naturally occurring pectin methyl esterase enzyme becomes active. Pectin methyl-esterase hydrolyzes methyl ester bonds in pectin molecules and frees carboxylate groups. The free carboxylate groups form cross-links between pectin polymers through salt-bridge formation with divalent cations such as Ca^{2+} and Mg^{2+} naturally present in the tissues or added to the blanching water (Nourian and Ramaswamy, 2003). Pectin methyl esterase is very active in the temperature range of 50 to 70°C, but it is rapidly inactivated above 70°C (Andersson et al., 1994; Nourian and Ramaswamy, 2003; Ni et al., 2005). Aguilar et al. (1997) found that the best texture and least oil absorption occurred for potato strips (5x5 mm) blanched at 55°C for 45 min and 65°C for 30 min, respectively.

Polyphenol oxidase causes enzymatic browning in potatoes as a consequence of the enzyme-catalyzed oxidation of phenolic substrates into quinones (Jolivet et al., 1998). It is inactivated at approximately 100°C (Marshall et al., 2000). Water blanching has the added feature of reducing browning by leaching reducing sugar, so it is preferred over

steam blanching. Reducing sugars result in non-enzymatic browning due to chemical reaction between carbonyl group of reducing sugars and amino acids at high temperatures.

Therefore, two-step water blanching, a combination of low temperature (50-70°C) followed by high temperature (80-100°C) blanching, increases firmness and improves color by inactivating undesired enzymes (Loon, 2005; Canet and Hill, 1987). Abu-Ghannam and Crowley (2006) reported that water blanching at 65°C followed by treatment at 95-100°C gave better texture compared to without pre-treated, for whole new potatoes. Canet and Hill (1987) compared different blanching techniques for the manufacture of frozen potatoes. The firmest texture was obtained in stepwise blanching by pretreatment at 70°C for 10 min followed by water cooling and conventional blanching at 97°C for 2 min.

Besides blanching conditions, potato variety is also an important factor that affects the yield, dry matter content and quality of potatoes. Mostly, high specific gravity and long storage life potatoes are preferred in frozen and potato chips processing. The Russet Burbank is the number one potato variety used for frozen potato fries production, because it is high in dry matter, has a long tuber type and accumulates only moderate amount of reducing sugars when storage temperature is adjusted properly (Smith et al., 1997). Norwis, a good long-term storage potato, is the standard for excellent baking and processing quality (PAA, 2007). Keuka Gold is similar to Norwis except with pale yellow flesh and scurfy skin. It is rich in flavor and provides high yields of large round tubers. Reba variety is high yielding and produces tubers that are large, and have white

skin and flesh. Reba has excellent flavor and is mainly used for baking and mashing (NYSAES, 2008).

The objective of this study was to determine the effect of blanching times, concentration of ascorbic acid and calcium chloride solutions, potato variety on color and textural quality and blanching conditions on dry matter loss of potato strips.

3.2. Materials and Methods

3.2.1. Potato Strips Preparation

Potatoes (Russet Burbank, Norwis, Keuka Gold and Reba varieties) were provided by Sterman Masser, Inc. (Sacramento, PA) and stored at 13-14°C until used. Potato tubers were washed and cut into 11x11x50 mm potato strips using a manual French fry slicer (Progressive International, Kent, WA). Only strips with minimal or no skin were used. Potato strips were held in ascorbic acid (AA) solution (0.25% w/v) immediately after being cut until blanching began to reduce surface oxidation and thereby prevent discoloration before blanching.

3.2.2. Frying Conditions of Potato Strips

To determine after-frying color and textural quality, potato strips were fried in corn oil (200 g strips/2.5 L oil) at an initial temperature of 185°C for 8 min. A cooker

(Model 0692001, 1500 W, Presto, Eau Claire, WI) connected to a temperature controller (Digi-Sense model 89000-10, Cole Parmer, Vernon Hills, IL) was used for frying.

3.2.3. Blanching Treatments

Two-step blanching with three different processing times for each blanching step was analyzed. Prepared Russet Burbank potato strips (enough to total about 650 g) were blanched at 60°C for 10, 20 or 30 min in 0.25% AA and 0.5% CaCl₂ solution. Strips were placed into potable water (~20°C) with no additives between blanching steps. Then, strips (200 g samples taken from the original 650 g) were blanched in boiling water (~98°C) for 5, 10 or 15 min and cooled in potable water for 2 min. After cooling, potato strips were drained, packaged into bags (liter-size Ziploc freezer bag, S.C. Johnson Company, Racine, WI) and stored at 4°C for one day. Texture and color analysis were applied after frying.

3.2.4. Ascorbic Acid and Calcium Chloride Treatments

Prepared Russet Burbank potato strips (650 g total) were blanched at 60°C for 20 min in combinations of 0, 0.125 or 0.25% ascorbic acid and 0, 0.25 or 0.5% CaCl₂ solution, followed by a second blanching (200 g/sample) in boiling water for 10 min, then cooled for 2 min in potable water, drained, packaged and stored as described above. Texture and color analysis were applied before frying.

3.2.5. Treatments with Different Potato Varieties

Four different potato varieties, Russet Burbank, Norwis, Keuka Gold and Reba, were used for treatments. Prepared strips were blanched (650 g/sample) at 60°C for 20 min in 0.5% CaCl₂ solution and then blanched (200 g/sample) in boiling water (~98°C) for 10 min, cooled, drained, packaged and stored as described above. Texture and color analysis were applied after frying.

3.2.6. Treatments for Determination of Dry Matter Loss during Blanching

Four different blanching treatments were analyzed for determination of dry matter loss of potato strips. Three potato tubers (Russet Burbank variety) were prepared and used for each treatment. After weighing, potato strips were dipped into blanching solution using a stainless steel sieve and mixed periodically every minute using a spatula. Treated strips were dried in an oven at 105°C for seven days and then weighed.

Blanching treatments:

1. Blanching in 0.5% CaCl₂ solution at 60°C for 10 min.
2. Blanching in water at ~98°C for 10 min.
3. Blanching in 0.5% CaCl₂ solution at 60°C for 10 min and then in water at ~98°C for 10 min.
4. Blanching in potable water at ~20°C for 10 min

Initial dry matter content was determined from untreated strips by using Equation 3.1 and percent dry matter loss was calculated using Equation 3.2.

$$\text{Dry Matter Initial} = \frac{(\text{Dry Weight of Strips})_{\text{Treatment 1}}}{(\text{Wet Weight of Strips})_{\text{Treatment 1}}} \quad (3.1)$$

$$\% \text{ Dry Matter Loss} = \frac{(\text{Wet Weight of Strips} \times \text{Dry Matter Initial}) - \text{Dry Weight of Strips}}{\text{Wet Weight of Strips}} \times 100 \quad (3.2)$$

3.2.7. Color Analysis

A Konica Minolta Chroma Meter CR-400 (Konica Minolta, Ramsey, NJ) was used to define color of potato strips by measuring L*a*b* color space. L* is the lightness which ranges from 0 to 100, and chromatic components of a* (from green to red) and b* (from blue to yellow) range from -60 to 60. ΔE^* indicates the total color difference which is calculated with Equation 3.3 (Konica Minolta, 1998; Nourian and Ramaswamy, 2003). That color difference is between the processed potato sample and the reference values from the white plate provided by the manufacturer.

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (3.3)$$

Prior to use, the Chroma Meter was calibrated against a standard white plate. During measurements (Figure 3.1), potato strips were placed snugly side-by-side in a single layer on a tray and the CIE L*a*b* values were recorded 30 times from 10 strips by measuring three different locations on each strip. Color analysis was applied before- or after-frying, depending on the experiment. In after-frying measurements, potato fries were held under room conditions for 3 min before measurement.



Figure 3.1. Color analysis of refrigerated potato strips.

3.2.8. Texture Analysis

An Instron model 4444 Universal Testing machine (Instron, Norwood, MA) was used to analyze texture of potato strips (Figure 3.2). A plate with a 3 mm diameter hole was attached to the machine. A potato strip was placed onto the plate and a 2 mm probe moved downward through the strip at a rate of 0.42 mm/s. The peak force required to puncture the top surface of the potato strip was used to determine textural quality. Ten strips were measured for each replication of each treatment. Each potato strip was measured at three locations, two ends and a center, giving a total of 30 data points. Textural quality was analyzed before and after frying based on the experiment. In after-

frying measurements, potato fries were held in room temperature for 5 min before measurement.



Figure 3.2. Texture analysis of refrigerated potato strips.

3.2.9. Statistical Analysis

All experiments were replicated three times and MINITAB statistical software (version15, MINITAB Inc, State College, PA) was used to analyze differences between treatments. ANOVA (Analysis of Variance) at a 95% confidence level and Tukey's Least

Significant Difference test were used to determine significant differences between treatments.

3.3. Results and Discussion

3.3.1. Effect of Blanching Time on Color and Texture of Potato Fries

The color and texture results for potato fries treated with different combinations of blanching times are listed in Table 3.1. The effect of blanching time on color was determined based on L^* and ΔE values. A higher L^* value indicated that lighter color was found in fries treated for 30-min first blanching followed by 15-min second blanching. However, there was no significant difference between the lightness of treatments. For 30-min low temperature (60°C) blanched potato fries, the lightness decreased when high temperature blanching time decreased ($P > 0.05$). A similar trend was observed in 20-min low temperature (60°C) blanched potato fries. When treatments were compared side-by-side as 20-5 min vs. 30-5 min, 20-10 min vs. 30-10 min and 20-15 min vs. 30-15 min, increasing first blanching time consistently increased the lightness, but not significantly. Therefore, differences in blanching times in 2-step blanching did not affect the fry color significantly. However, experimental results support that increasing both low and high temperature blanching time decreased the color difference. Lower ΔE value indicated that less color difference ($P < 0.05$) was observed in fries treated for 20- or 30-min first blanching followed by 15-min second blanching compared to fries treated for 10-min first blanching and then 5-min second blanching.

Table 3.1. Texture and color analysis of potato fries treated in different blanching times.

Treatments ¹ (min)	Texture Analysis Peak Force (N)	Color Analysis	
		L* Value	ΔE Value
10-5	2.20 ± 0.40 a	65.87 ± 3.92 a	44.99 ± 4.18 a
20-5	3.55 ± 0.71 bc	67.01 ± 4.27 a	41.30 ± 5.78 ab
20-10	3.37 ± 0.43 abc	67.57 ± 1.30 a	39.65 ± 1.46 ab
20-15	2.66 ± 0.31 ab	70.05 ± 2.14 a	35.94 ± 0.66 b
30-5	4.32 ± 0.42 c	68.34 ± 1.30 a	38.77 ± 1.48 ab
30-10	3.66 ± 0.48 bc	69.43 ± 2.73 a	36.92 ± 1.71 ab
30-15	2.71 ± 0.38 ab	72.47 ± 0.68 a	33.86 ± 0.38 b

¹ Treatment 10-5 indicates that potato strips were first blanched at 60°C for 10 min and then second blanched in boiling water (~98°C) for 5 min. Other treatments are indicated similarly.

² Within the same column, values not followed by the same letter are significantly different (P < 0.05).

To investigate the effect of blanching time on textural quality, the peak force required to puncture the top surface of the potato fries was determined. Other parameters from the force-time curves were preliminarily tried to analyze textural quality (Figure 3.3). No trend was observed in second peak force (puncture of lower surface) analysis. Additionally, there was no relationship between initial slope and treatments. Lima and Singh (2001) also found that initial slope was not a factor that identifies difference between the treatments. Hence, slope and lower surface peak parameters were not investigated further. Top surface peak force was used as the parameter that best differentiated between treatments.

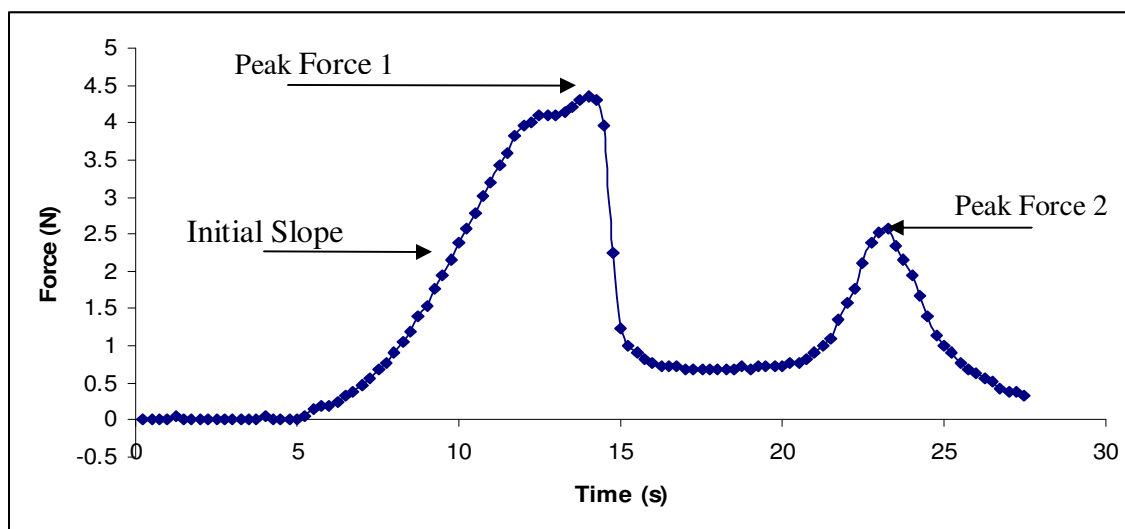


Figure 3.3. Graphical representation of puncture force on a single potato fry.

The results clearly indicated that the longer first blanching time, the greater required force (Table 3.1). Higher peak force ($P < 0.05$) was obtained in fries blanched at low temperature (60°C) for 20 or 30 min and then at high temperature ($\sim 98^{\circ}\text{C}$) for 5 min compared to fries blanched at low temperature for 10 min and then at high temperature for 5 min. Low-temperature long-time blanching improves the textural quality of potato fries (Aguilar et al., 1997) by activating pectin methylesterase enzyme (Andersson et al., 1994; Nourian and Ramaswamy, 2003; Ni et al., 2005). Despite the long first blanching time, increasing second blanching time decreased the peak force. Longer high temperature blanching decreased the peak force of potato strips. Abu-Ghannam and Crowley (2006) reported that blanching at 100°C for 60 min caused 96% loss in firmness compared to raw potatoes. There was no significant difference ($P > 0.05$) between the potato fries blanched at low temperature for 20 or 30 min then at high temperature for 15

min and potato fries blanched at low temperature for 10 min then at high temperature for 5 min. As a result, increasing low temperature and decreasing high temperature blanching times improved the textural quality of potato fries. However, increasing both low and high temperature blanching times improved the color of potato fries. This occurs, because long blanching time increases leaching of reducing sugars which cause maillard browning. Besides the polyphenol oxidase enzyme inactivation, high temperature blanching increases the diffusion rate of reducing sugars as well. (Gekas et al., 1993) Therefore, the best compromise was the combination of low temperature long time and high temperature short time blanching (Agblor and Scanlon, 2000) which improved the color quality of potato fries without decreasing textural quality.

3.3.2. Effects of Ascorbic Acid and Calcium Chloride on Quality of Potato Strips

Color and texture analysis of blanched potato strips treated with different concentrations of ascorbic acid (AA) and CaCl_2 solutions are shown in Table 3.2. Potato strips were analyzed before frying in order to determine the effect of AA on enzymatic browning and CaCl_2 on firmness of potato strips. Although ascorbic acid is effective on phenolase (Whitaker, 1994), no significant difference ($P > 0.05$) was obtained in L^* and ΔE values of potato strips treated with six different combinations of AA and CaCl_2 solutions. Though not significant, lighter color and less color difference was determined in potato strips treated with only 0 or 0.25 or 0.5% calcium chloride solution compared to strips treated with only 0.125 or 0.25% ascorbic acid solution. Consequently, besides the tissue firming, calcium treatments may also increase the lightness of potato strips. This

trend was seen by Severini et al. (2003) and was most likely due to the phenolase inhibition by the chloride ion (Lamikanra, 2002).

Table 3.2. Texture and color analysis of refrigerated potato strips treated in different concentrations of ascorbic acid and calcium chloride.

Treatments ¹	Texture Analysis	Color Analysis	
	Maximum Peak Force (N)	L* Value ²	Δ E Value ²
0% AA + 0% CaCl ₂	1.20 ± 0.17 a ²	69.41 ± 1.43 a	28.57 ± 1.39 a
0% AA + 0.25% CaCl ₂	2.04 ± 0.17 b	69.69 ± 1.83 a	28.31 ± 1.79 a
0% AA + 0.5% CaCl ₂	2.83 ± 0.06 c	70.48 ± 1.43 a	27.52 ± 1.39 a
0.125% AA + 0% CaCl ₂	1.45 ± 0.31 ab	68.47 ± 0.82 a	29.51 ± 0.80 a
0.25% AA + 0% CaCl ₂	1.75 ± 0.10 ab	68.89 ± 0.85 a	29.10 ± 0.84 a
0.25% AA + 0.5% CaCl ₂	3.04 ± 0.37 c	70.36 ± 1.14 a	27.65 ± 1.09 a

¹Treatment 0% AA + 0% CaCl₂ indicates that potato strips were blanched at low temperature (60°C) in 0% ascorbic acid and 0% calcium chloride solution for 20 min and then blanched at high temperature (~98°C) in water for 10 min. Other treatments are indicated similarly.

²Within the same column, values not followed by the same letter are significantly different (P < 0.05).

Increasing the calcium chloride concentration increased the peak force values. Higher peak force (P < 0.05) was obtained for potato strips treated with 0.5% calcium chloride solution compared to strips treated with 0.25%. Results were in agreement with Jaswal (1970) who found the best textural quality in strips blanched for 15 min at 70°C in

0.5% calcium chloride solution. As expected, ascorbic acid was not effective on firmness of potato strips. According to the experimental results, there was no significant difference ($P > 0.05$) between peak force of potato strips treated with only 0.5% calcium chloride solution and potato strips treated with 0.25% ascorbic acid and 0.5% calcium chloride solution.

3.3.3 Effect of Potato Variety on Quality of Potato Fries

Potato strips were blanched at low temperature (60°C) in 0.5% CaCl₂ solution for 20 min and then blanched at high temperature (~98°C) in water for 10 min. This processing method was applied to four potato varieties which were recommended by the potato supplier, Sterman Masser, Inc. The results are revealed in Table 3.3. Higher L* value indicated that Norwis and Reba varieties of potato fries were lighter in color ($P < 0.05$) compared to fries prepared with Keuka Gold and Russet Burbank. There was no significant difference in the lightness of potato fries prepared neither between Keuka Gold and Russet Burbank varieties nor between Norwis and Reba. ΔE values were significantly different for the four varieties due to the effect of chromaticity (a*, b*). Lower ΔE value indicated that less color difference ($P < 0.05$) was observed in Reba variety compared to the three other varieties. Significant color difference ($P < 0.05$) was also determined in potato fries prepared with Norwis, Keuka Gold and Russet.

Table 3.3. Texture and color analysis of different varieties of refrigerated potato fries.

Potato Variety	Texture Analysis	Color Analysis	
	Peak Force (N)	L* Value	Δ E Value
Keuka Gold	2.51 ± 0.35 a ¹	65.35 ± 0.78 a	45.94 ± 0.44 a
Norwis	2.23 ± 0.07 a	74.08 ± 1.11 b	36.42 ± 0.49 b
Reba	2.49 ± 0.20 a	71.48 ± 0.87 b	34.78 ± 0.05 c
Russet Burbank	3.37±0.16 b	64.43 ± 1.30 a	47.15 ± 0.41 d

¹ Within the same column, values not followed by the same letter are significantly different (P < 0.05).

Higher peak force (P < 0.05) was determined in potato fries prepared from Russet Burbank variety, commonly used in frozen French fries, compared to other three varieties. There was no significant difference between textural quality of potato fries prepared from Keuka gold, Norwis and Reba varieties. Norwis and Reba varieties provided better color quality compared to Keuka Gold and Russet Burbank. However, Russet Burbank variety was superior in textural quality compared to Keuka gold, Norwis and Reba.

3.3.4 Effect of Blanching Conditions on Dry Matter Loss of Potato Strips

The amount of dry matter leached from potato strips during different blanching conditions was investigated. Dry matter loss was 4.4% in strips blanched at 60°C in 0.5% CaCl₂ solution for 10 min. Blanching in boiling water (~98°C) and cooling in potable water (~20°C) for 10 min resulted in 9.8% and 1.1% dry matter loss, respectively. Two-step blanching, 60°C blanch in 0.5% CaCl₂ for 10 min and ~98°C blanch in water for 10 min, caused 8.2% dry matter loss. Results indicated that lower dry matter loss was observed in two-step blanched strips compared to one-step high temperature blanched strips. This can be explained by the fact low temperature blanching (60°C) improves the texture by activating pectin methyl esterase enzyme (Nourian and Ramaswamy, 2003) which decreases the leaching of dry matter from strips during a subsequent high temperature blanching process.

Table 3.4. Blanching conditions for dry matter loss determination of potato strips.

Treatments	First blanching at 60°C in 0.5% CaCl ₂ solution for 10 min	Second blanching in boiling water (~98°C) for 10 min	Cooling in potable water (~20°C) for 10 min	% Dry Matter Loss
1	✓			4.4
2		✓		9.8
3	✓	✓		8.2
4			✓	1.1

3.4. Conclusions

Increasing low temperature (60°C) and decreasing high temperature (~98°C) blanching times improved the textural quality of refrigerated potato strips as indicated by high peak force measurements. Increasing both low and high temperature blanching times increased the lightness and decreased the color difference of potato fries. Calcium chloride (0.5% w/v) was required for firm potato structure. Since high temperature blanching inactivated the polyphenolase enzyme which would otherwise lead to color change, ascorbic acid did not affect before-frying color. Light color was observed in Norwis variety potato fries. However, the lightness of Reba variety fries was not significantly different than Norwis. Lower ΔE (color difference) was found for Reba variety potato fries and significant differences were observed between all varieties. Higher textural quality was determined in potato fries prepared from Russet Burbank potato tubers but no significant difference was observed in textural quality of fries from Norwis, Keuka Gold and Reba. Approximately 8% dry matter loss was found for 2-step blanched potato strips.

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Chapter 4

Shelf-life of Near-Aseptically Packaged Refrigerated Potato Strips

Abstract

Near-aseptic packaging is an alternative non-chemical method to extend the shelf-life of refrigerated potato strips. In near-aseptic packaging, the packaging chamber and packaging materials are pasteurized with steam at atmospheric pressure for 30 min then cooled to room temperature and continuously pressurized with filter sterilized air. This study was undertaken to determine the shelf-life of blanched and near-aseptically packaged refrigerated potato strips based on quality (microbial, textural and color).

Potato strips were first blanched at low temperature (60°C) for 10- or 20-min, then second blanched at high temperature (98°C) for 1-, 5- or 10-min. After 2-step blanching, potato strips were cooled and packaged into near-aseptic polyethylene bags using a near-aseptic packaging chamber. The packaged strips were stored at 7±1°C for four weeks. Microbiological quality was determined by analyzing mesophilic bacteria, psychrotrophic bacteria and yeast-mold count. Color quality was determined by using L* (lightness) and ΔE (total color difference) values and textural quality by peak penetration force values. These values were also compared with data collected from unprocessed (neither blanched nor near-aseptically packaged) samples. Color and texture were measured both before and after frying.

Microbial spoilage was observed for all treatments which received a second blanch of only 1-min. No microbial growth was observed within 28 days of refrigerated storage for strips treated for either 10- or 20-min in first blanch followed by 5- or 10-min in second blanch. Measurements made using total plate counts and an enrichment protocol confirmed the results. Measured after frying, near-aseptically packaged refrigerated potato fries were lighter in color than unprocessed fries and less color difference was observed in near-aseptic potato fries compared to unprocessed fries. Near-aseptic potato fries were higher in textural quality compared to unprocessed fries. Before and after frying, no significant changes were observed in the quality of near-aseptically packaged refrigerated potato strips during 28 days of storage at $7\pm 1^{\circ}\text{C}$.

4.1. Introduction

Potatoes are a highly nutritious food which consists of 80% water and 20% dry matter (Salunkhe et al., 1991). Based on the Economic Research Service (ERS-USDA, 2007), per person per year consumption of potatoes is 57.2 kg in the United States. Frozen potatoes, frozen fries, tater tots, spiral fries, home fries, wedges and frozen whole potatoes are the most consumed with 24 kg per person per year. Fresh, chips, dehydrated and canned potatoes are consumed at a rate of 20, 7.2, 5.9 and 0.5 kg per person per year, respectively.

The demand for fresh-cut produce has also increased steadily because of its nutritional quality, convenience and about 2 weeks shelf-life. Although fresh-cut produce is considered as safe, there have been many foodborne outbreaks in recent years (FDA,

2009), because conventional washing and sanitizing treatments have insufficient effect on inactivating pathogens on the surface of produce (Sapers et al. 2006). In the fresh-cut potato industry, chemicals such as sulfites and chlorine based agents are commonly used to prevent browning and to sanitize produce (Beltran et al., 2005). Application of these compounds can provoke allergic reactions (Peroni and Boner, 1995) and produce carcinogens (Fawell, 2000). Although use of sulfites is allowed for fresh potatoes, because SO₂ evaporates during cooking process (Petri et al., 2008), processors have been looking for alternative methods due to the probability of further regulatory action against the use of sulfites and decrease in consumer demand on sulfite-treated products (Mcevilly et al., 1992).

Surface pasteurization with hot water is a more effective and acceptable method for sanitizing produce compared to chemical washes. Immersion in hot water inactivates bacteria by providing excellent heat transfer through the food surface, but it sometimes decreases the quality. Annous et al. (2004) were able to reduce *Salmonella* population $\geq 5 \log_{10}$ CFU/cm² on cantaloupe surfaces by commercial-scale hot water immersion at 76°C for 3 min. Pao and Davis (1999) were able to reduce *E. coli* population on orange surfaces up to 5 log₁₀ CFU/g by hot water immersion either at 70°C for 2 min or 80°C for 1 min.

However, surface pasteurization alone is not sufficient to extend shelf-life, especially for cut produce where the product cell contents are readily available to culture any recontamination. In order to prevent contamination after pasteurization, products should be cooled rapidly and packaged in an environment free of microorganisms. Near-aseptic packaging is a promising technique to extend shelf-life of the pasteurized

products. In near-aseptic packaging, pasteurized food product is cooled and packaged into near-aseptic containers within a chamber which is pasteurized with steam at atmospheric pressure then cooled to room temperature and continuously pressurized with filter sterilized air. Because the potato strips themselves are not sterile, there is no need to ensure complete sterility for the packaging system. Near-aseptically packaged refrigerated potato strips, intended for frying with minimum preparation, can be non-chemical treatment alternative to fresh or frozen products.

Potato strips intended for French frying are typically blanched at low temperature (50-70°C) to improve texture by activating pectin methylesterase enzyme (Andersson et al., 1994; Nourian and Ramaswamy, 2003; Ni et al., 2005). Active pectin methylesterase hydrolyses methyl ester bonds of pectin chains and results in free carboxylic groups to react with divalent bonds such as Ca^{2+} (Ni et al., 2005). Therefore, addition of calcium chloride into blanching water enhances the firmness (Jaswal, 1970). A second, high temperature blanch (e.g. boiling water) improves color by inactivating phenolase enzyme (Canet and Hill, 1987; Agblor and Scanlon, 2000) and provides surface pasteurization of the potato strips.

Color and texture are important quality parameters for the acceptability of a food product. It is important to keep the color of the potato strips fresh-like throughout shelf-life and to obtain golden light color after frying. Maintaining firm texture during storage and achieving crispiness after frying is considered high textural quality for potato strips. Fresh and fresh-cut potato strips are generally not preferred in deep-fat frying because they become soggy, limp, greasy and too dark (Talbert and Smith, 1987).

The shelf-life of a refrigerated food product depends on a reduction in initial microbial load and maintaining a low refrigeration temperature throughout the storage. Refrigeration is required during the storage of potato strips which are pasteurized with hot water and are not considered even commercially sterile. Mesophilic bacteria grow well between 20 to 45°C (Jay, 1992) and psychrotrophic bacteria grow optimally above refrigeration temperature (Kraft, 1992; Hui, 2006). Also, a number of yeasts and molds can grow at refrigeration temperature.

The objective of this study was to determine the effects of low and high temperature blanching times and storage time on microbial, color and textural quality of near-aseptically packaged refrigerated potato strips.

4.2. Materials and Methods

4.2.1. Potato Strips Preparation and Processing

Potatoes (Russet Burbank) were provided by Sterman Masser, Inc. (Sacramento, PA) and stored at 13-14°C until used. Potatoes were washed and cut into 11x11x50 mm strips with a manual potato cutter. Only strips with minimal or no skin were used. Potato strips were held in potable water (~20°C) without chemicals during preparation to minimize browning. Then, strips were blanched at 60°C for two different times, 20 or 10 min, in 0.5% CaCl₂ solution. Blanched potato strips were kept in potable water (~20°C) until second blanching. Then, potato strips were blanched for 1, 5 or 10 min in boiling

water (~98°C), cooled for 10 min and packaged by using a near-aseptic packaging system.

4.2.2. Near-Aseptic Packaging of Potato Strips

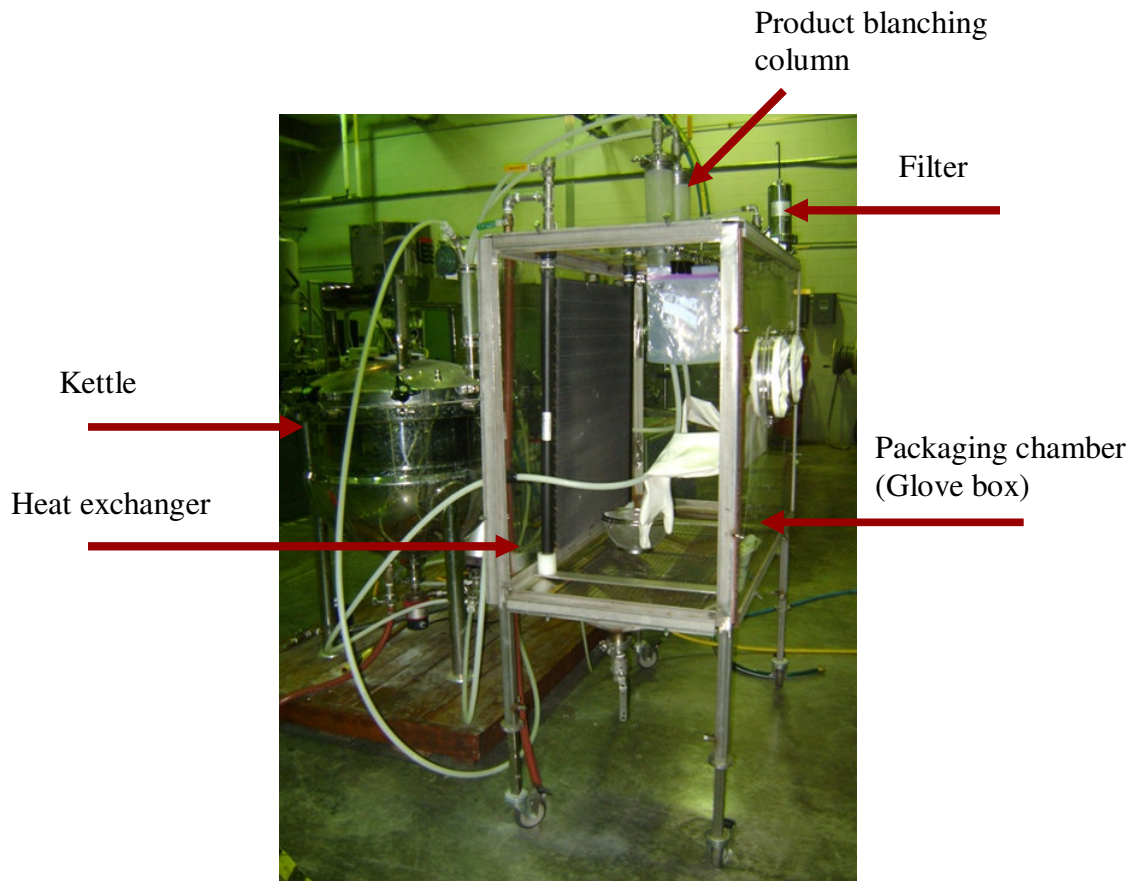


Figure 4.1. Near-aseptic packaging system.

The glove box (interior dimensions: 60 x 94 x 122 cm) shown in Figure 4.1 was used as the packaging chamber for a near-aseptic packaging system. As shown in Figure 4.2, with the packaging bags suspended inside, the chamber was sealed and heated with steam at atmospheric pressure for 30 min after steam flow was observed exiting the chamber. The air filter was similarly and simultaneously pasteurized. After pasteurization, the steam was gradually replaced with filtered air and then the chamber was further cooled by recirculating water, cooled to 4°C by a refrigeration system, through the heat exchanger located inside the chamber. During steam heating, cool-down and operation, a minimal but continuous positive pressure was maintained inside the chamber as indicated by inflation of the gloves.

After preparation of the near-aseptic packaging system, potato strips were given a low temperature blanch, held in potable water until the second blanch (~15 min) and then placed into the product blanching column (height x diameter: 32.5 x 7.9 cm) for second blanching in recirculating boiling water (~98°C) provided from a kettle (187 L, Model D9MT, Lee Industries Inc., Philipsburg, PA). The strips were discharged from the column into the chamber where they were drained and air-cooled for 10 min. Twenty potato strips were packaged into each bag (liter-size Ziploc freezer bag, S.C. Johnson Company, Racine, WI). The bags remained inside the chamber until all samples were made and then were removed from the chamber by disassembling a chamber wall. The filled packages were then stored in a refrigerator at 7±1°C for up to four weeks.

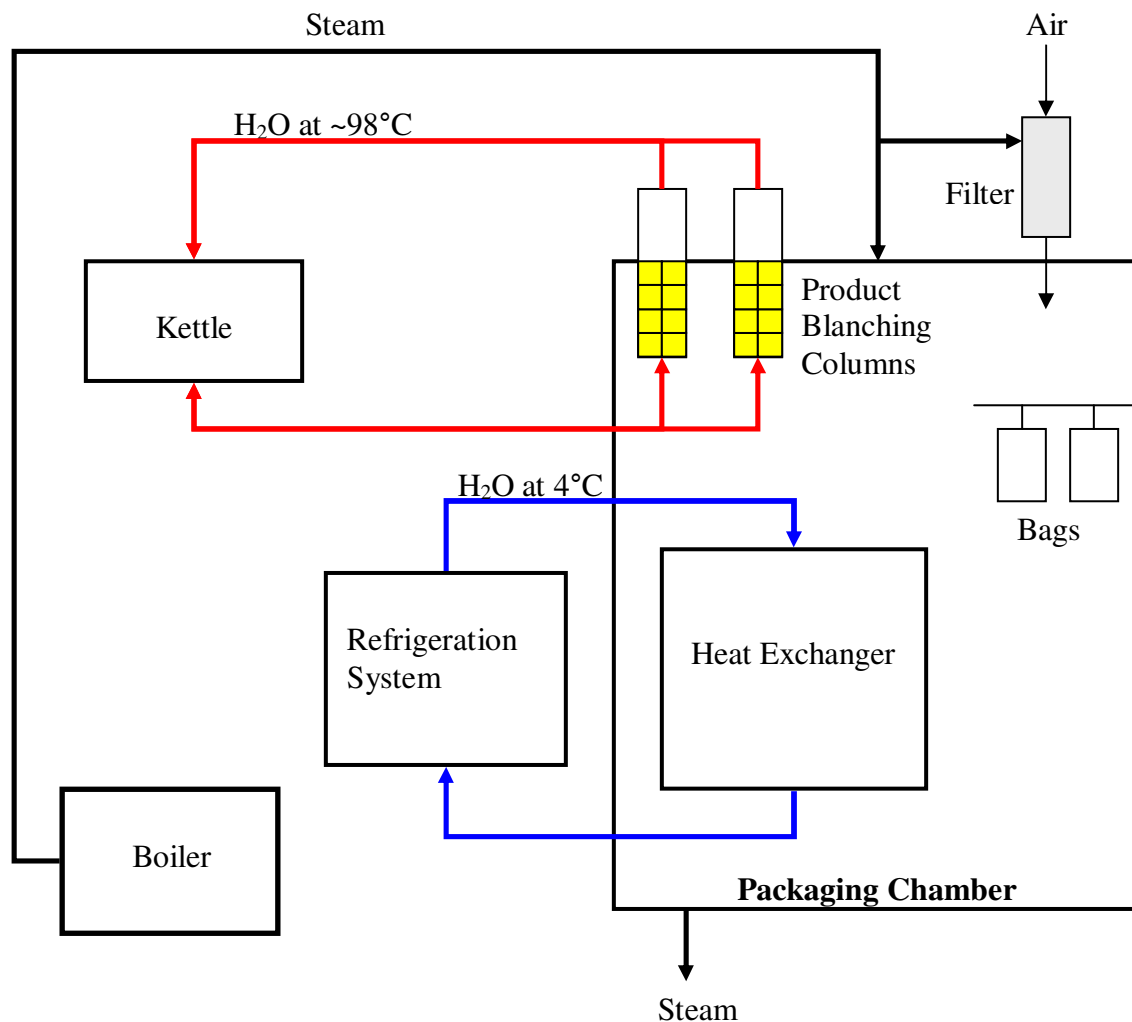


Figure 4.2. Schematic representation of near-aseptic processing.

Mesophilic and psychrotrophic bacteria and yeast-mold populations were determined periodically during storage. Three potato strips (~25 grams) were homogenized with a stomacher for 2.5 min in a sterile stomacher filter bag containing 225 mL 0.1% sterile peptone water (Difco, Detroit, MI). Mesophilic and psychrotrophic

bacteria were enumerated by spiral plating (Autoplate 4000, Spiral Biotech, Norwood, MA) by using plate count agar (PCA) by incubating plates at $30\pm 1^{\circ}\text{C}$ for 48 h and $7\pm 1^{\circ}\text{C}$ for 10 days, respectively. Yeast-mold counts were performed in potato dextrose agar by incubating at $25\pm 1^{\circ}\text{C}$ for 5 days. Microbial analyses were made after 1, 7, 14, 21 and 28 days of storage. All samples were analyzed in duplicate. Colonies were counted by using an autounter (Q-Count, Version 2.1, Spiral Biotech, Norwood, MA) after incubation and results were expressed as CFU/g of potato. When spoilage was visually detected in a sample, microbiological analysis was not applied and the population was assumed to be the maximum count that could be determined from plate count.

To ensure detection of low levels of microbial growth, an enrichment protocol was used. Enrichments were done by transferring 1 mL of the peptone water rinse solution to 9 mL of trypticase soy broth for mesophiles and potato dextrose broth for mold and yeast (Difco, Detroit, MI). After incubating at 30°C for 2 days, growth in the enrichments was determined visually.

4.2.3. Texture and Color Analysis

Texture and color of near-aseptically packaged refrigerated potato strips and unprocessed samples (neither blanched nor near-aseptically packaged) were compared before and after frying. Near-aseptically packaged strips were analyzed after 7 and 28 days of storage at $7\pm 1^{\circ}\text{C}$. Unprocessed potato strips were prepared from the same batch of potato tubers using the same technique as for the blanched product. Potato tubers were cut into strips just before quality analysis in order to prevent quality degradation.

To determine after-frying quality, 10 potato strips were fried for 4 min in 2.5 L corn oil heated to an initial temperature of 177°C in an electric fry cooker (Model 0692001, 1500 W, Presto, Eau Claire, WI) controlled by an external temperature controller (Digi-Sense model 89000-10, Cole Parmer, Vernon Hills, IL). Potato fries were held at room temperature for 3 and 5 min before beginning color and texture measurements, respectively.

4.2.3.1. Texture Analysis

An Instron model 4444 Universal Testing machine (Instron, Norwood, MA) was used to analyze the texture of products (Figure 3.2). A plate with a 3 mm hole was attached to the machine. A potato strip was placed onto the plate and a 2 mm probe moved downward through the strip at a rate of 0.42 mm/s. The maximum force required to puncture the top surface of the potato strip was used to determine textural quality. Each potato strip was measured from three locations, two ends and a center. A total of 15 data were obtained from five potato strips both before and after frying.

4.2.3.2. Color Analysis

A Konica Minolta Chroma Meter CR-400 (Konica Minolta, Ramsey, NJ) was used to define color of the potato strips by measuring L*a*b* color space. In this color space, L* is the lightness which ranges from 0 to 100, and chromatic components of a* (from green to red) and b* (from blue to yellow) range from -60 to 60. ΔE^* indicates the

total color difference which is calculated with Equation 4.1 (Konica Minolta, 1998; Nourian and Ramaswamy, 2003). That color difference is between the processed potato sample and the reference values from the white plate provided by the manufacturer.

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (4.1)$$

Prior to use, Chroma Meter was calibrated against a standard white plate. During measurements (Figure 3.1), potato strips were placed snugly side-by-side in a single layer on a tray and the CIE L*a*b* values were recorded 20 times from five strips by measuring two different locations on each strip. Color analysis was applied before and after frying. In after-frying measurements, potato fries were held under room conditions for 3 min before measurement.

4.2.4. Statistical Analysis

All experiments were replicated three times and MINITAB statistical software (version 15, MINITAB Inc, State College, PA) was used to analyze differences between treatments. ANOVA (Analysis of Variance) at a 95% confidence level and Tukey's Least Significance Difference test were used to determine significant differences between treatments.

4.3. Results and Discussion

4.3.1. The Effects of Blanching and Storage Times on Microbial Load

Most combinations of two-step blanching and near-aseptic packaging of the potato strips decreased the microbial load to give a shelf-life of at least 4 weeks (Table 4.1). However, microbial growth was observed in strips treated for either 10- or 20-min first blanching (low temperature) followed by 1-min second blanching (high temperature). Consequently, one minute second blanching in boiling water was not sufficient to extend shelf-life based on microbial quality. As shown in Table 4.1, no mesophilic or psychrotrophic bacteria or yeast-mold growth was determined in potato strips treated for 10- or 20-min first blanching followed by 5- or 10-min second blanching even after 28 days of storage. Also, the enrichment protocol confirmed that there was not even a low level of microbial growth in these potato strips. Populations as high as 5.95 \log_{10} CFU/g were found for the treatment with only one-minute of high temperature blanching.

Table 4.1. Effect of blanching treatments and near-aseptic packaging combination on survival of mesophilic and psychrotrophic bacteria and mold-yeast (\log_{10} CFU/g) after 14 and 28 days of storage at $7\pm 1^\circ\text{C}$.

Treatments ²	14 days of storage					28 days of storage				
	Mesophilic Bacteria	Psychrotrophic Bacteria	Yeast-mold	TSB ¹	PDB ¹	Mesophilic Bacteria	Psychrotrophic Bacteria	Yeast-mold	TSB	PDB
10-1	4.67	4.38	1.36	+	+	5.95	5.95	3.97	+	+
10-5	0 ³	0	0	-	-	0	0	0	-	-
10-10	0	0	0	-	-	0	0	0	-	-
20-1	5.54	5.12	4.26	+	+	5.95	5.52	5.95	+	+
20-5	0	0	0	-	-	0	0	0	-	-
20-10	0	0	0	-	-	0	0	0	-	-

¹ TSB: growth in enrichment of trypticase soy broth, PDB: growth in enrichment of potato dextrose broth. Positive (+) and negative (-) values designated low level of growth and no growth in enrichment, respectively.

² Treatment 10-1 indicates that potato strips were first blanched for 10 min and then second blanched for 1 min. Other treatments are indicated similarly.

³ 0 indicates non-detectable (minimum detection level is $1.95 \log_{10}$ CFU/g).

Mesophilic bacteria growth was observed after 7 days of storage in near-aseptically packaged potato strips treated for 10- or 20-min first blanching followed by 1-min second blanching (Figure 4.3). Microbial populations in strips, treated as 10-min first blanching followed by 1-min second blanching, were 1.23, 4.67, 5.36 and 5.95 \log_{10} CFU/g after 7, 14, 21 and 28 days of storage, respectively. In 20-min first blanched and 1-min second blanched potato strips, mesophilic bacteria population was 4.34, 5.54, 5.79 and 5.95 \log_{10} CFU/g after 7, 14, 21 and 28 days of storage, respectively. It was observed that the populations for the 20-1 treatment, although not significant, were higher than for the 10-1 treatment and this was surprising because even the first blanch temperature was expected to be high enough to provide some level of pasteurization. Those differences notwithstanding, growth was expected for treatments with 1-min second-blanch time and is an important part of the study, because it is the basis for concluding that the longer second-blanch treatments were indeed effective. As shown in Figure 4.3, there were no mesophilic bacteria found in strips blanched for 10- or 20-min at low temperature and then blanched for 5- or 10-min at high temperature. Visible microbial growth was considered to be greater than maximum countable population and designated as “>” in Figures 4.3, 4.4 and 4.5. Since microbial counts were determined from samples without dilution, the maximum countable microbial population was 5.95 \log_{10} CFU/g.

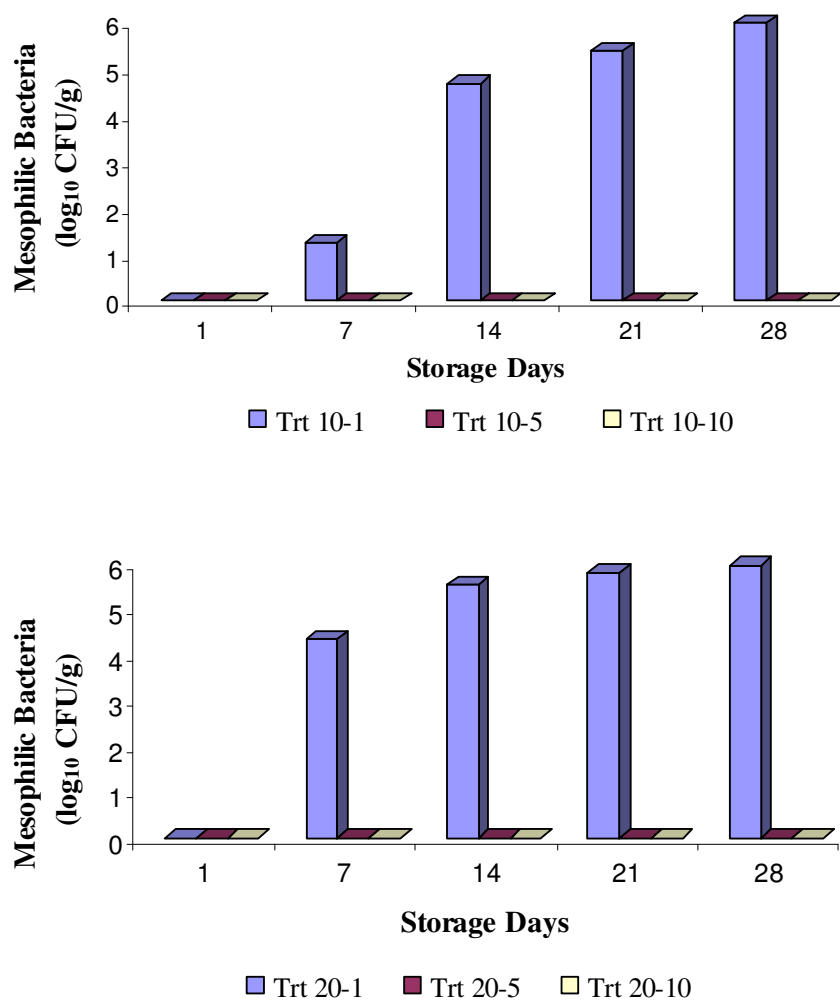


Figure 4.3. Mesophilic bacteria population in near-aseptically packaged refrigerated potato strips during 28 days of storage.

* Trt 10-1 indicates that potato strips were first blanched for 10 min and then followed by second blanching for 1 min. Other treatments are indicated similarly.

Psychrotrophic bacteria population in near-aseptically packaged refrigerated potato strips is illustrated in Figure 4.4. No growth was observed after one day storage. Psychrotrophic population increased in strips treated for 10-min first blanching followed by 1-min second blanching, as 1.91, 4.38, 5.58 and 5.95 \log_{10} CFU/g for 7, 14, 21 and 28 days of storage, respectively. Growth in strips treated for 20-min first blanching and then 1-min second blanching, was 4.47, 5.12, 5.45 and 5.52 \log_{10} CFU/g for each week during the 4 weeks of storage. As for the mesophilic bacteria, positive growth results for the 1-min second-blanch were the basis for concluding that the longer treatments were effective. There was no psychrotrophic growth in strips treated for 10- or 20-min first blanching and then 5- or 10-min second blanching even after 28 days of storage at $7\pm 1^{\circ}\text{C}$.

Although mesophilic and psychrotrophic bacteria were determined after 7 day storage, yeast and mold growth was obtained after 14 days in strips treated for 10- or 20-min of first blanching followed by 1-min second blanching (Figure 4.5), because bacteria grow faster than yeast and mold (ICMSF, 1978). After 14, 21 and 28 days of storage, yeast and mold population in 1-min second blanched strips was 1.36, 2.04, 3.97 \log_{10} CFU/g and 1.58, 5.08, 5.95 \log_{10} CFU/g for 10- and 20-min first blanching, respectively. No yeast and mold growth was determined in potato strips treated as 10- or 20-min first blanching followed by 5- or 10-min second blanching even after 28 days of storage.

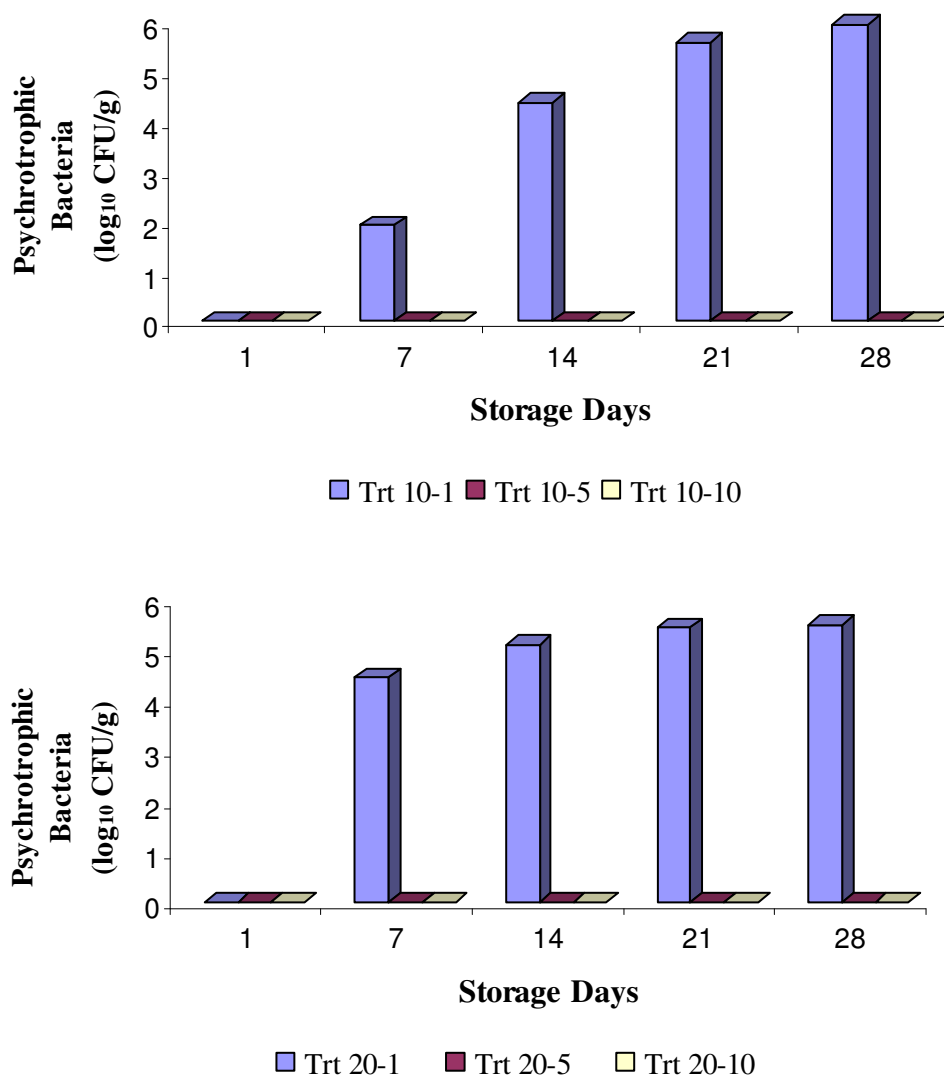


Figure 4.4. Psychrotrophic bacteria population in near-aseptically packaged refrigerated potato strips during 28 days of storage.

*Trt 10-1 indicates that potato strips were first blanched for 10 min and then followed by second blanching for 1 min. Other treatments are indicated similarly.

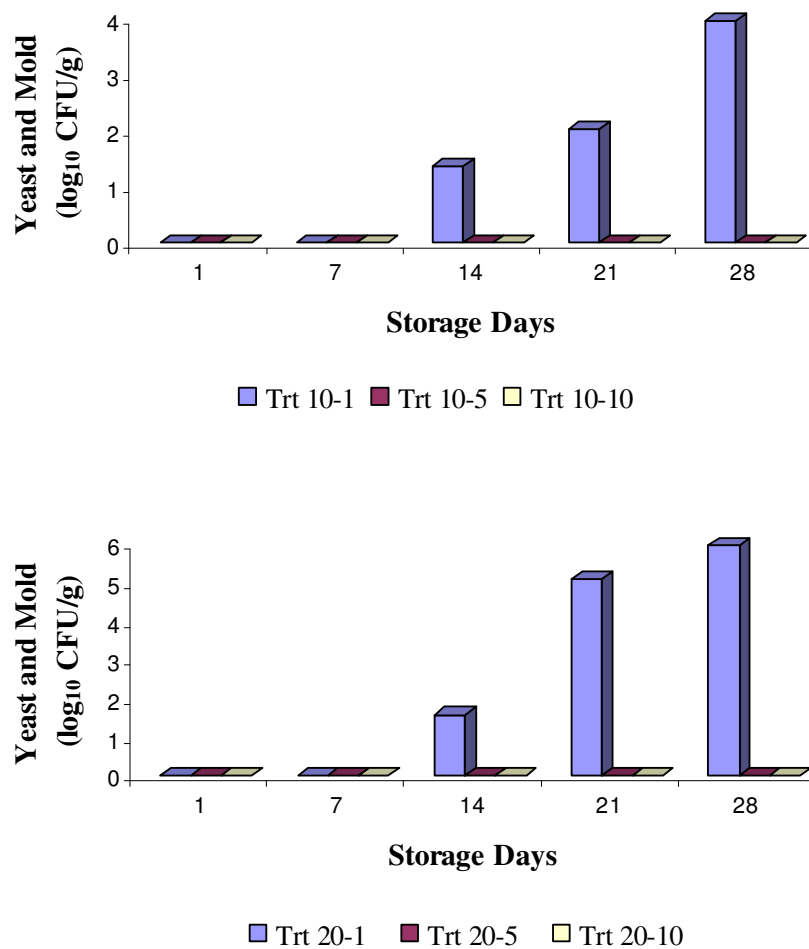


Figure 4.5. Yeast and mold population in near-aseptically packaged refrigerated potato strips during 28 days of storage.

*Trt 10-1 indicates that potato strips were first blanched for 10 min and then followed by second blanching for 1 min. Other treatments are indicated similarly.

4.3.2. The Effects of Blanching Time and Storage Time on Color and Textural Quality

Potato strips treated for 10- or 20-min first blanching followed by 5- or 10-min second blanching, were analyzed based on color and textural quality. Color and textural quality was determined after 7 and 28 days of storage at $7\pm 1^\circ\text{C}$ and compared with values for freshly cut strips with no thermal treatment or storage. Measurements were not made on treatments receiving 1-min second blanch because the resulting microbial growth made the samples unacceptable for commercial consideration.

4.3.2.1. Textural Quality

To investigate the effect of blanching time and storage time on textural quality, the maximum force required to puncture the top surface of the potato strip was determined. Besides the near-aseptically packaged refrigerated potato strips, measurements were made on unprocessed potato strips (neither blanched nor near-aseptically packaged). Texture measurements were applied before- and after-frying.

Peak force values for the near-aseptic strips stored four weeks and for unprocessed potato strips are presented in Table 4.2. Lower peak force was determined in near-aseptically packaged refrigerated potato strips before-frying compared to unprocessed strips but after frying, higher peak forces were obtained for most of the near-aseptic treatments than for the unprocessed fries. Comparisons between the before-frying peak force values of different near-aseptic treatments shows that, as expected, higher

peak force results from the longer first-blanch time and the shorter second-blanch time (Agblor and Scanlon, 2000). The result is consistent in all four side-by-side comparisons: 10-5 min vs. 20-5 min, 10-10 min vs. 20-10 min, 10-5 min vs. 10-10 min and 20-5 min vs. 20-10 min. All treatment differences were significant and the highest peak force for the near-aseptic products was with low temperature blanching for 20 min and then high temperature blanching for 5 min. These results are consistent with increased bonding with longer treatment times during low temperature blanching and the increased destruction of these and other bonds during high temperature blanching.

According to the after-frying peak force values, higher textural quality ($P < 0.05$) was obtained in near-aseptically packaged refrigerated potato fries compared to unprocessed potato fries (Table 4.2). The highest peak force was obtained in the crust of strips treated for 20-min first blanching and followed by 5-min second blanching. There was no significant difference between the after-frying textural quality of 10-min first blanched product and unprocessed fries ($P < 0.05$). Second blanching time also affected the texture. Increasing second blanching time from 5 to 10 min decreased the textural quality of 20-min first blanched strips. Regardless of second blanching time, 20-min blanching at low temperature (60°C) significantly improved texture of near-aseptic potato strips ($P < 0.05$) even after 4 weeks of storage compared to unprocessed potato strips.

Table 4.2. Peak force (N) for near-aseptically packaged refrigerated potato strips after 4 weeks of storage at $7\pm 1^\circ\text{C}$.

Treatments ¹	Before frying	After frying
10-5 min	2.22 ± 0.31 b ²	1.63 ± 0.09 ab
10-10 min	1.04 ± 0.04 a	1.50 ± 0.23 a
20-5 min	4.13 ± 0.17 c	2.36 ± 0.06 c
20-10 min	2.69 ± 0.29 b	1.94 ± 0.15 b
Unprocessed	7.78 ± 0.48 d	1.27 ± 0.16 a

¹ Trt 10-5 indicates that potato strips were first blanched for 10 min and then followed by second blanching for 5 min. Other treatments are indicated similarly.

² Within the same column, values not followed by the same letter are significantly different ($P < 0.05$).

The effect of storage time on before- and after-frying textural quality of near-aseptically packaged refrigerated potato strips is illustrated in Figure 4.6. For either measure, there was no significant difference between the 7 and 28 days stored samples ($P > 0.05$). This is further evidence that the near-aseptically packaged product has a shelf-life of at least 28 days.

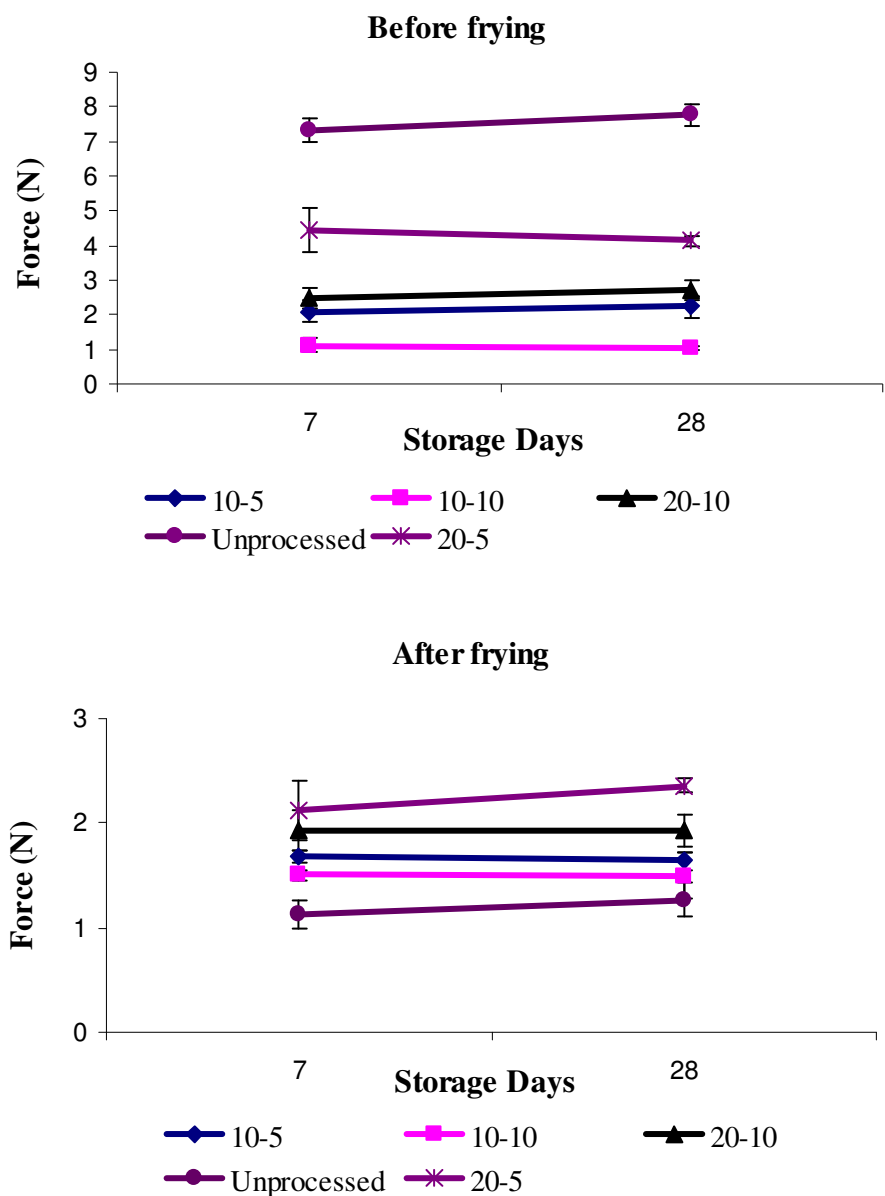


Figure 4.6. Before- and after-frying textural quality of near-aseptically packaged refrigerated potato strips after 7 and 28 days of storage at $7\pm 1^\circ\text{C}$. Treatment 10-5 indicates that potato strips were first blanched for 10 min and then followed by second blanching for 5 min. Other treatments are indicated similarly.

4.3.2.2. Color

Lightness (L^*) and total color difference (ΔE) values of near-aseptically packaged potato strips after 28 days of storage are shown in Table 4.3. Comparing only the near-aseptic treatments, no significant differences were determined in L^* and ΔE values either before or after frying. Therefore, differences in blanching time did not affect the color of refrigerated strips significantly.

However, there were significant differences between the near-aseptic and unprocessed strips. Blanching improved after-frying color. Higher L^* values indicate that lighter after-frying color was found in near-aseptic potato strips ($P < 0.05$) compared to unprocessed strips. However, before-frying unprocessed strips were lighter in color ($P < 0.05$) than near-aseptic strips. Lower ΔE values indicate that less after-frying color difference was observed for near-aseptic potato strips ($P < 0.05$) compared to unprocessed strips. But, less color difference was determined in before-frying color of unprocessed strips ($P < 0.05$). In other words, unprocessed strips were considered to have better color quality than near-aseptic before frying but near-aseptic strips had better color quality than did unprocessed after frying.

Table 4.3. L* and ΔE values of near-aseptically packaged refrigerated potato strips after 28 days storage at $7 \pm 1^\circ\text{C}$.

Treatments ¹	Before frying		After frying	
	L*	ΔE	L*	ΔE
10-5 min	62.29 \pm 2.68 a ²	35.50 \pm 2.69 a	58.11 \pm 1.40 a	50.39 \pm 0.83 a
10-10 min	62.77 \pm 0.68 a	35.06 \pm 0.62 a	58.16 \pm 1.17 a	48.09 \pm 1.31 a
20-5 min	62.48 \pm 1.89 a	35.28 \pm 1.84 a	57.75 \pm 1.02 a	49.33 \pm 0.92 a
20-10 min	61.23 \pm 0.17 a	36.45 \pm 0.13 a	57.61 \pm 0.98 a	48.03 \pm 0.80 a
Unprocessed	68.14 \pm 1.34 b	31.72 \pm 1.50 b	51.74 \pm 1.33 b	53.55 \pm 0.31 b

¹Treatment 10-5 indicates that potato strips were first blanched for 10 min and then followed by second blanching for 5 min. Other treatments are indicated similarly.

²Within the same column, values not followed by the same letter are significantly different ($P < 0.05$).

Figures 4.7 and 4.8 illustrate changes in color of near-aseptically packaged refrigerated potato strips during storage. L* and ΔE values were measured after 7 and 28 days. There was no significant difference in before-frying L* and ΔE values between 7 and 28 days stored near-aseptic strips ($P > 0.05$) (Figure 4.7). There were a slight differences in after-frying L* and ΔE values between 7 and 28 days storage, but the differences were not significant ($P > 0.05$) (Figure 4.8). Consequently, storage time did not affect the color of near-aseptic strips significantly. No significant difference was observed in color of unprocessed potato strips between those freshly cut on day 7 and freshly cut on day 28 ($P > 0.05$).

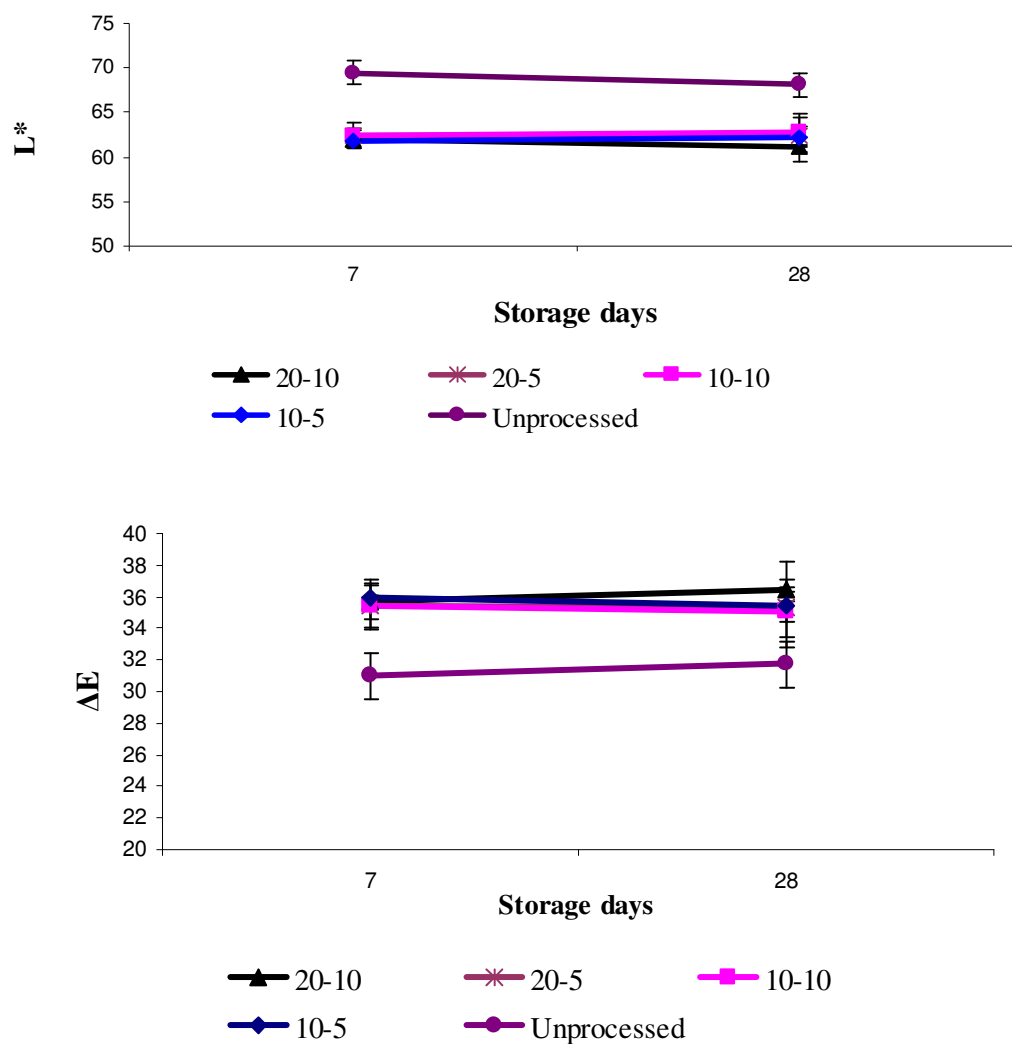


Figure 4.7. Changes in before-frying L* and ΔE values of near-aseptically packaged refrigerated potato strips after 7 and 28 days of storage at $7\pm 1^\circ\text{C}$. Treatment 10-5 indicates that potato strips were first blanched for 10 min and then followed by second blanching for 5 min. Other treatments are indicated similarly.

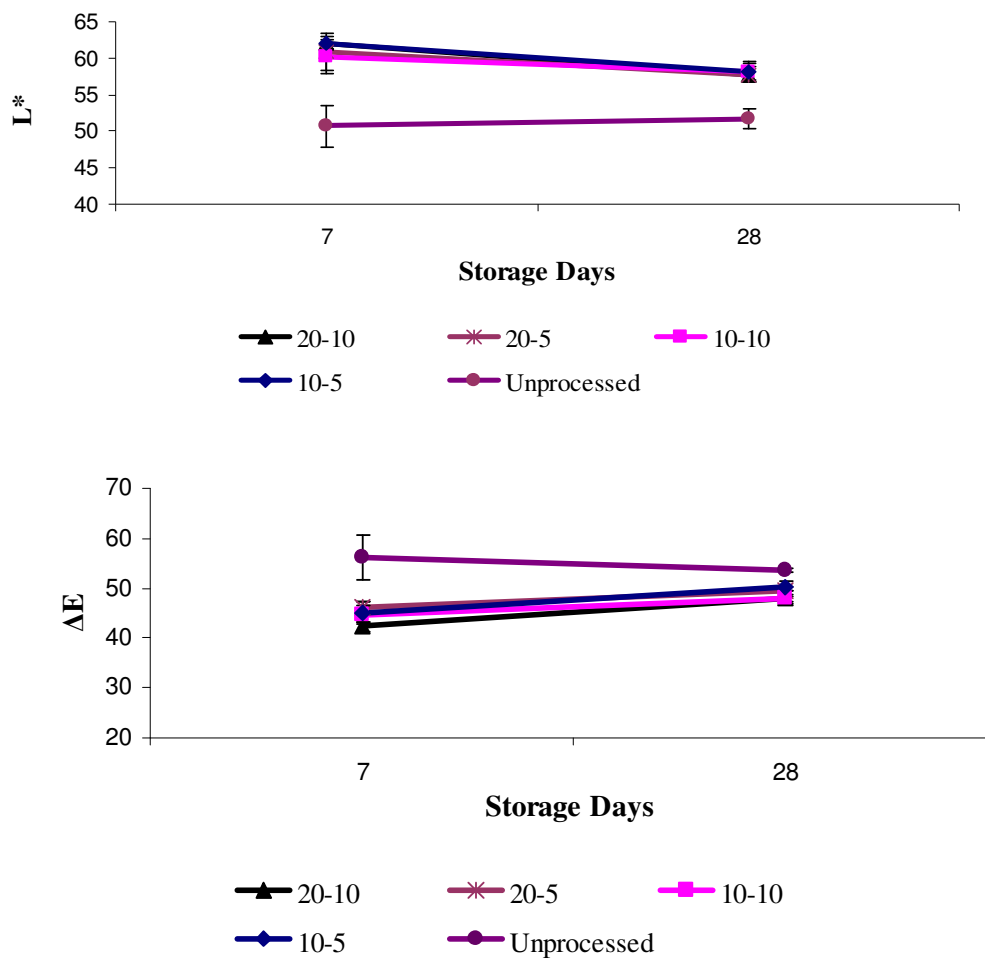


Figure 4.8. Changes in after-frying L^* and ΔE values of near-aseptically packaged refrigerated potato strips after 7 and 28 days storage at $7\pm 1^\circ\text{C}$. Treatment 10-5 indicates that potato strips were first blanched for 10 min and then followed by second blanching for 5 min. Other treatments are indicated similarly.

4.4. Conclusions

In near-aseptically packaged refrigerated potato strip processing, mesophilic and psychrotrophic bacteria and yeast-mold populations were found using plate counts after 7

days of storage for treatments receiving a 10- or 20-min low temperature (60°C) blanch followed by a 1-minute high temperature (98°C) blanch. There was no growth in any treatments receiving a 5- or 10-min high temperature blanch. The enrichment protocol confirmed the results. Before-frying peak force of the unprocessed strips (neither blanched nor near-aseptically packaged) was higher compared to near-aseptic strips. After frying, higher peak force was determined for the blanched rather than unblanched product. Higher after-frying peak force was obtained in strips treated for 20-min low temperature blanching followed by 5-min high temperature blanching, compared to any other treatments. Differences in blanching times did not affect the color of near-aseptic strips before frying. After frying, lighter color and less color difference was determined in near-aseptic potato fries compared to unprocessed fries, while before-frying the trend was reversed. No significant changes were observed in color and texture of near-aseptic strips during the four weeks storage. With their demonstrated shelf-life of at least 28 days with no detectable color or texture degradation or microbial growth, and better after-frying quality than fresh potatoes, near-aseptically packaged refrigerated potato strips should be considered as a commercial alternative to other products for making French fries.

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Chapter 5

Effect of In-Package Gaseous Ozone Treatment on Shelf-life of Blanched Potato Strips during Refrigerated Storage

Abstract

Surface pasteurization with hot water is an effective method used for refrigerated fruits and vegetables to destroy microorganisms and improve quality. However, microbial recontamination and resulting growth will occur unless a proper environment is provided during packaging. Blanching combined with near-aseptic packaging improves the quality compared to freshly cut potato strips and extends the shelf-life to 28 days at refrigerated storage but near-aseptic packaging is expected to be expensive to commercialize because cost of the near-aseptic packaging system is determined based on cost assumptions for aseptic packaging system which requires more safeguards in order to provide and maintain sterilization. In-package gaseous ozone treatment is an alternative technique which extends the shelf-life and maintains the quality. Hot water treatment improves quality and reduces microbial load and in-package gaseous ozone treatment prevents microbial growth caused from recontamination and provides microorganism free environment for strips in the package.

In this study, potato strips were first blanched in 0.5% CaCl₂ solution at 60°C for 10 min to improve texture by activating pectin methyl-esterase, second blanched in

boiling water for 5 min to reduce microbial load and improve color by inactivating polyphenol oxidase, then recontaminated by exposure to room air for 30 min and packaged into polyethylene bags. Ozone gas (5% wt/wt) was injected into each bag. Strips were subjected to a batch ozone treatment for 20 s or a continuous ozone treatment for 5, 15 or 30 min. Treated strips were stored at $7\pm 1^{\circ}\text{C}$ for 28 days. During refrigerated storage, samples were taken periodically and analyzed for microbial growth. Microbial growth was observed on day one for bags with no ozone treatment. Continuous ozone treatment was effective in extending shelf-life of refrigerated potato strips compared to batch ozone treatment and there was no microbial growth for 30- and 15-min continuous ozone treated strips after 28 and 21 days of storage, respectively and an enrichment protocol confirmed the plate test results. No significant difference was observed between the color of blanched strips and ozone treated blanched strips. Therefore, in-package gaseous ozone treatment can be used for improving shelf-life of blanched potato strips.

5.1. Introduction

Potatoes are one of the most widely cultivated vegetables in the world. The United States is fourth in potato production with approximately 20 million tonnes per year (ERS-USDA, 2004). Most potatoes in the U.S. are consumed as frozen potato fries, potato chips and dehydrated potato products. However, 28% of the potatoes are consumed as fresh (NPC, 2007). Refrigerated fresh-cut produce with fresh-like properties, an extended shelf-life and a minimum preparation time is an alternative to fresh fruits and vegetables for demanding consumers. Nevertheless, frozen potato fries

are commonly preferred over fresh potato fries in deep-fat frying because of their crispy outside, soft inside and golden brown color.

A mild thermal treatment such as surface pasteurization with hot water, blanching, is used for refrigerated fruits and vegetables to improve quality and destroy microorganisms. Blanching is the most commonly used process to improve quality in conventional canning and frozen food industry. Blanching temperature is generally 70-105°C (Marshall et al., 2000). In frozen potato fries industry, a two-step water blanching process uses a low temperature (50-70°C) step to increase firmness followed by high temperature (80-100°C) step to inactivate undesired enzymes (Abu-Ghannam and Crowley, 2006; Loon, 2005). Low temperature blanching activates the pectin methyl esterase enzyme, which links pectin molecules and decreases porosity, thereby improving texture and reducing oil absorption of potato strips (Aguilar et al., 1997). The addition of calcium chloride into the blanching water enhances the firmness (Jaswal, 1970). High temperature blanching improves the color by inactivating the phenolase enzyme (Agblor and Scanlon, 2000). In frozen potato fries processing, thermal treatments—partial frying and drying—and freezing improve textural quality and extend shelf-life but consumers may perceive fresh potato strips as being healthier and/or higher quality.

Blanched and refrigerated potato strips can be an alternative to fresh potato strips for deep-fat frying with higher quality, extended shelf-life and minimum preparation time. However, hot water treatment alone is not a good option to improve shelf-life. Microbial recontamination and resulting growth will occur unless a proper environment is provided during packaging. Spoilage characteristics in fresh-cut products can be defined as rot development, mold growth, fermentation, browning, off-odor and off-

flavors (Nguyen-the and Carlin, 1994). In-package chemical treatment or near-aseptic packaging is required to prevent microbial growth which might occur due to recontamination after blanching. Antimicrobials such as ozone, chlorine, peroxyacetic acid or chlorine dioxide are used to minimize microbial growth in refrigerated food products.

Ozone is a GRAS status antimicrobial agent that is used for food treatment, storage, and food processing (FDA, 2001). It is becoming a popular alternative to traditional antimicrobial agents such as chlorine, chlorine dioxide and organic acids because of its effective antimicrobial property and lack of residual substances (Guzel-Seydim et al., 2004). Gaseous ozone treatments are generally more effective than aqueous ozone treatments. Bialka and Demirci (2007) were able to reduce *Salmonella* and *E. coli* O157:H7 on strawberries by 2.60 and 2.96 log₁₀ CFU/g, respectively, using gaseous ozone treatments. Akbas and Ozdemir (2008) were able to reduce *B. cereus* in dried figs up to 2 log₁₀ CFU/g with gaseous ozone. In both studies, there were not significant changes in color after ozone treatments. Klockow and Keener (2009) analyzed the effectiveness of 'in-package' gaseous ozone treatment on spinach leaves. They were able to reduce *E. coli* O157:H7 in spinach by 3-5 log₁₀ CFU/leaf after 24 h storage. Ozone gas also extended the shelf-life by preventing fungal decay and rot on fruits and vegetables such as bananas, citrus fruits, berries, potatoes (Sapers et al., 2006). Therefore, in-package gaseous ozone treatment can be an alternative method to extend shelf-life blanched potato strips by preventing microbial growth.

In this present study, potato strips were blanched, recontaminated by exposure to room air and then packaged in polyethylene bags. Strips were then treated by injecting

ozone gas inside the bag and stored for up to 28 days at $7\pm 1^{\circ}\text{C}$. The goal of this study was to analyze the effect of gaseous ozone treatment on mesophilic bacteria, psychrotrophic bacteria and mold-yeast growth and color quality of blanched potato strips during the storage.

5.2. Materials and Methods

5.2.1. Preparation of Potato Strips

Potatoes (Russet Burbank) were provided by Sterman Masser, Inc. (Sacramento, PA) and stored at $13\text{-}14^{\circ}\text{C}$ until processing. Twenty five potato tubers were washed and cut into $11\times 11\times 50$ mm strips with a manual potato cutter. Only strips with minimal or no skin were used. Potato strips were held in potable water ($\sim 20^{\circ}\text{C}$) during preparation to minimize browning.

5.2.2. Blanching and Packaging of Potato Strips

Approximately 200 strips were blanched in 0.5% CaCl_2 solution at 60°C for 10 min and then blanched in boiling water ($\sim 98^{\circ}\text{C}$) for 5 min. Potato strips were held in potable water ($\sim 20^{\circ}\text{C}$) between blanching treatments. After two-step blanching, potato strips were cooled in potable water for 5 min. Strips were drained, arranged in a single layer on the sieve (Figure 5.1) and held open to the normal laboratory atmosphere for 30

min in order to provide the opportunity for surface recontamination. Five potato strips were then placed into each of 30 bags (liter-size Ziploc freezer bag, S.C. Johnson Company, Racine, WI). Ten bags were kept as a control. The other twenty were vacuumed and heat sealed by using a vacuum packaging machine (Model MV45, Minipack-torre S.P.A, Dalmine, Italy) and then given an ozone treatment. One or two septa, depending on ozone application method, were attached to each bag before receiving an ozone treatment.



Figure 5.1. Recontamination of blanched potato strips before ozone treatment.

5.2.3. Ozone Treatment

A laboratory scale ozone generator (Model H-50, Hess Machines International, Ephrata, PA) equipped with an oxygen concentrator was used for ozone treatment. Ozone concentration in the gas stream was measured before treatments with a Teledyne 450H

bench-top analyzer (Teledyne Technologies, Inc., Los Angeles, CA). Potato strips were exposed to 5% (wt/wt) ozone gas with a flow rate of 0.34 m³/h (Bialka and Demirci, 2007) inside the bag. The bag was turned over once each 5 min during the application (Figure 5.2). Two different ozone treatments were used: batch and continuous ozone treatment. In batch ozone treatment, ozone gas was injected into the vacuumed bag with a needle connected to the ozone generator and inserted through the applied septum. The septa minimized leakage in or out of the bag after treatment. Potato strips were subjected to ozone gas for 20 s. For continuous ozone treatment, ozone gas was injected similarly to batch ozone treatment except a second needle and septum allowed for a continuous flow through the bag. Potato strips were exposed to ozone gas for 5, 15 and 30 min. The exhaust ozone gas was passed through a 2% (wt/vol) potassium iodide aqueous solution to prevent ozone from being released into the environment. All ozone treatments were performed in a fume hood for safety considerations. Ozone treated and control potato strips were stored at 7±1°C for up to four weeks.

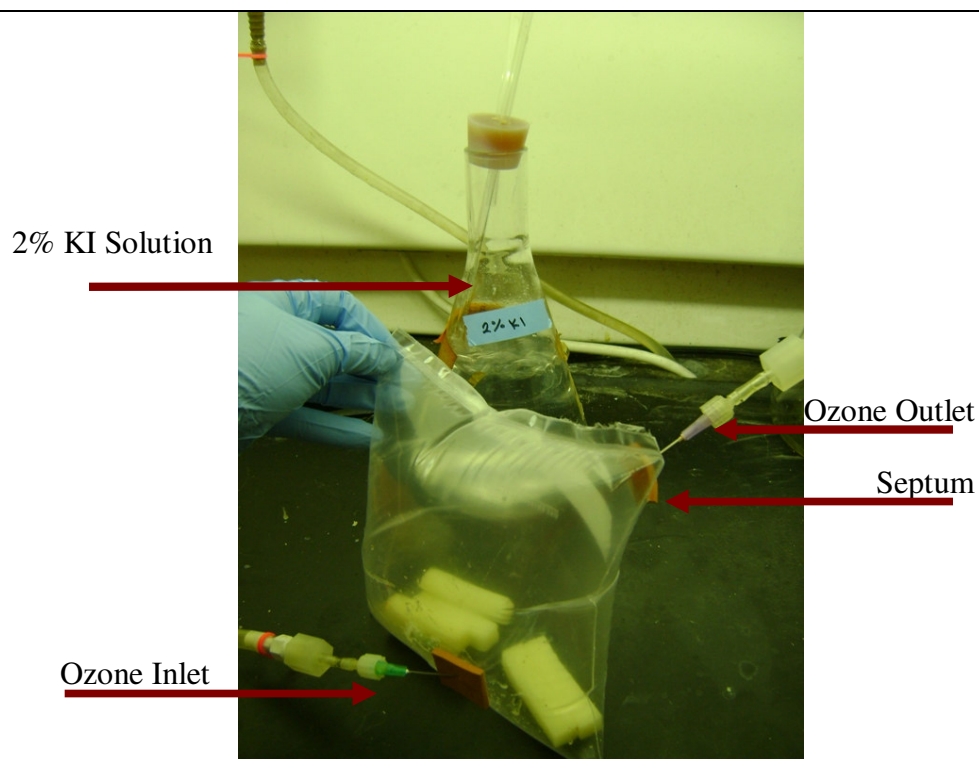


Figure 5.2. Application of continuous ozone treatment to blanched potato strips. The two septa are shown.

5.2.4. Microbiological Analysis

Samples were analyzed for mesophilic and psychrotrophic bacteria and mold-yeast growth after 1, 7, 14, 21 and 28 days of storage. Each day, one bag from each of the four treatments and one control bags were selected arbitrarily for analysis and three potato strips were selected arbitrarily from each bag. The three potato strips (~25 grams) were homogenized with a stomacher for 2.5 min in a sterile stomacher filter bag with a 225 mL 0.1% sterile peptone water (Difco, Detroit, MI). Mesophilic and psychrotrophic bacteria were enumerated by spiral plating method (Autoplate 4000, Spiral Biotech,

Norwood, MA) using plate count agar (PCA) by incubating plates at $30\pm 1^{\circ}\text{C}$ for 48 h and $7\pm 1^{\circ}\text{C}$ for 10 days, respectively. Mold and yeast counts were performed on potato dextrose agar by incubation at $25\pm 1^{\circ}\text{C}$ for 5 days. All samples were analyzed in duplicate. Colonies were counted by using an autounter (Q-Count, Version 2.1, Spiral Biotech, Norwood, MA) after incubation and results expressed as CFU/g of potato tissue. When spoilage was visually detected in a sample, microbiological analysis was not applied and the population was assumed to be the maximum count that could be determined from plate count.

To ensure detection of low levels of microbial growth, samples were enriched. Enrichments were done by transferring 1 mL of the peptone water rinse solution to 9 mL of trypticase soy broth for mesophilic bacteria and potato dextrose broth for mold and yeast (Difco, Detroit, MI). After incubating at 30°C for 2 days, growth in the enrichments was determined visually.

5.2.5. Quality Analysis

A Konica Minolta Chroma Meter CR-400 (Konica Minolta, Ramsey, NJ) was used to define color of potato strips by measuring $L^*a^*b^*$ color space. In this color space, L^* is the lightness which ranges from 0 to 100, and chromatic components of a^* (from green to red) and b^* (from blue to yellow) range from -60 to 60. ΔE^* indicates the total color difference which is calculated with Equation 5.1 (Konica Minolta, 1998; Nourian and Ramaswamy, 2003). That color difference is between the processed potato sample and the reference values from the white plate provided by the manufacturer.

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (5.1)$$

Prior to use, the Chroma Meter was calibrated against a standard white plate. During measurements (Figure 3.1), potato strips were placed snugly side-by-side in a single layer on a tray and the CIE L*a*b* values were recorded 20 times from five strips by measuring two different locations on each strip. Color analysis was applied before and after frying. In after-frying measurements, potato fries were held under room conditions for 3 min before measurement.

5.2.6. Statistical Analysis

All experiments were replicated three times and MINITAB statistical software (version 15, MINITAB Inc, State College, PA) was used to analyze differences between treatments. ANOVA (Analysis of Variance) at a 95% confidence level and Tukey's Least Significance Difference test were used to determine significant differences between treatments.

5.3. Results and Discussion

5.3.1. The Effects of Ozone Treatments on Microbiological Quality

Average populations of mesophilic bacteria, psychrotrophic bacteria and mold-yeast in potato strips stored at $7 \pm 1^\circ\text{C}$ for one day are shown in Table 5.1. Microbial

population on the control samples averaged 4.34 ± 0.77 , 4.47 ± 0.76 and $3.83 \pm 0.26 \log_{10}$ CFU/g of potato tissue for mesophilic bacteria, psychrotrophic bacteria and mold-yeast, respectively. The results for the batch ozone treatments were not significantly different from the control even though the averages for the batch treatments were numerically smaller than for the control for all three of the microbial types. No plate counts showed microbial growth for any of the continuous ozone treatments. However, only 15- and 30-min ozone treatments yielded negative growth in the enrichment protocol.

Table 5.1. Effect of ozone treatments on survival of mesophilic and psychrotrophic bacteria and mold-yeast (\log_{10} CFU/g) after one day of storage.

Ozone Treatments	Treatment Times	Mesophilic Bacteria	Psychrotrophic Bacteria	Mold - Yeast
Control	0	$4.34 \pm 0.77^2 a^3$	$4.47 \pm 0.76 b$	$3.83 \pm 0.26 c$
Batch	20 s	$3.47 \pm 0.74 a$	$3.51 \pm 0.90 b$	$3.02 \pm 0.51 c$
Continuous	5 min	ND ¹	ND	ND
Continuous	15 min	ND	ND	ND
Continuous	30 min	ND	ND	ND

¹ ND: Non-detectable (minimum detection level is $1.95 \log_{10}$ CFU/g).

² Values are mean growth \pm standard deviation.

³ Within the same column, values were not significantly different ($P > 0.05$).

Effect of storage time on mesophilic bacteria growth is illustrated in Figure 5.3.

No mesophilic bacteria growth was observed for potato strips treated with gaseous ozone by continuous treatment for 30 min during 28 days storage and visible microbial growth

was detected only at 28 days storage for 15-min continuous ozone treated potato strips. Visible microbial growth was considered to be greater than maximum countable population and designated as “ > ” in Figures 5.3, 5.4 and 5.5. Since microbial counts were determined from samples without dilution, the maximum countable microbial population was $5.95 \log_{10}$ CFU/g. Mesophilic bacteria population was $4.56 \pm 0.51 \log_{10}$ CFU/g in 5-min continuous ozone treated potato strips after 14 days of storage. Therefore, decreasing treatment time of ozone decreased the acceptable storage time of strips. After 21 days of storage, microbial growth was detected visually in 5-min continuous ozone treatment. Batch ozone treatment did not improve the microbiological quality when compared to the control. Mesophilic bacteria population for batch ozone treated strips was significantly lower with $3.47 \pm 0.74 \log_{10}$ CFU/g growth after one day of storage compared to 7 days of storage with 4.57 ± 1.33 and 14 days of storage with $5.65 \pm 0.53 \log_{10}$ CFU/g. Visible microbial growth was determined in the control after 7 days of storage.

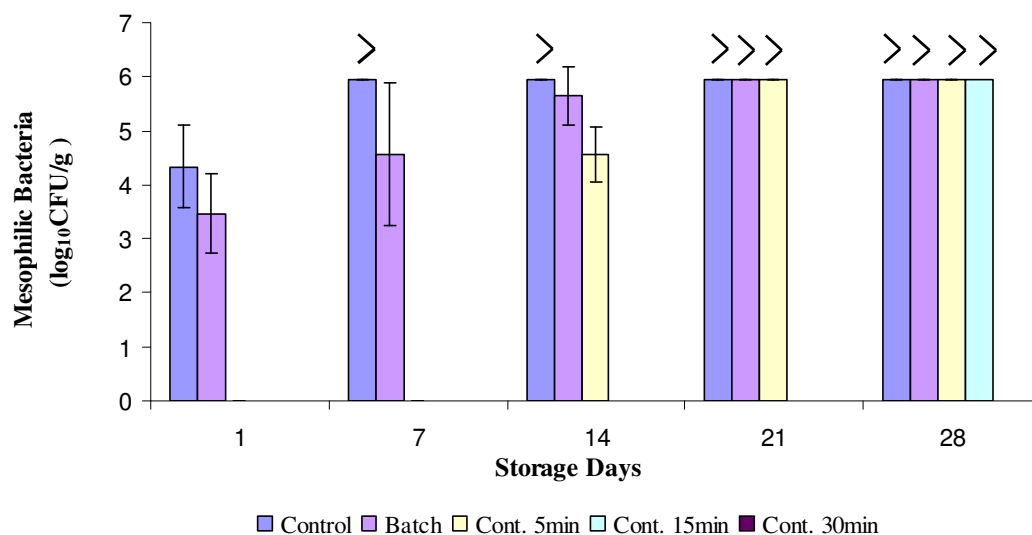


Figure 5.3. Mesophilic bacteria populations in control and ozone treated potato strips stored at $7\pm 1^\circ\text{C}$ for 28 days.

> indicates that microbial population is greater than $5.95 \log_{10} \text{CFU/g}$.

Psychrotrophic bacteria populations during 28 days storage are shown in Figure 5.4. There was no psychrotrophic bacteria growth in 30-min continuous ozone treated potato strips during 28 days of storage and no growth was observed for 15-min continuous ozone treated strips until 28 days storage, the same result as for mesophilic bacteria. After 14 days of storage, microbial growth was $4.77\pm 1.04 \log_{10} \text{CFU/g}$ in strips treated by continuous ozone for 5 min. Psychrotrophic bacteria growth was observed in batch flow ozone treated strips as 3.51 ± 0.90 , 4.39 ± 1.42 and $4.56\pm 1.27 \log_{10} \text{CFU/g}$ after 1, 7, and 14 days storage, respectively. Microbial spoilage was detected visually in the control samples after 7 days of storage.

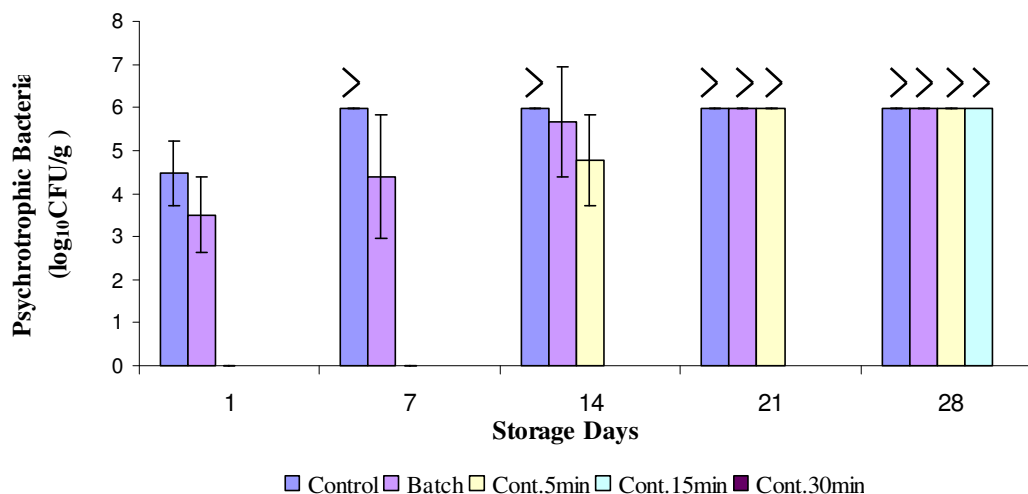


Figure 5.4. Psychrotrophic bacteria populations in control and ozone treated potato strips stored at $7\pm 1^\circ\text{C}$ for 28 days.

> indicates microbial population is greater than $5.95 \log_{10} \text{CFU/g}$.

The effect of ozone treatment on mold-yeast growth of potato strips during 28 days of storage is shown in Figure 5.5. Mold and yeast can grow at a temperature range between 5 and 35°C (Mislivec et al., 1992). Ozone treatments improved shelf-life of potato strips stored at $7\pm 1^\circ\text{C}$. Thirty minute continuous ozone treatment prevented mold-yeast growth in potato strips during 28 days of storage, the same result as for mesophilic and psychrotrophic bacteria. Microbial spoilage was visually observed in 15-min continuous flow ozone treated strips after 28 days of storage. Five minute continuous ozone treatment inhibited mold-yeast growth at least 14 days. When compared to continuous ozone treatments, batch ozone treatment provided the shortest shelf-life with a growth of $3.02\pm 0.51 \log_{10} \text{CFU/g}$ for one day and $4.48\pm 1.37 \log_{10} \text{CFU/g}$ for seven days

storage. Microbial spoilage was observed visually in batch ozone treated strips after 14 days. Spoilage in the control was visually detected after 7 days.

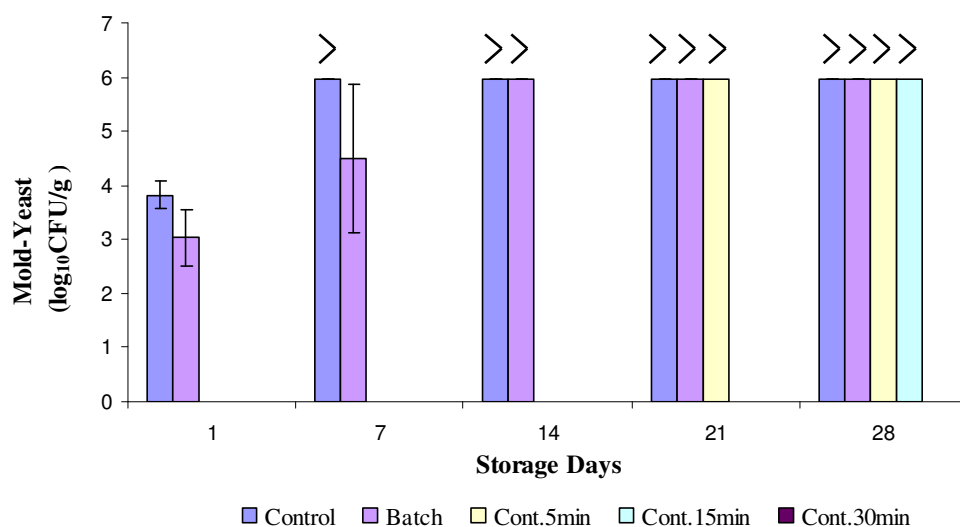


Figure 5.5. Mold-yeast populations in control and ozone treated potato strips stored at $7\pm 1^\circ\text{C}$ for 28 days.

> indicates microbial population is greater than $5.95 \log_{10} \text{CFU/g}$.

Enrichment protocol results are provided in Table 5.2. Since enrichment was used to determine a low level of microbial growth, it was not applied to samples which had visible growth. Positive growth was determined in control and batch ozone treated potato strips using the enrichment protocol, which confirmed the plate counts. Although the microbial populations for 5-min continuous ozone treated strips were non-detectable during 7 and 14 days of storage for mesophilic and psychrotrophic bacteria and mold-yeast respectively based on plate counts, positive growths were observed in the

enrichment protocol. The enrichment protocol confirmed that there was no growth in 15- and 30-min continuous ozone treated strips during 21 and 28 days of storage respectively.

Table 5.2. Enrichment protocol results for control and ozone treated potato strips³.

Treatments	Storage Days									
	1		7		14		21		28	
	TSB ¹	PDB ²	TSB	PDB	TSB	PDB	TSB	PDB	TSB	PDB
Control	+	+	VG ⁴	VG	VG	VG	VG	VG	VG	VG
Batch	+	+	+	+	VG	VG	VG	VG	VG	VG
Continuous 5 min	+	+	+	+	+	+	VG	VG	VG	VG
Continuous 15 min	-	-	-	-	-	-	-	-	VG	VG
Continuous 30 min	-	-	-	-	-	-	-	-	-	-

^{1,2} TSB: Trypticase soy broth (for mesophilic and psychrotrophic bacteria populations),
PDB: Potato dextrose broth (for mold and yeast populations)

³ + and - values indicated low level of microbial growth and no growth, respectively.

⁴ VG: Visible growth.

5.3.2. The Effects of Ozone Treatments and Storage Time on Color of Strips

The effects of ozone treatment on color of potato strips were analyzed based on lightness (L^*) and size of color difference (ΔE) values. Data collected from the strips after one day storage at $7\pm 1^\circ\text{C}$ is shown in Table 5.3. Higher L^* and lower ΔE values are interpreted as lighter color and less color difference, respectively. When L^* and ΔE values of one day stored potato strips were compared, there was no significant difference

between control and ozone treated strips ($P > 0.05$). As shown in Table 5.4., no significant changes were observed in L^* and ΔE values of 15- and 30-min continuous ozone treated strips during 21 and 28 days of storage at $7 \pm 1^\circ\text{C}$, respectively ($P > 0.05$). Since high temperature blanching prevents browning by inactivating phenolase enzyme, ozone treatment did not affect the color of the blanched potato strips.

Table 5.3. L^* and ΔE values for control and ozone treated potato strips after one day storage at $7 \pm 1^\circ\text{C}$.

Ozone Treatments	Treatment Times	L^* Value ¹	ΔE Value
Control	0	56.46 ± 2.41 a ²	41.35 ± 2.37 b
Batch	20 s	54.17 ± 3.86 a	43.52 ± 3.84 b
Continuous	5 min	56.03 ± 3.28 a	41.72 ± 3.72 b
Continuous	15 min	56.60 ± 2.42 a	41.16 ± 2.45 b
Continuous	30 min	55.84 ± 3.45 a	41.85 ± 3.43 b

¹ Values are mean values \pm standard deviation

² Within the same column, values were not significantly different ($P > 0.05$).

Table 5.4. L* and ΔE values for 30- and 15-min continuous ozone treated strips during the storage.

Storage Days	30-min Continuous Ozone Treatment		15-min Continuous Ozone Treatment	
	L* Value ¹	ΔE Value	L* Value	ΔE Value
1	55.84 \pm 3.45 a ²	41.85 \pm 3.43 b	56.60 \pm 2.42 c	41.16 \pm 2.45 d
7	58.90 \pm 1.14 a	39.04 \pm 1.01 b	58.49 \pm 1.96 c	39.30 \pm 1.92 d
14	59.55 \pm 1.14 a	38.38 \pm 1.06 b	57.07 \pm 1.78 c	40.85 \pm 1.68 d
21	58.66 \pm 1.67 a	39.46 \pm 1.50 b	59.96 \pm 0.64 c	38.01 \pm 0.69 d
28	58.11 \pm 1.97 a	39.84 \pm 2.09 b		

¹ Values are mean values \pm standard deviation

² Within the same column, values were not significantly different ($P > 0.05$).

5.4. Conclusions

Microbiological quality and color values indicate that in-package gaseous ozone treatment can be used for blanched potato strips to improve shelf-life up to 28 days. Based on mesophilic and psychrotrophic bacteria and mold-yeast count, there was no microbial growth in potato strips treated for 30 min with continuous gaseous ozone even after 28 days storage at $7 \pm 1^\circ\text{C}$. Similarly, 15 min continuous ozone treatment gave 21 days shelf-life but for 5-min continuous ozone treated strips, bacteria and mold-yeast growth were observed after 14 and 21 days of storage, respectively. Increasing exposure time of gaseous ozone improved the microbiological quality and shelf-life accordingly. Batch ozone treatment was not effective in decreasing microbial population as much as

continuous treatments. Based on L^* and ΔE values, there were no significant differences in color between control and ozone treated strips during storage ($P > 0.05$) for treatments which allowed no microbial growth.

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Chapter 6

Effect of Processing and Packaging Conditions on Quality of Refrigerated Potato Strips

Abstract

Sulfiting agents are commonly used in the fresh-cut potato industry for sanitation and higher quality. However, concerns about further regulatory restrictions of sulfite use and consumer fear of sulfite treated foods have lead to increased research in alternative processing methods. Blanching is a mild thermal treatment which is used for refrigerated fruits and vegetables to inactivate bacteria and improve quality. Near-aseptic packaging is a non-chemical alternative method to prevent recontamination of blanched potato strips, thereby to extend shelf-life, but it is expected as expensive for commercial production because cost of the near-aseptic packaging system is determined based on cost assumptions for aseptic packaging system which requires more safeguards in order to provide and maintain sterilization Alternative chemicals to sulfites, using in-package treatment, were tested to destroy microorganisms on recontaminated produce for the purpose of extending shelf-life. The quality of freshly cut and commercially frozen potato strips were compared to refrigerated potato strips, both those near-aseptically packaged and those in-package chemically treated with SM solution, gaseous ozone or FIT wash. The effects of near-aseptic packaging and in-package chemical treatments on blanched

potato strips were compared based on microbial counts, color, texture and oil content after 28 days of storage at $7\pm 1^{\circ}\text{C}$. Potato strips were first blanched at low temperature (60°C) in 0.5% CaCl_2 solution for 20 min and then second blanched at high temperature ($\sim 98^{\circ}\text{C}$) in water for 5 min. After 2-step blanching, strips were packaged in a near-aseptic environment or treated in-package with gaseous ozone, sodium metabisulfite (SM) solution or FIT wash. Before in-package treatments, blanched potato strips were recontaminated by exposure to room air for 30 min.

For SM treated strips, lighter color and less color difference were observed after frying compared to other treatments. The lightness of near-aseptically packaged fries, FIT treated fries and frozen fries were not significantly different, however less color difference was determined in near-aseptically packaged fries and FIT treated fries compared to frozen fries. Gaseous ozone treatment decreased before- and after-frying color quality of potato strips, significantly. In comparison of before-frying textural quality, lower peak force was determined in near-aseptically packaged, SM treated, ozone treated and FIT treated strips than unprocessed strips (freshly cut strips without blanching and/or chemical treatment). Higher after-frying peak force was observed in FIT treated compared to other treatments. After-frying textural quality of near-aseptically packaged fries, SM treated and ozone treated fries were not significantly different and higher than unprocessed and frozen fries. There was no significant difference in oil absorption of near-aseptically packaged strips, in-package chemical treated strips and unprocessed strips. These results indicate that either near-aseptic packaging or in-package FIT treatment are the better alternatives for blanched potato strips to extend shelf-life and maintain quality.

6.1. Introduction

Fresh-cut fruits and vegetables are one of the fastest growing categories in the food industry. Since they are fresh, healthy and convenient, fresh-cut products are experiencing greater demands. In the United States, fresh-cut produce sales continue to increase with an annual growth rate between 10 and 20% (ARS-USDA, 2005). In fresh-cut produce processing, the least possible treatments are applied to extend shelf-life up to 14 days and improve safety of the food product without changing the fresh quality (Ohlsson and Bengtsson, 2002). Produce pass through unit operations such as washing, sorting, peeling and cutting, are subjected to chemical treatments, and are packaged in modified atmosphere environment (Wiley, 1994).

Sulfiting agents such as sodium metabisulfite are preferred in preservation of food products in the industry due to their antimicrobial action (DiPersio et al., 2003), ability to prevent enzymatic and non-enzymatic browning (Marshall et al., 2000) and low cost. However, there are some regulatory restrictions on usage of sulfites preventing use in meats, other foods recognized as a source of thiamine and fruits and vegetables which are consumed fresh, due to adverse affects on human health (FDA, 1994). Thus, researchers have focused on finding alternative chemicals but none of them are as effective as sulfites (Gunes and Lee, 1997; Laurila et al., 1998). Although sulfites are allowed to use for fresh potatoes since they are cooked before consumption (Petri et al., 2008), alternative processing methods have been searched due to concerns about future federal restrictions on sulfite usage.

Like sulfites, ozone is also a highly reactive antimicrobial, but with a lack of residual effect or chemical residue. Ozone is a GRAS status antimicrobial agent. “It may be safely used in the treatment, storage, and processing of foods, including meat and poultry” (FDA, 2001). Aqueous ozone has reduced microbial populations and extended shelf-life of some fresh-cut fruits and vegetables (Beuchat, 1998; Kim et al., 1999). However, Beltran et al. (2005) reported that aqueous ozone treatment was not effective in improving microbial quality of fresh-cut potato strips. Beside that, a significant increase in browning was observed for ozone treated raw potato strips. Gaseous ozone treatments are generally more effective than aqueous ozone treatments. Bialka and Demirci (2007) were able to reduce *Salmonella* and *E. coli* O157:H7 on strawberries by 2.60 and 2.96 \log_{10} CFU/g, respectively using gaseous treatments. No significant changes observed in color after ozone treatments. Klockow and Keener (2009) analyzed the effectiveness of ‘in-package’ gaseous ozone treatment on spinach leaves. They were able to reduce *E. coli* O157:H7 in spinach by 3-5 \log_{10} CFU/leaf after 24 hours storage.

FIT Fruit and Vegetable Wash (Procter and Gamble Co., Cincinnati, OH) is marketed as an effective antimicrobial. The original FIT formulation consists of oleic acid, glycerol, ethyl alcohol, potassium hydrate, sodium bicarbonate, citric acid and grapefruit oil. Beuchat et al. (2001) were able to reduce *Salmonella* and *Escherichia coli* O157:H7 populations from 1.7 to 2.3 \log_{10} CFU/g and 1.7 to 5.4 \log_{10} CFU/g, respectively, with 30 min FIT treatment. Park et al. (2008) were able to reduce levels of microorganisms on potatoes up to 6.6 \log_{10} CFU/g. However, Zhao et al. (2009) invented what became the new formula FIT Fruit and Vegetable Wash™. It consists of levulinic acid and sodium dodecyl sulfate (SDS), which can kill significant numbers of

Escherichia coli and *Salmonella* in less than a minute. Levulinic acid (FDA, 2004) (21 CFR 172.515) and sodium dodecyl sulfate (FDA, 1978) (21 CFR 172.822) are generally recognized as safe by FDA. Zhao et al. (2009) were able to reduce both *Salmonella* and *E. coli* O157:H7 populations on lettuce greater than $6.7 \log_{10}$ CFU/g by using 3% levulinic acid and 1% SDS for less than 20 s.

Hot water surface pasteurization is an effective sanitizing method. Immersion in hot water reduces microbial population by providing excellent heat transfer through the food surface (Annous et al., 2004; Pao and Davis, 1999). Beside the microbial effects, hot water treatment improves general quality. Two-step water blanching improves the textural and color quality of potato strips. Low temperature blanch (50-70°C) improves texture by activating pectin methylesterase enzyme (Andersson et al., 1994; Nourian and Ramaswamy, 2003; Ni et al., 2005) and the following high temperature blanch (e.g. boiling water) improves color by inactivating phenolase enzyme (Canet and Hill, 1987; Agblor and Scanlon, 2000). The addition of calcium chloride into blanching water enhances the firmness (Jaswal, 1970) and the whitening (Severini et al., 2003) of the potato strips. However, hot water treatment has limited use in the fresh-cut industry because of their negative effect on freshness of produce (Sapers et al., 2006).

Treating potato strips with chemicals or hot water is not sufficient to extend shelf-life unless proper packaging is used. Either treating potato strips with chemicals inside the package or packaging in pasteurized environment (near-aseptic packaging) might be useful methods to improve shelf-life up to 28 days. The objective of this study was to determine the effect of near-aseptic packaging and in-package treatments with gaseous ozone, SM solution and FIT wash for blanched potato strips based on color and textural

quality and oil content. The quality of unprocessed (freshly cut strips without blanching or chemical treatment) and commercially processed frozen potato strips were compared with refrigerated potato strips prepared using four different methods.

6.2. Materials and Methods

6.2.1. Preparation and Blanching of Potato Strips

Potatoes (Russet Burbank variety) were provided by Sterman Masser, Inc. (Sacramento, PA) and stored at 13-14°C until used. Potatoes were washed and cut into 11x11x50 mm strips with a manual potato cutter. Only strips with minimal or no skin were used. Potato strips were held in potable water (~20°C) during preparation to minimize browning. Approximately 300 potato strips were first blanched at 60°C for 20 min in 0.5% CaCl₂ solution and then second blanched in boiling water (~98°C) for 5 min. Potato strips were kept in potable water (~20°C) between blanching treatments.

6.2.2. Near-Aseptic Packaging of Blanched Potato Strips

The near-aseptic packaging system (Figure 4.1) and its operation (Figure 4.2) are described in section 4.2.2. The near-aseptic packaging system was used to provide second blanching, cooling and packaging of potato strips for all treatments except the unprocessed treatment. After second blanching in product column, potato strips were

discharged into the chamber where they were drained and air-cooled for ~10 min. Twenty potato strips were packaged into each bag (liter-size Ziploc freezer bag, S.C. Johnson Company, Racine, WI)). The bags remained inside the chamber until all samples were made and then were removed from the chamber by disassembling a chamber wall. Three bags of near-aseptically packaged potato strips were stored in a refrigerator at $7\pm 1^{\circ}\text{C}$ for four weeks.

Approximately 60 near-aseptic potato strips were taken from the bags and placed on a sieve, arranged in a single layer (Figure 5.1) and held for 30 min in order to allow surface contamination from laboratory atmosphere. After contamination, 20 strips were placed into each bag and were used for each treatment with gaseous ozone, SM solution and FIT solution as described in below. Three bags with contaminated strips were also kept as a control.

6.2.3. Ozone Treatment of Blanched Potato Strips

Bags with twenty blanched and contaminated strips were vacuumed and heat sealed by using a vacuum packaging machine (Model MV45, Minipack-torre S.P.A, Dalmine, Italy) and two septa were attached to each bag scheduled to receive an ozone treatment. Continuous ozone gas (5% wt/wt) was injected into each vacuumed bag for 30 min with a needle connected to the ozone generator and inserted through one of the septum. A second needle and septum allowed for a continuous flow through the bag (Figure 5.2). The septa minimize leakage of gas in or out of the bag after treatment.

A laboratory scale ozone generator (Model H-50, Hess Machines International, Ephrata, PA) equipped with an oxygen concentrator was used for ozone treatment. Ozone concentration in the gas stream was measured before treatments with a Teledyne 450H bench-top analyzer (Teledyne Technologies, Inc., Los Angeles, CA). The exhaust ozone gas was passed through a 2% (wt/vol) potassium iodide aqueous solution to prevent ozone from being released into the environment. All ozone treatments were performed in a fume hood for safety considerations. Ozone treated potato strips were stored at $7\pm 1^{\circ}\text{C}$ for four weeks.

6.2.4. Sodium Metabisulfite and FIT Treatments of Blanched Potato Strips

Twenty blanched and re-contaminated potato strips were treated with 0.7 L sodium metabisulfite (SM) solution (9 g/L) and FIT Fruit and Vegetable Wash™ solution (diluted to achieve pH 3) inside the bag for 1 min. One chemical solution was poured into each Ziploc bag containing the strips and sealed by using the zipper closure. The bag was turned over once each second during the treatment. After treatment, the solution was drained from the bag, while allowing no air to enter, and then the bag was sealed using the zipper. Treated potato strips were stored at $7\pm 1^{\circ}\text{C}$ for four weeks.

6.2.5. Microbiological Analysis

Mesophilic bacteria, psychrotrophic bacteria and yeast-mold populations were determined after 28 days of storage. Three potato strips (~25 grams) were homogenized with a stomacher for 2.5 min in sterile stomacher filter bags containing 225 mL 0.1% sterile peptone water (Difco, Detroit, MI). Mesophilic and psychrotrophic bacteria were enumerated by spiral plating (Autoplate 4000, Spiral Biotech, Norwood, MA) method using plate count agar (PCA) and incubating plates at $30\pm 1^{\circ}\text{C}$ for 48 h and $7\pm 1^{\circ}\text{C}$ for 10 days, respectively. Yeast-mold counts were performed in potato dextrose agar by incubating at $25\pm 1^{\circ}\text{C}$ for 5 days. All samples were analyzed in duplicate. Colonies were counted by using an autounter (Q-Count, Version 2.1, Spiral Biotech, Norwood, MA) after incubation and results expressed as CFU/g of potato tissue.

To ensure detection of low levels of microbial growth, samples were enriched. An enrichment protocol was performed by transferring 1 mL the stomaching solution to 9 mL of trypticase soy broth (TSB) for mesophiles and potato dextrose broth (PDB) for mold and yeast (Difco, Detroit, MI). After incubating at 30°C for 2 days, growth in the enrichments was determined visually.

6.2.6. Texture, Color and Oil Content Analyses

Texture, color and oil content analyses were applied to near-aseptically packaged potato strips, ozone treated strips, SM treated strips and FIT treated strips after 28 days of storage at $7\pm 1^{\circ}\text{C}$. Unprocessed samples (freshly cut strips without blanching and/or

chemical treatment) and commercial frozen potato fries (9.5x9.5 mm Ore-Ida, Golden Fries, H.J. Heinz Company, Pittsburgh, PA) were also analyzed. Unprocessed potato strips were prepared from the same batch of potato tubers using the same method as for the blanched product. Potato tubers were cut into strips just before quality analysis in order to prevent quality degradation. Texture and color quality of potato strips were compared before and after frying.

To determine after-frying quality, 10 potato strips were fried in 2.5 L of corn oil, heated to an initial temperature of 177°C, for 4 min using an electric fry cooker (Model 0692001, 1500 W, Presto, Eau Claire, WI) controlled by an external temperature controller (Digi-Sense model 89000-10, Cole Parmer, Vernon Hills, IL). Frozen potato strips were fried at 190°C for 7 min as recommended on their bag. Potato fries were held at room conditions for 3 and 5 min before beginning color and texture measurements, respectively.

6.2.6.1. Texture Analysis

An Instron model 4444 Universal Testing machine (Instron, Norwood, MA) was used to analyze texture of potato strips (Figure 3.2). A plate with a 3 mm hole was attached to the machine. A potato strip was placed onto the plate and a 2 mm probe moved downward through the strip at a rate of 0.42 mm/s. The peak force required to puncture the top surface of the potato strip was used to determine textural quality. Each potato strip was measured at three locations, two ends and a center. A total of 15 data were obtained from five potato strips.

6.2.6.2. Color Analysis

A Konica Minolta Chroma Meter CR-400 (Konica Minolta, Ramsey, NJ) was used to define color of potato strips by measuring L*a*b* color space. In this color space, L* is the lightness which ranges from 0 to 100, and chromatic components of a* (from green to red) and b* (from blue to yellow) range from -60 to 60. ΔE^* indicates the total color difference which is calculated with Equation 6.1 (Konica Minolta, 1998; Nourian and Ramaswamy, 2003). That color difference is between the processed potato sample and the reference values from the white plate provided by the manufacturer.

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (6.1)$$

Prior to use, Chroma Meter was calibrated against a standard white plate. During measurements (Figure 3.1), potato strips were placed snugly side-by-side in a single layer on a tray and the CIE L*a*b* values were recorded 20 times from five strips by measuring two different locations on each strip. Color analysis was applied before and after frying. In after-frying measurements, potato fries were held under room conditions for 3 min before measurement.

6.2.6.3. Oil Content Analysis

Oil content was determined by Soxhlet extraction method using a Goldfish Fat Extractor apparatus (Labconco Corp., Kansas City, MO). Four potato strips from each treatment were dried in an oven at 105°C for 2 days and then ground into small particles. A porous cellulose thimble containing a 2 gram sample and a beaker containing ethyl

ether were placed in the extraction chamber. The beaker was heated and the ether evaporated up into the condenser. The evaporated ether was condensed into a liquid which drained through and leached the oil from the sample and then drained back to the beaker. Ether refluxed through thimble for 16-18 hours. After extraction, the ether was evaporated from the beaker, leaving the oil. The weight of the oil was measured and the percentage of oil in the initial sample was calculated as in Equation 6.2.

$$\% \text{ Oil content} = \frac{\text{Weight of extracted oil}}{\text{Weight of dried sample}} \times 100 \quad (6.2)$$

6.2.7. Statistical Analysis

All experiments were replicated three times and MINITAB statistical software (version 15, MINITAB Inc, State College, PA) was used to analyze differences between treatments. ANOVA (Analysis of Variance) at a 95% confidence level and Tukey's Least Significance Difference test were used to determine significant differences between treatments.

6.3. Results and Discussion

6.3.1. Microbiological Quality of Potato Strips

Mesophilic bacteria, psychrotrophic bacteria and mold-yeast populations were analyzed for treated potato strips after 28 days of storage at $7\pm 1^{\circ}\text{C}$. Plate counts revealed no microbial growth in potato strips either near-aseptically packaged or in-package treated with gaseous ozone, SM solution or FIT wash. Enrichment protocols confirmed the results. Microbial spoilage was detected visually in the control samples after 7 days of storage.

6.3.2. Textural Quality of Potato Strips

Textural quality results are listed in Table 6.1. Higher peak force ($P < 0.05$) was determined in unprocessed potato strips when measured before frying. Lower peak forces were determined in blanched strips because the high temperature blanching treatment, effectively a cooking treatment, weakens the cell wall of the strips (Djomdi and Ndjouenkeu, 2007), and causes the texture degradation. There was no significant difference between before-frying textural qualities of near-aseptically packaged, SM treated and ozone treated strips. Average values of before-frying peak force for ozone treated strips were lower compared to near-aseptically packaged strips ($P > 0.05$), SM treated strips ($P > 0.05$) and FIT treated strips ($P < 0.05$).

When after-frying textural quality was compared, the lowest peak force ($P < 0.05$) was determined in the unprocessed fries. No significant difference was observed in after-frying textural quality of fries which were near-aseptic packaged, SM treated and ozone treated. Higher peak force ($P < 0.05$) was determined in FIT treated fries. Peak force for frozen potato fries was higher ($P < 0.05$) than unprocessed fries and lower ($P < 0.05$) than fries processed as near-aseptically packaged, SM treated, FIT treated and ozone treated fries. In frozen potato fries, processing conditions such as blanching, drying, addition of surface coatings, and partial frying can cause differences in crust formation compared to other treatments.

Table 6.1. Peak force (N) of potato strips for six different processes after 28 days of storage at $7 \pm 1^\circ\text{C}$.

Processes	Before frying	After frying
Unprocessed	8.23 ± 0.28 a ¹	1.34 ± 0.19 a
Near-aseptic packaging	5.36 ± 0.23 bc	2.92 ± 0.18 b
Sodium metabisulfite	5.45 ± 0.38 bc	2.89 ± 0.12 b
Ozone	5.07 ± 0.13 b	3.11 ± 0.31 b
FIT	5.94 ± 0.39 c	3.84 ± 0.22 c
Frozen		2.13 ± 0.24 d

¹Within the same column, values not followed by the same letter are significantly different ($P < 0.05$).

6.3.3. Color Quality of Potato Strips

Lightness (L^*) and total color difference (ΔE) values of potato strips for six different processes are listed in Table 6.2. Higher L^* value and lower ΔE values are interpreted as lighter color and less color difference, respectively. There was no significant difference in before-frying L^* and ΔE values of FIT treated strips compared to unprocessed strips and SM treated strips. However, FIT treated strips were better ($P < 0.05$) in before-frying color than near-aseptically packaged strips and ozone treated strips. The nominal 3.0 pH of the FIT solution can be effective at inactivation of phenolase because irreversible inactivation of phenolase can be achieved below 3.0 pH (Richardson and Hyslop, 1985). SM inhibits enzymatic browning (Marshall et al., 2000) and this is consistent with the higher L^* and lower ΔE color values that were determined in before-frying SM treated strips compared to near-aseptically packaged potato strips even though the difference was not significant. Lower L^* and higher ΔE values were determined in before- and after-frying of ozone treated strips compared to other treatments. Although potato strips were 2-step blanched, phenolase enzyme may not have been completely inactivated. Since ozone decomposes quickly (Guzel-Seydim et al., 2004), oxygen level increases inside the package and may cause browning. Beltran et al. (2005) found that significant increase in browning for ozone treated modified atmosphere packaged potato strips.

Table 6.2. L* and ΔE values of potato strips for six different processes after 28 days of storage at $7 \pm 1^\circ\text{C}$.

Processes	Before Frying		After Frying	
	L*	ΔE	L*	ΔE
Unprocessed	70.38 ± 0.30 a ¹	29.99 ± 0.31 ab	52.33 ± 1.02 a	56.54 ± 2.26 a
Near-aseptic packaging	65.64 ± 0.12 bc	32.15 ± 0.16 b	61.32 ± 0.24 b	43.31 ± 0.28 b
Sodium metabisulfite	67.85 ± 1.52 ce	30.13 ± 1.44 ab	65.93 ± 0.70 c	36.51 ± 0.73 c
Ozone	61.83 ± 1.43 d	36.46 ± 1.51 c	40.58 ± 0.73 d	64.99 ± 0.77 d
FIT	69.83 ± 0.43 ae	28.03 ± 0.44 a	60.25 ± 0.33 b	44.05 ± 0.67 b
Frozen	65.32 ± 0.60 b	40.64 ± 0.33 d	59.80 ± 0.93 b	52.37 ± 1.74 e

¹Within the same column, values not followed by the same letter are significantly different ($P < 0.05$).

The appearance of potato fries from the six different treatment processes is shown in Figure 6.1, illustrating the differences that are shown numerically in Table 6.2. SM treated potato fries were lighter in color ($P < 0.05$) compared to other treatments and less color difference ($P < 0.05$) was also observed in SM treated fries because sulfiting agents inhibit both enzymatic and non-enzymatic browning (Marshall et al., 2000). No significant difference was determined in after-frying L* values of near-aseptically packaged fries, FIT treated fries and frozen fries. However, total color difference was higher ($P < 0.05$) compared to near-aseptically packaged fries and FIT treated fries.



Near-aseptic packaged potato fries



Sodium metabisulfite treated potato fries



Ozone treated potato fries



FIT treated potato fries



Unprocessed potato fries



Frozen potato fries

Figure 6.1. Appearance of potato fries treated in different processing conditions.

6.3.4. Oil Content of Potato Strips

The oil content data for the prepared potato fries are shown in Table 6.3. Frozen potato fries were higher ($P < 0.05$) in oil content compared to the other treated potato fries and unprocessed potato fries. No significant difference was observed in oil content of untreated near-aseptically packaged, SM treated, ozone treated and FIT treated fries. Aguilar et al., (1997) reported that low temperature ($55-70^{\circ}\text{C}$) long time blanching (15-60 min) of potato strips decreased the oil content compared to unblanched strips. Although near-aseptically packaged, SM treated, ozone treated and FIT treated strips were blanched at low temperature (60°C) for 20 min, here only insignificantly higher oil content was found in the unprocessed fries compared to 2-step blanched potato fries. This was most likely due to the subsequent 5 min high temperature blanching ($\sim 98^{\circ}\text{C}$) which causes weakening of cellular structure in the strips.

Table 6.3. Oil content of potato fries processed in six different conditions.

Processes	Oil content (% d.b.)
Unprocessed	8.838 ± 0.432 a
Near-aseptic packaging	7.946 ± 1.152 a
Sodium metabisulfite	8.133 ± 2.275 a
Ozone	8.213 ± 1.276 a
FIT	8.087 ± 0.222 a
Frozen	21.602 ± 2.340 b

¹Within the same column, values not followed by the same letter are significantly different ($P < 0.05$).

6.4. Conclusions

Two-step blanching is necessary in potato strips processing for after-frying color and textural quality. Either near-aseptic packaging or in-package chemical treatment extended the shelf-life up to 28 days at $7\pm 1^\circ\text{C}$ without microbial growth. No significant difference was observed in color, textural quality and oil content of near-aseptically packaged strips compared to SM treated strips. However, the lighter color and the less color difference were determined in SM treated fries. There was no significant difference in before-frying color and textural quality of strips treated with FIT wash and SM solution. Furthermore, FIT treatment increased the after-frying peak force of fries. Gaseous ozone treated potato strips were not significantly different compared to SM treated strips based on textural quality and oil content but ozone treatment decreased the color quality significantly. No significant difference was observed in oil content of unprocessed fries, near-aseptically packaged fries and fries treated with gaseous ozone, SM and FIT, but all had lower oil content than did frozen fries.

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Chapter 7

Conclusions and Future Research

The main goal of this research was to find alternative processing and packaging techniques to achieve safe and high quality refrigerated potato strips for French frying with a minimum shelf-life of four weeks.

According to the first study, there was no significant difference in textural quality of potato strips receiving either a 30- or 20-min low temperature (60°C) blanch and then a 10- or 5-min high temperature (~98°C) blanch. Increasing low temperature blanching time to 30 min and high temperature blanching time to 15 min increased the lightness and decreased the color difference in potato fries. Calcium chloride (0.5% w/v) increased the before-frying peak force of potato strips. Higher peak force was determined in potato fries prepared from Russet Burbank potato tubers compared to fries prepared from Norwis, Reba and Keuka Gold varieties. Approximately 8% dry matter loss was found in 2-step blanched potato strips. Besides the instrumental analysis, potato fries treated with different blanching conditions were brought to an expert chef to gain information about customer preferences (Appendix B). Although potato fries receiving a 30-min low temperature blanch followed by a 10-min high temperature blanch were lighter in color, and expected to be considered better, the expert found them too light. Furthermore, fries receiving a 20-min low temperature blanch followed by a 5-min high temperature blanch were higher in peak force compared to other treatments. However the expert chef determined that the best fries were first blanched at low temperature for 10 min and then

second blanched at high temperature for 10 min, giving a softer texture. The expert chef confirmed that color and texture are important quality parameters for potato fries and that desired quality may vary from customer to customer.

The second study illustrated that there was no mesophilic or psychrotrophic bacteria or yeast-mold populations during the 28 days of storage in any treatments of near-aseptically packaged strips receiving 5- or 10-min high temperature blanch. Before-frying peak force of the unprocessed strips (neither blanched nor near-aseptically packaged) was higher ($P < 0.05$) compared to near-aseptic strips. However, higher after-frying peak force ($P < 0.05$) was found in near-aseptic potato fries. Lighter color ($P < 0.05$) and less color difference ($P < 0.05$) was found in near-aseptic potato fries compared to unprocessed fries, while before-frying the trend was reversed. No significant changes were observed in color and texture of near-aseptic strips during the four weeks storage. Moreover, the shelf-life of near-aseptically packaged strips, processed at a commercial potato processing plant by using full-size two-step blanching equipment and the lab-scale near-aseptic packaging chamber, was 60 days at 2°C based on visual observation (Appendix A). Furthermore, a continuous near-aseptic packaging system for commercial production was conceptually designed and it was determined that that the system could operate 8 h without re-pasteurization (Appendix C).

In the third study, there was no microbial growth in potato strips receiving gaseous ozone inside the bag for 30- and 15-min after 28 and 21 days of storage at $7 \pm 1^\circ\text{C}$, respectively. Batch ozone treatments were not as effective in decreasing microbial population as were continuous treatments. There was no significant difference in before-frying color of control and ozone treated strips.

In the final study, the effects of the best near-aseptic packaging and in-package chemical treatment with gaseous ozone, sodium metabisulfite (SM) solution and FIT wash on quality of 2-step blanched potato strips were compared. There was no significant difference in color, texture and oil content of near-aseptically packaged strips compared to SM treated strips but SM treated strips were lighter ($P < 0.05$) in after-frying color. FIT treatment increased ($P < 0.05$) the after-frying peak force of fries. Gaseous ozone treatment decreased ($P < 0.05$) the color quality. Oil content of unprocessed fries, near-aseptically packaged fries and fries treated with gaseous ozone, SM and FIT were not significantly different. After-frying color of near-aseptic packaged strips and those in-package treated with SM or FIT were lighter in color ($P < 0.05$) compared to freshly cut strips. After-frying peak force was significantly higher for refrigerated potato strips compared to unprocessed samples.

In this research, several processing conditions and packaging methods were evaluated to improve quality and extend shelf-life of refrigerated potato strips. Results indicate that the combination of 2-step blanching and near-aseptic packaging was an effective non-chemical processing method, giving 28 days refrigerated shelf-life. Similarly, FIT wash proved to be an effective chemical alternative to SM and avoids the allergen concern.

However, further research is needed to optimize these new treatments. In this research, the quality of potato strips was determined based on color and texture by using instrumental analysis. Because the optimum is not a maximum or a minimum value, it is difficult to relate mechanical measurements to customer opinion. Therefore, further

research is needed to evaluate the quality of potato fries by using sensory evaluation methods.

Two-step blanching improved quality in refrigerated potato strips processing. However, water blanching of strips caused dry matter loss which directly affects profit. In order to decrease the amount of dry matter loss from the strips, a combination of water and steam blanching treatments should be considered in future research.

Near-aseptic processing was found to be effective in providing a long refrigerated shelf life. However, a near-aseptic packaging system is expected to be expensive for commercial production, assuming the cost is similar to that for aseptic packaging. In order to provide and maintain commercial sterilization, aseptic packaging requires more safeguards, and thereby cost, compared to a near-aseptic system. The cost of near-aseptic packaging system needs to be evaluated by considering the appropriate level of safeguards needed.

In this research, the quality of refrigerated potato strips was compared mostly to freshly cut strips. Further research needs to be conducted to determine differences between frozen and refrigerated potato strips, both prepared from same variety and batch of tubers.

Due to time limitations, recommended conditions such as concentration, pH and process time were used for in-package treatments with SM solution and FIT wash. Additional research is required to determine optimum conditions for these treatments.

Furthermore, 2-step blanching was used for all in-package chemical treatments in order to provide same conditions as for near-aseptic packaging. However, only one-step low temperature blanching might be sufficient for in-package treatments with SM

solution and FIT wash because they are antimicrobials and there was some indication they might have been effective at polyphenol oxidase enzyme inactivation, which are the purposes of the second, high temperature blanch.

Since in-package chemical treatments were effective in extending shelf-life of refrigerated potato strips, a pilot scale packaging system for in-package chemical treatment should be designed and tested. Experiments to this point have been confined to a lab-scale equipment.

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Appendix A

Shelf-life Study for Near-Aseptically Packaged Refrigerated Potato Strips at a Commercial Potato Processing Plant

The aim of this study was to validate the effect of near-aseptic packaging on shelf-life of refrigerated potato strips in the commercial environment by using full-size two-step blanching equipment. The near-aseptic packaging system described earlier was set up at a commercial potato processing plant. The packaging chamber was connected to the second blancher shown in Figure A.1 via the duct shown in Figure A.2. Potato tubers were cut into strips by a water knife, first blanched at low temperature (60°C) for 20 min in 0.5% CaCl₂ solution and then second blanched at high temperature (i.e. in boiling water) for 7 min, all using commercial-size equipment. After the second blanching, potato strips were dropped into the duct and moved horizontally to the packaging chamber by using a paddle (Figure A.2). After cooling, approximately 1 kg potato strips were packaged in each of several polyethylene bags and heat sealed. Samples were stored in a cardboard box in a refrigerated room at 2°C. The quality of samples was evaluated visually by plant personnel based on color, moisture, smell and any other signs of breaking down.

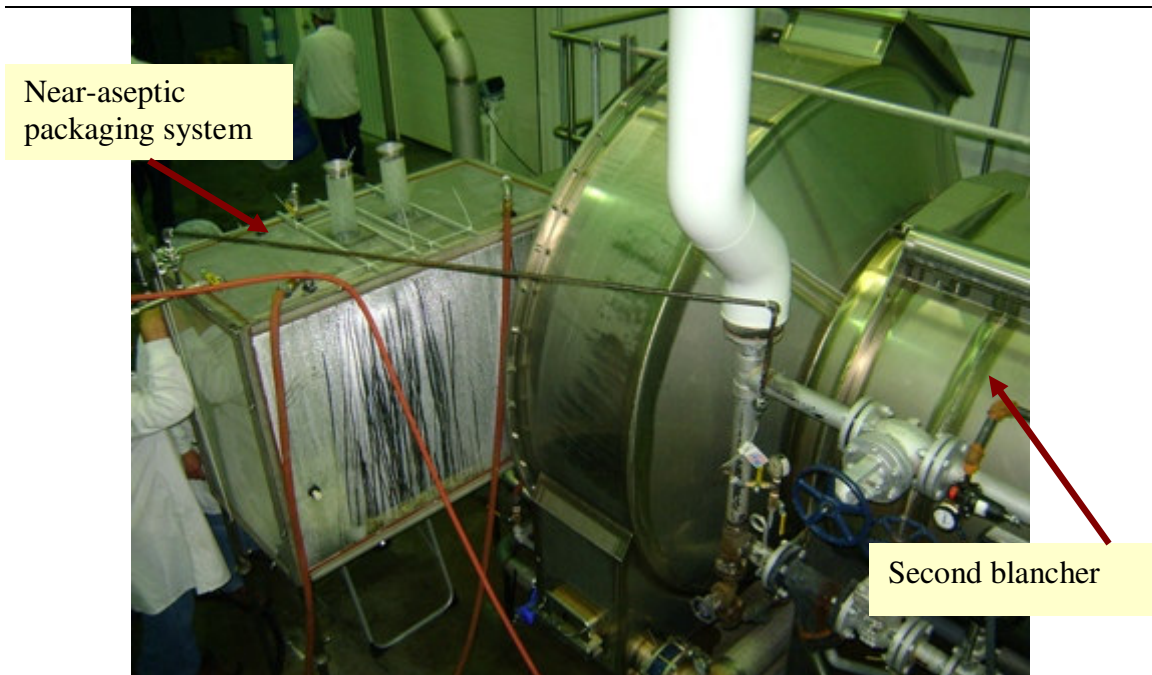


Figure A.1. Near-aseptic packaging of potato strips in commercial processing plant.

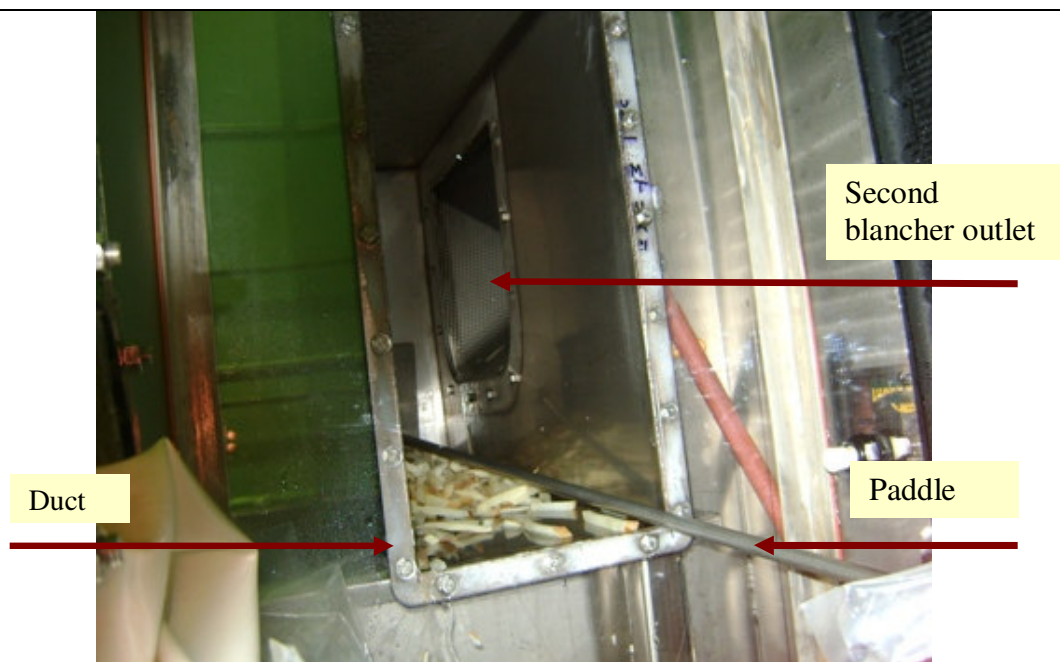


Figure A.2. View of connection from second blancher to packaging chamber. Photograph was taken from packaging chamber so that so that the outlet of the second blancher can be viewed through the connection duct.

There was no significant change in near-aseptically packaged refrigerated potato strips during the first 30 days of storage. Potato strips were white in color, had an odor like freshly blanched potato strips, and there was no sign of break down. However, there was water, about 1 cm deep, in the corner of the bag. After 46 days of storage, color of the most potato samples was generally white but gray color was observed in a few samples and water, about 2 cm deep, was found in the corner of each bag. Furthermore, there was still a pleasant potato odor even though it was not as fresh as at 30 days. After 55 days storage, little additional change was observed. A slight increase in gray color and a little more water were observed, however, the progression was slow. Finally, samples were observed after 61 days of storage. Potato strips were mostly white in color but grayer compared to 7 days stored samples. In addition, all samples had the odor of freshly processed potatoes but it was not as strong as odor of 7 days stored samples. It should be considered that packaging chamber was pilot-plant size, and potatoes were packaged manually. Since large amount of potatoes were processed, proper cooling and drying were not provided and this was likely a cause of the observed water build up.

In conclusion, the shelf-life of near-aseptically packaged refrigerated potato strips processed in commercial environment was extended about 60 days at 2°C based on visual observations. Near-aseptic packaging was thus confirmed be an alternative packaging technique in commercial production of extended shelf-life blanched potato strips for refrigerated distribution.

Appendix B

Quality of Refrigerated Potato Fries Based on Expert Opinion

Optimal quality of potato fries changes varies based on customer preferences and sensory evaluation testing would be beneficial to determine customer opinions about the product. Due to resource limitations, sensory evaluation was not a part of this research project. However, potato fries treated in different blanching conditions were brought to an expert chef to gain such information about the customer preferences in fries. Tests were applied two times.

In the first test, potato strips (9.5x9.5x50 mm, Russet Burbank) treated for two different conditions were investigated.

- 30 min at 60°C in 0.5% CaCl₂ solution followed by 10 min in boiling water (~98°C) (30-10)
- 20 min at 60°C in 0.5% CaCl₂ solution followed by 10 min in boiling water (~98°C) (20-10)

Potato strips were fried in commercial test kitchen at 177°C initial oil temperature for 4 min. Although 30-10 treated fries were judged lighter in color than 20-10 treatments, 20-10 fries were preferred. 30-10 fries were found too light. Furthermore, 11x11 mm cross-section strips were recommended in order to achieve better textural quality.

In the second test, potato strips (11x11 mm, Russet Burbank) representing six different treatments were investigated.

- 20 min at 60°C in 0.5% CaCl₂ solution followed by 10 min in boiling water (~98°C) (30-10)
- 20 min at 60°C in 0.5% CaCl₂ solution followed by 5 min in boiling water (~98°C) (30-5)
- 20 min at 60°C in 0.5% CaCl₂ solution followed by 2 min in boiling water (~98°C) (30-2)
- 10 min at 60°C in 0.5% CaCl₂ solution followed by 10 min in boiling water (~98°C) (20-10)
- 10 min at 60°C in 0.5% CaCl₂ solution followed by 5 min in boiling water (~98°C) (20-5)
- 10 min at 60°C in 0.5% CaCl₂ solution followed by 2 min in boiling water (~98°C) (20-2)

Again, potato strips were fried in a test kitchen at 177°C for 4 min. The best treatment was 10-10, followed by the 20-10 and then the 10-5. Textural quality was reported as the differentiating factor. There was no noticeable color difference between any of the samples; they all had good color. The expert noted that frozen French fries are generally crispier, mostly due to the adjuvants used as a coating. He also noted that many customers would prefer the refrigerated product, even though less crispy, because of the reality or just perception of it as a more natural, lower fat product.

Appendix C

Continuous Near-Aseptic Packaging System for Refrigerated Potato Strips Production

In this research, near-aseptic packaging was determined as an alternative technique to extend shelf-life of blanched potato strips up to 4 weeks without microbial growth. Near-aseptically packaged refrigerated potato strips were processed in lab-scale equipment and provided longer shelf-life and higher quality fries compared to freshly-cut potato fries. Based partly on observation made during the conduct of the research presented herein, Walker (2009) conceptually designed a continuous, near-aseptic packaging system for commercial production. As shown in Figure C.1., potato strips pass through the low and high temperature blanchers and then fall via a discharge conveyor into a dewatering conveyer which also provides cooling. After cooling, potato strips are accumulated and metered by a third conveyor and are then packaged in a near-aseptic packaging chamber.

The blancher will be too hot and the cooler will be too cold for rapid microbial spoilage. However, at a region between, the temperature will be optimal for such growth. It is intended that the entire system be pasteurized at the beginning of the shift. The aim of this study was to determine how frequently the entire system has to be pasteurized in order to prevent microbial contamination.

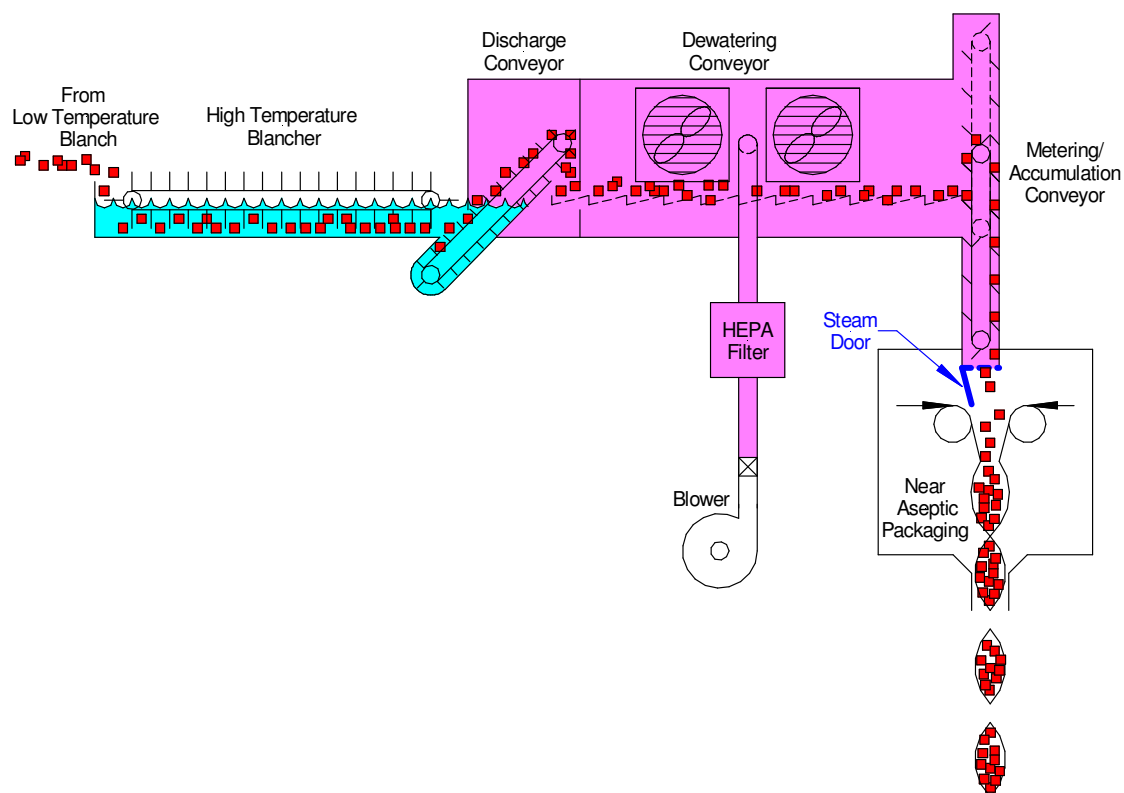


Figure C.1. Conceptual commercial-size near-aseptically packaged refrigerated potato strips processing system (Walker, 2009).

Conceptual commercial-size near-aseptic packaging system was simulated in pilot-scale. Potatoes were cut into ~150 strips, first blanched at 60°C for 10 min in 0.5% CaCl₂ solution, and then second blanched in boiling water for 5 min. These minimal processing times were chosen in order to simulate a worst case scenario. After blanching, potato strips were cooled for 10 min and packaged (5 strips/bag) into Ziploc freezer bags in a near-aseptic environment. Near-aseptically packaged potato strips were kept in the incubator at 30°C for four different time periods (0, 2, 4 and 8 hours). After incubation, near-aseptic strips were stored at 7±1°C for 28 days. There was no microbial spoilage in

any near-aseptically packaged samples based on visual observation. Consequently, warm temperature condition for blanched potato strips was not effective in microbial spoilage. This indicates that continuous near-aseptic packaging system can operate 8 h without re-pasteurization.

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