DE-OILING AND PRE-TREATMENTS FOR HIGH-QUALITY POTATO CHIPS

A Thesis

by

TAE HOON KIM

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2010

Major Subject: Biological and Agricultural Engineering

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Approved by:

Co-Chairs of Committee,	Rosana Moreira
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ABSTRACT

De-oiling and Pre-treatments for High-Quality Potato Chips. (December 2010)

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Co-Chairs of Advisory Committee: Dr. Rosana Moreira
Dr. Maria Elena Castell-Perez

A de-oiling step using a centrifuge ensures oil content reduction and improves the quality of fried snacks. A commercial deep-fat fryer with the basket loaded with potatoes and a sample holder was used to fry potato slices, non-pretreated, blanched in hot water (85°C/3.5min) and rinsed in 3% NaCl solution (25°C/5min). A de-oiling step (350±1 rpm and 457±1 rpm) for 1 min was conducted after the frying (145°, 165° and 185°C or 165°C) and cooling (0, 15, 30, 45 and 60 s or 0.60 and 120 s) steps.

Lower frying temperature, higher centrifuge speed, and shorter cooling time resulted in the lowest oil uptake in potato chips. Pre-treatments (blanching and soaking) decreased (5% and by at least 10%), respectively, compared to the untreated chips.

De-oiling led to increased hardness of the chips fried at 145° and 165°C (0 s cooling time), and the hardness decreased as cooling time. Pre-treatments (blanching and soaking) increased hardness (by 46% and 38%) and decreased work (by 20% and 27%), respectively, so that, during rupture, the pre-treated chips resulted in more crunchiness and firmness than the untreated chips.

Potato chips showed less lightness and redness when fried at 145°C, and more lightness and redness when fried at 185°C; yellowness increased b^* values as

temperature increased. As cooling time increased, the lightness of the chips decreased, and the redness and the yellowness of the chips increased. Pre-treated samples resulted in increasing in lightness (L*) and yellowness (b*), whereas the redness (a*) values of the final products fluctuated.

Higher frying temperature, centrifuge speed, and higher cooling time usually resulted in increasing shrinkage in thickness of potato chips; the chips fried at 165°C resulted in increasing in thickness. All the fried and de-oiled products resulted in a decrease in thickness, diameter, and volume except for the thickness of the chip soaked in NaCl, compared to raw slices.

A consumer test showed that, blanching and de-oiling without cooling enhanced texture and overall quality of the chip, soaking and de-oiling improved the color, flavor, and the overall quality, and the two pre-treatments did not significantly influence the odor of the chip.

DEDICATION

To my parents, Wooyoung Kim and Chanho Cho

It is hard to find any words that

express all my gratitude and my love,

for believing in me, their unconditional support,

patience and love, advice, and willingness to help in any possible way.

Gam-sa-ham-ni-da. Go-mab-seup-ni-da

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CHAPTER I

INTRODUCTION

Currently, saturated and trans-fat are main elements related to causing diseases, and many researchers have conducted studies to reduce or remove the oil content from fried foods. Potato chips are the most popular snacks in the USA. It is of great interest by the processor to produce reduced or non-fat potato chips due to the increase consumer concerns to fried products.

During the frying process of potato chips, moisture content changes from approximately 80% (w.b.) in the raw potato to below 2% (w.b.) in the final product during the 2-5 min time for completion (Gamble et al., 1987). Deep-fat frying of potato slices involves an initial, very short period of heating at high moisture level (causing the gelatinization of starch) followed by a rapid dehydration period to a final moisture content (Ufheil et al., 1995). Oil content in fried foods has been related to pre-frying treatment (Gamble et al., 1987; Moreira et al., 1999), initial moisture content (Gamble et al, 1987; Moreira et al, 1995a), convective drying time in the closed fryer (Sun et al., 1994), and structural changes during frying (Lee, 1991; Rock-Dudley, 1993).

Generally, the oil is not absorbed into the chips during the frying process due to an increase pressure in the pore space. Moreira et al. (1997) observed that during cooling, tortilla chips absorbed about 64% of the total content and 36% remained on the surface of the chips. In addition, during the first 15 s of cooling, the internal oil content increases at a fast rate and then slowly during the next cooling period. Thus, by being able to

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This thesis follows the style of Journal of Food Engineering.

control the cooling using a centrifuge force, we may reduce the oil content from the chips. The centrifuge can reduce oil absorption from the chips' surface during cooling.

One approach is to investigate the synergistic effect of de-oiling process and pre-treatments with blanching in hot water and soaking in NaCl solution. In the commercial production of French fries, blanching helps control the color, the texture and some extent, the flavor of the final product (Agnlor & Scanlon, 2000; Andersson et al., 1994). Also, blanching improves in the reduction of oil adsorption (Smith, 1977). Blanching previous to frying potato chip improved the color and texture, and could reduce in some cases the oil uptake by gelatinization of the surface starch (Califano and Calvero, 1983). Furthermore, the treatment resulted in loss of firmness and other product quality characteristics such as flavor and color (Alvarez et al., 2000).

Soaking potato strips in NaCl solution under the best conditions (3% w/w NaCl concentration and 50 min soaking time) decreased oil uptake and increased hardness of French fries, without changing color, moisture content, and sensory acceptability (Bunger et al., 2003). Longer soaking time and higher NaCl concentrations improved the texture. Potato slices were darker after frying with increase of blanching temperature from 60ºC/5min to 80ºC/5min, for NaCl soaked slices against water-soaked slices (Santis et al., 2007); low blanching temperatures before frying enhanced the color of the potato chips (Santis et al., 2007).

No studies on de-oiling characteristics of potato chips using a centrifuge speed related to atmospheric frying were found in the literature. It is expected that this technique would decrease oil-uptake during cooling thus reducing the oil-uptake of potato chips.

The major goal of this research was to evaluate the effect of a de-oiling technique using a centrifuge force with varying frying temperatures and cooling times. The main hypothesis is that the use of a centrifuge enhances the quality attributes of potato chips including oil content, shrinkage, thickness, color, and texture.

The specific objectives of this research study were:

1. To evaluate the effect of frying temperatures (145 ^{o}, 165 ^{o}, and 185°C) in the de-oiling process
2. To evaluate the effect of centrifuge speed (8.1 and 13.8) relative centrifugal force (RCF) for de-oiling in potato chips
3. To evaluate the effect of cooling times (0, 15, 30, 45, 60 s or 0, 60 and 120 s) before de-oiling the potato chips in product quality.
4. To evaluate the effect of two pre-treatments on the chips' quality attributes

   4.1 No pre-treatment served as the control

   4.2 Blanching in hot water (85°C/3.5min)

   4.3 Rinsing in 3% NaCl solution (25°C/5min)

CHAPTER II

LITERATURE REVIEW

2.1 Snack Food

Deep-fat frying is one of the oldest methods to prepare foods with unique texture and flavor. Some of the products produced by deep-fat frying include potato chips, French fries, extruded snacks, doughnuts, fish sticks, and fried chicken products (Moreira et al., 1999).

Sales of snack products have been growing. The world snack food market was estimated at $66 billion in 2003 with baked goods, cookies and crackers, meat snacks, and popcorn accounting for about 22% of these sales (Hodgen, 2004). In 2005, the global savory snacks market generated total revenues of $46.1 billion (Potatopro, 2010). Healthier and low fat products for consumers unwilling to sacrifice the organoleptic properties of their food, are the driving force in the snack industry for developing alternative processing technologies (Mariscal & Bouchon, 2008).

2.1.1 Potato Chips

Potato chips have been a popular savory snack for 150 years. The usage portions of processed potato chips are frozen French fries (32%), table stock (26%), chips and shoestrings (12%), and dehydrated products (10%) (USDA-NAAS, 2009). The sale of potato chips world-wide was about $16.4 billion in 2009 (Potatopro, 2010). Frito-Lay, Inc. is a dominant company in the world market for potato chips and handles over 3.5 million tons of the raw potatoes used to produce chips. The company's potato usage, including those for Baked Lays®, which is one of the pre-formed potato products, is estimated to increase to up to 4 million tons, about half of the world's total (Vreugdenhil et al., 2007).

Potato chips are thin potato slices which are dehydrated by deep fat frying until they contain about 2% (w.b.) moisture content and have an oil content that ranges from 35% to 45% (w.b.) (Garayo & Moreira, 2002; Mellema, 2003). The shelf life of good-quality manufactured potato chips is 10 weeks plus or minus 2 weeks depending on storage temperatures, packaging materials, and/or exposure to direct light (Lusas & Rooney, 2001). Potato chips can be grouped into regular potato chips and fabricated potato chips. Most of the regular potato chips are made from whole fresh potatoes, and fabricated potato chips are made from dried potatoes rather than from whole raw potatoes (Aline, 2001). Dried potato chips are dried in conventional or impingement ovens with no oil to allow for easier control of the color and moisture content of the chips (Lusas & Rooney, 2001).

2.1.2 Healthy Snack Food

The oil uptake during deep-fat frying is one of the most important quality parameters of fried food. Several studies have reported that excess consumption of fat is a key dietary contributor to coronary heart disease, and perhaps breast, colon, and prostate cancers (Browner et al., 1991). If snack food was designed to carry micronutrients, phytochemicals, and vitamins, the snack food could play a major role in dietary improvement, especially in the United States where consumption is high. The industry must seek products designed to create snack foods that are healthful (Shukla, 1994). However, most fried foods still retain significant amounts of fat because the food industry has not yet been able to produce low-fat products with just enough fat to impart the desired quality attributes of deep-fat fried food, such as flavor, texture, appearance, and mouth feel (Bouchon and Pyle, 2004).

2.1.3 Reduced Oil Content Potato Chips

To produce low or no-fat potato chips, non-caloric fat replacements and alternative techniques have been evaluated. Fat plays an important role in determining the four main sensory characteristics of potato food products: (1) appearance (gloss, translucency, color, surface uniformity, and crystallinity), (2) texture (hardness and crispness), (3) flavor, and (4) mouthfeel. In addition, fat influences the physical and chemical properties of the product, and several implications like the behavior of the food product during processing (heat stability, viscosity, crystallization, tackiness, migration, and dispersion), storage stability, chemical stability (rancidity or oxidation), and microbiological stability (water activity and safety) (Roller & Jones, 1996).

Fat replacement is classified into several categories: starch-derived, fiber-based, protein-based, gums, gels and thickeners, emulsifiers, bulking agents, low-calorie fats, fat extenders, synthetic fat substitutes, and combination systems (Roller & Jones, 1996). Two examples include Simplesse® and Olestra ™. Simplesse® is based on a microparticulated protein (whey protein) that mimics fat (Roller & Jones, 1996). Olestra ™, polyester of sucrose, is the synthetic non-caloric fat replacement.

2.2 Potato Characteristics

Potatoes, in the genus *Solanum tuberosum* belonging to the Solanaceae family, have over 3,000 varieties (Rastovsk & Van Es, 1987). They are the fourth most important food crops in the world, after maize, rice and wheat, and are consumed by more than 323 million people (FAOSTAT, 2007).

A potato tuber is composed of approximately 77.5% water and about 22.5% dry matter. Dry matter consists of starch (18.90%), protein (1.95%), ash (.97%), fiber (0.58%) and fat (0.1%) (Smith, 1987). The two major components of starch are amylase (15-21%) and amlyopectin (79-85%) (Schoelles, 1987).

One of the important varietal characteristics of potatoes is the time of maturity. Early maturing varieties are generally produced for the table potato market, while late varieties, which are high in starch content, are destined for processing (Lisinka and Lescszynski, 1989). Fully mature potato tubers, high in dry matter, are highly desirable for potato chipping. As potatoes become mature, they increase in specific gravity (Tablburt & Smith, 1987). The quality of potato chips is significantly dependent on the genetic characteristics of the potato varieties. Cultural and environmental factors modify the genetic control of dry matter content in the varieties. Gould (1995) recommends storing potatoes to be used for chips at a minimum temperature of 10°C and above 90% relative humidity since cooler temperatures might cause conversion of starch to reducing sugars.

Atlantic is the standard variety of potato for chipping due to high yield potential, high specific gravity, uniform tuber size and shape, and excellent color attributes (Marwaha, 1997).

2.3 Deep-fat Frying

Deep-fat frying can be defined as the process of drying and cooking food by contact with hot oil (Moreira et al., 1999). The high temperature results in the evaporation of water, which moves away from the food and through the surrounding oil. Frying oil is then absorbed by the food, replacing the lost water. When the potato slices are submerged in hot oil, moisture is rapidly evaporated in a stream of bubbles and the moisture content reduces rapidly. The dry outer surface provides a diffusion gradient, and the inner moisture is converted to steam causing a pressure gradient. The steam is attracted to selective weakness in the cellular adhesion and escapes through these areas. On the surface of the chips, steam evaporates in a discontinuous manner through a small number of major sites and a larger number of minor sites. Thereafter, the areas surrounding moisture-escape sites lose their hydrophobicity due to the dryness of the areas. As a result, oil may adhere to the slices and place in damaged areas. The outer surface of the slice is the first area to take up oil and has more oil than average since the area has a greater exposed surface in contact with the oil (Gamble et al., 1996).

The purpose of deep-fat frying is to seal the food by immersing it in hot oil so that all the flavors and the juices are retained in a crisp crust. Also, oil imparts nutrients and flavor when entering the food as well as provides a heat transfer medium (Moreira et al., 1999).

During deep-fat frying, heat and mass transfer mechanisms are coupled. Heat transferred from the hot oil to the product surface by convection moves to the center of the food by conduction (Moreira et al., 1999). Heat transfer results in protein denaturation, starch gelatinization, water evaporation, crust formation, and color development. During the process, the temperatures inside a food material are restricted to values below the boiling point of liquid. Since the liquid in foods is mostly water with some solutes, the boiling point of the liquid inside a food increases slightly above the boiling point of water. As the frying proceeds, more water continues to evaporate from the outer regions of the product and consequently the temperature of the dried regions starts rising above the boiling point (Singh 1995).

Farkas (1994) categorized the frying process into four distinct stages: initial heating, surface boiling, falling rate, and the bubble end-point. During the initial heating stage, which lasts a few seconds, the surface temperature of food in the oil reaches the elevated boiling point of the liquid. The mode of heat transfer between the food and the oil is natural convection. During the surface boiling stage, which is signaled by the vaporization of water, the convective mode of heat transfer varies from natural to forced convection due to the presence of considerable turbulence in the oil surrounding the food. During this stage, the crust starts forming on the surface of the food. During the falling rate stage, where more internal moisture evaporates, the internal core temperature reaches the boiling point. In addition, several physicochemical changes, such as starch gelatinization and cooking, occur in the internal core region. After adequate time, the evaporation rate at the surface of the food decreases, signaling the end of the stage. During the bubble end-point stage, no more bubbles are observed escaping from the surface of the food. A negligible amount of water remains in the crust region and its temperature is much higher than the boiling point of water.

The temperature profiles in the core region are unaffected by the oil temperature due to the presence of a boundary at a slightly elevated boiling point of water. The thermal conductivity and specific heat of the core material influences the heating rates of the core region. The final moisture content of the fried product is strongly influenced by the moisture diffusivity of the material. The crust thickness is attributed to the thermal conductivity of the crust, oil temperature, moisture content, and the thermal conductivity of the core region. An increase in the oil temperature causes increased crust thickness (Singh, 1995).

During commercial deep-fat frying, the major chemical reaction that takes place is hydrolysis a result of interactions between the food and the oil. Vapor reacts with triglycerides to form free fatty acids, monoglycerides, diglycerides, and glycerol. The free fatty acids cause the oil and the fried product to develop off flavors (Moreira et al., 1999). Degradation of frying oil occurs as a result of food materials leaching into the oil, water vapor condensing in the oil, thermal breakdown of the oil, and oxygen absorbed at the oil-air interface (Singh, 1995). These materials influence the heat transfer at the oil-food interface, and reduce the surface tension between the two immiscible materials. These materials are also considered surfactants, like a wetting agent. As the oil degradation continues, more surfactants appear, causing increased contact between the food and oil (Moreira et al., 1999), resulting in excessive oil absorption and an increased rate of heat transfer to the surface of the food (Blumenthal, 1991).

2.4 Post-frying Cooling

It has been established that the largest portion of oil that ends up in the food, is absorbed into the porous crust region once the fried product is removed from the oil baths, stressing the importance of this time interval. The immersion frying period was described by a transient moving-front model that illustrated the movement between the crust/core interfaces, while post-frying cooling oil absorption was considered to be a pressure driven flow mediated by capillary forces (Moreira and Barrufet, 1998). Moreira, Sun, & Chen (1997) studied the oil content on the surface and in the core of tortilla chips to determine the oil distribution during frying and cooling. They observed that during frying only 20% of the oil was absorbed by the chips, and 80% remained on the chip's surface. During cooling, the chips absorbed about 64% of the total oil content, and 36% remained on the chips' surface. Therefore, the cooling period is a very important factor that determines the final oil content of the product.

2.5 De-oiling Process Using a Centrifuge

During frying, the fried products are at high temperature and pressure; therefore, oil is not absorbed. When the freshly fried chips are removed from the oil bath, most of the oil remains on the surface and oil is absorbed by the chip as it cools until the equilibrium of temperature gradients is reached (Moreira et al., 1999). A method using a de-oiling centrifuge removes surface oil and de-oils the freshly fried chips resulting in very low oil content in the final product. During this process, the centrifugal force acts perpendicularly to the surface of the chips and separates the oil directly from the porous surface (Pandey, 2009).

Centrifugal separation of an immiscible liquid/solid, liquid/liquid, or solid/solid relies on the effect of gravity on the product/media. Every material has its own specific gravity, which on application of rotational force (centrifugal force outwards) may part, relying on its material specific gravity. In other words, the net force on the oil at the product surface is a balance between gravity and centrifugal force. As the centrifugal force increases as angular momentum or the rotational speed increases, the distance from the rotational axis plays a very important role in the development of the g-forces (Pandey, 2009). The component with a different specific gravity separates from the media when the applied centrifugal force is greater than the gravitational force (Earle, 1983).

The centrifugal force on a material rotating in circular motion is written:

$$F_c = m \times r \times w^2 \tag{2.1}$$

where, F_c is the centrifugal force [N] acting on the particle to continue moving it in a circular path, r is the radius [m] of the path, m is the mass [kg] of the material, and ω is the angular velocity [rad/s] of the material. Since $\omega = v/r$, where v is the tangential velocity [m/s] of the material, Eqn. 2-1 can be denoted as:

$$F_c = \frac{m \times w^2}{r} \tag{2.2}$$

Rotational speeds are normally expressed in revolutions per minute, so that Eqn. 2-1 can also be denoted, as $\omega = 2\pi N/60$ (as it has to be in s^{-1}, divided by 60):

$$F_c = m \times r \times \left(\frac{2\pi N}{60} \right)^2 \quad (2.3)$$

$$F_c = 0.011 \times m \times r \times N^2 \quad (2.4)$$

where N is the rotational speed in [rev/min].

Eqn 2-4 is compared with the gravitational force and $F_c = F_g$, then

$$F_g = m \times g \quad (2.5)$$

$$m \times g = 0.011 \times m \times r \times N^2 \quad (2.6)$$

$$g_c = 0.011 \times r \times N^2 \quad (2.7)$$

The centrifugal force is often expressed for comparative purposes as so many "g_s" (Earle, 1983).

2.6 Physical and Quality Characteristics

2.6.1 Oil Content

Oil content is a critical attribute of product quality for fried products, and methods to reduce oil uptake while maintaining other quality assessments have been studied in the frying process. Frying is the process in which the frying oil partially replaces the internal water in cells that evaporates as the cells are dehydrated (Moreira and Barrufet, 1996).

Oil absorption is primarily a surface phenomenon introduced by a balance between adhesion and oil drainage on removal of the food from the hot oil (Ufheil and Escher, 1996). According to Keller, Escher, & Solms (1986), oil deposit on French fries is strictly limited to the surface and the outermost layers of cells of the potato sticks during frying. There is no diffusion toward the center, even after prolonged frying. These results suggest that oil is absorbed from the surface during the post-frying cooling step. When the food is quickly removed from the fryer and while the temperature is continuously rising, only 15% of the oil is absorbed into the food, while the remainder is located on the surface (Matz, 1993). Moreira et al. (1997) observed that most of the oil penetrates into the structure of a tortilla chip during the post-frying cooling period. In other words, only 20% of the oil is absorbed during the immersion period, whereas 64% of the total oil content is absorbed during post-frying cooling. They suggest that oil absorption is related to capillary pressure differences as described in the percolation theory.

Kawas et al. (2000) found that tortilla chips fried in oil with a high temperature had higher internal oil content during frying and cooling, probably since the pressure gradient inside the chip’s pores was greater once the chips were immersed in the oil. Also, pore size distribution, developed during frying of tortilla chips, was observed to be the main cause for oil absorption during cooling. Small pores, developed in the fine grain tortilla chips, trapped more air during frying, resulting in higher capillary pressure during cooling and, therefore, higher internal oil content. The higher initial moisture content of tortilla chips resulted in higher internal oil absorption during frying and cooling (Kawas, 2000).

Lamberg, Hallstrom, & Olsson (1990) observed that an increased initial surface moisture content of potato chips resulted in an increased oil content in the chips. During frying, oil enters the product through damaged areas on the chip's surface, which has lost their hydrophilic nature. Vapor developed in the chips escapes through the areas of weakness in cellular adhesion. When most of the water evaporates from the potato chips, temperature also increases and oil uptake rates decrease because of a decrease in the interfacial tension between the oil and the water vapor. Once the products are removed from the fryer, the cooling period begins and the temperature of the chips drops, resulting in a decrease in the pressure in the pores. According to Moreira et al., (1997), as the temperature decreases during cooling, the surface tension between the oil and the air inside the chip's pore increases, resulting in an increase in capillary pressure. Therefore, the surface oil is absorbed into the porous chips so that its internal oil content increases.

Baumann & Escher (1995) investigated the effect of initial moisture content, slice thickness (0.8-1.6 mm), and oil frying temperature (150°, 160°, 170°, and 180°C) on potato chip oil content. The less initial moisture matter, the less drying time is needed to reach the desired final moisture content. Increasing initial moisture content results in a higher oil content based on the wet weight of chips, thus potato slices with high initial dry matter absorb less oil within the same frying time. The relative change in the drying curve is fairly proportional to the reciprocal value of the thickness of the potato slices. The ratio of surface to volume and the specific surface for oil absorption decreases as the thickness of the potato slice increases. Increase in thickness leads to a decrease in oil uptake, however, it shows a non-linear relationship. In other words, there is a larger increase in fat content between 0.8 and 1.2 mm than between 1.2 and 1.6 mm. Drying is accelerated with increasing oil temperature since higher oil temperatures lead to a faster development of a solid crust and with this to surface properties that are favorable for oil absorption. However, its acceleration from 150° to 160°C is faster than from 170° to 180°C. Baumann and Escher (1995) concluded that deep-fat frying of potato slices is influenced primarily by oil temperature, slice thickness, and initial dry matter content of potatoes, resulting in higher oil content with increasing oil temperature, increasing initial moisture content, and decreasing slice thickness.

Kawas et al. (2002) emphasize the importance of pore size distribution for oil absorption of tortilla chips during the cooling period. In other words, the smaller the pores in the chips, the more air is trapped during frying, and higher capillary pressure during cooling results in higher internal oil content. Bouchon et al. (2003) found that only a small amount of oil is absorbed as structural oil during the immersion period due to the vigorous escape of water vapor against oil migration into the porous structure. After cooling, oil was located either on the surface of the chip or sucked into the porous crust microstructure.

Pre-treatment changes the cell membranes, which play a key role in the changes that occur within the tissue during further processing (Boukkamp, 1985; Taiwo, Angerbash, Ade-Omowaye, & Knorr, 2001). Blanching reduces oil absorption of fried potatoes by gelatinizing the surface starch, while air dehydration also leads to reduced oil absorption (Krokida et al. 2001). Osmotic pre-treatment of potatoes by immersion, an alternative to air drying, is used primarily for a partial dehydration effect on materials through removal of a large portion of the contained water (Krokida et al., 2001).

Osmotic dehydration is a technique used to eliminate water from fruits and vegetables by immersing the solid food, whole or in pieces, in aqueous sugar or salt solutions at high osmotic pressure. During this process, water flows out of the product because of the water and solute activity gradients across the cell's membrane (Torreggiani, 1993). Soaking potato strips in a NaCl solution before frying has been reported as a simple pretreatment to reduce the oil uptake in French fries; a higher concentration resulted in increasing saltiness and reduced the remaining oiliness of the product (Bunger, Moyano, & Rioseco, 2003). Soaking the solid food in an NaCl solution before frying is a simple pretreatment to control the surface of the potato so that the solute penetrates into the surface preventing water loss by osmotic dehydration (Bunger, Moyano, & Rioseco, 2003).

Gamble et al. (1987b) used microwaves, hot air (49° and 105°C), and freeze-drying before frying to study the final oil content of potato chips. The microwave drying led to a reduction in the final oil content by 20% of the value. The hot air drying led to a reduction of 38-41% in final oil content. Hot air drying did not produce large areas that were oil-free, but eliminated moisture in a more regular pattern than microwave drying, resulting in an even drying effect. Freeze drying increased the final oil content of the potato chips with increasing freeze-drying time. Once the potato slices were fried, the oil deposition was very even, with small droplets of oil in all regions of the chip, a few oil-free areas, and with total oil coverage.

Kawas et al., (2000) showed that the degree of starch gelatinization influences the final oil content in tortilla chips. Freeze-drying of the samples before frying led to no gelatinization of the starch. On the other hand, treating tortilla chips with steam before frying causes the starch granules to swell, resulting in lower oil content.

2.6.2 Texture

Texture is an important quality of fried food products. It is defined as " all the mechanical, geometrical and surface attributes of a product perceptible by means of mechanical, tactile, and, where appropriate, visual and auditory receptors" (Rosenthal, 1999).

Texture is a response to the structural change of products during thermal processing and cooking (Alvarez et al., 2000). Bourne (1982) categorized the methods of measuring the texture of a fried product, according to physical sensations or group of physical characteristics: (1) to arising from the structural elements of the food; (2) sensing by touching; (3) relating to the deformation, disintegration, and flow of food under force; and (4) measuring objectively using functions of mass, time, and distance.

Texture of a food product can be evaluated by instrumental analysis and sensory evaluation. Texture determination by instrumental examination is more accurate, simpler, and is less time consuming (Kayacier & Sing, 2003). The Instron and the Texture Analyzer (Texture Technologies Corp., New York) are usually used for force deformation studies (Kawas-Escoto, 2000).

Hardness is one of the various parameters that can be identified from a texture profile curve, and is defined as the force at maximum compression during the first bite. Popular terms describing hardness include soft, firm and hard (Steffe, 1996).

Fracturability is determined as the first peak of the force vs. the distance curve. Garayo (2001) used a rupture test on potato chips--the same approach used by Kawas (2000), the hardness of the chips was evaluated by obtaining the maximum force at compression (Steffe, 1996).

2.6.3 Color

Color is one of the most significant attributes in food products (Lisinska & Leszczynski, 1989). In the potato processing industry, probably the critical point of quality evaluation is the maintenance of the satisfactory color of chips. Color of fried potatoes is usually defined in the unit $L^*a^*b^*$ which is an international standard to measure color adopted by the Commission International d'Eclairage (CIE) in 1976. L*, a* and b* define the luminance or lightness (0 to 100), the degrees from green to red, and from blue to yellow (-120 to 120), respectively (Papadakis, Abdul-Malek, Kamdem, & Yam, 2000).

Process variables, such as time, oil temperature, oil type, and pre-treatments of the raw materials are expected to influence the color of the fried products (Santis et al., 2007). The color of the chip is the consequence of the nonenzymatic browning associated with the Maillard reaction during frying (Santis et al., 2007). It is the result of reaction of amino acids with the reducing sugars, mainly D-glucose, accumulated during low-temperature storage (Jankowski, Parkin, & Von Elbe, 1997; Marquez. & Anon, 1986; Weaker & Reave, 1975). Vacuum frying, which uses a lower oil temperature, can help decrease the effect of higher temperatures on the color of fried foods. Granda (2005) observed lower values of a*, which is related to the Maillard reactions, when using vacuum frying (-2.718 and 0.309, respectively). Garayo & Moreira (2002) found a higher L*at a vacuum pressure of 3.115 kPa at 140°C frying temperature. The production of lighter colored chips desired by the market often requires some pre-treatment of the sliced potatoes in processing (Krokida, Oreopoulou, Maroulis, &Marinos-Kouris, 2001). Blanching, one of the most important unit operations in vegetable processing helps control the color of the final product (Agnlor & Scanlon, 2000; Andersson, Gekas, Lind, Oliveira, & Oste, 1994).

It is difficult to control the color of the chips because it is determined by many aspects unrelated to heating such as potato storage conditions, potato variety, and maturity of the tubers (Smith, 1975). Reducing and non-reducing sugars accumulate markedly in potatoes stored at low temperatures (Talburt & Smith, 1987). Gould (1995) recommends storing potatoes in the refrigerator at above 90% relative humidity at a minimum temperature of 7°C for French fries and 10°C for fresh potatoes to be made into chips. Excessive browning and the development of off-flavors due to extreme reducing sugar content are not acceptable for processed potato products (Sahin, 2000).

2.6.4 Degree of Shrinkage and Expansion

Shrinkage of biological materials during frying takes place simultaneously with moisture diffusion and thus may affect the mechanism between the moisture removal rate and oil-uptake rate. A study of the shrinkage phenomenon is of importance for a better understanding of drying (Khraisheh, Cooper, & Magee, 1997).

Mittelman, Mizrahi, & Berk (1984) realized that the crust of potato chips started to form as soon as the potatoes were immersed in the hot oil. Water vapor escaped uniformly through the entire surface as very small bubbles during the first stage of the process. As frying continues, the crust becomes thicker, thus creating resistance to the escape of water vapor and reducing the rate of evaporation. Taiwo & Baik (2007) found that sweet potato chips shrink in the radial direction and expand in the axial direction during frying. Bail and Mittal (2005) observed that frying potatoes at a higher temperature resulted in greater shrinkage when fried for the same period.

Kawas et al. (2000) indicated that most diameter shrinkage (9%) of tortilla chips occurred in the first 5 s of frying. In addition, no expansion changes were observed for freeze-dried or steamed-baked tortilla chips. The control chips (tortillas prepared from nixtamalized dry masa flour) expanded in thickness by 10% after 30 s of frying. The thickness increased as a result of crust formation, and gas expansion on the surface caused some bubbles. As frying time increases, the size distribution of pores became more uniform (Kawas et al, 2000). Higher temperature led to faster shrinkage, yet the equilibrium values of thickness were not temperature dependent (Costa, 2000).

Higher drying temperatures better preserve the potato structure due to the faster surface-drying rate causing the outer layers of the material to become rigid, and the volume fixed earlier in drying (Wang & Bennan, 1995). However, a thick crust is not related to overall shrinkage, although this develops earlier in frying at 180°C (Costa, 2000). In French fries, Costa (2000) showed that the shrinkage rate increased with frying temperature and decreased with potato thickness. Temperature did not affect the final product, and volume decreased mainly as a result of moisture loss, except for potatoes with very low water content. At the end of frying, volume increased due to oil uptake and accumulation of trapped water vapor.

CHAPTER III

MATERIALS AND METHODS

To study the effect of a de-oiling process technique on the quality attributes of potato chips (oil content, texture, color, shrinkage) different operating conditions were considered. The experimental design is presented in Tables 3.1 and 3.2.

3.1 Experimental Setup

3.1.1 Potato Preparation

Potatoes (*Solanum tuberosum*) were received from Frito-Lay Inc. (Plano, TX) and stored at 10ºC and 90% relative humidity. Before frying, the potatoes were reconditioned at room temperature (~23^{o}C) for 3-4 days to lower the reducing sugar content before processing. The average moisture content of the potatoes was 73.72+0.62% w.b. (AACC, 1986) and the specific gravity S.G = 1.084+0.001(Gould, 1995b).

Three pre-treatment were used in this study:

(a) Control

The potato slices were peeled and sliced (1.5 mm average thickness) using a Mandolin slicer (Matfer model 2000, France), and then cut to a diameter of 5.08 cm using a cylindrical metal cutter. The potato slices were rinsed in distilled water to prevent color changes due to the Maillard reaction in the chips during frying. The potato chips were then bloated with paper towels and then wrapped in aluminum foil to avoid any moisture loss before further treatments.

(b) Blanching in water at 85°C for 3.5 min (Moyano, 2005)

The rinsed slices were blanched in 5 l of water at 85°C for 3.5 min (potato-to-water ratio ~0.005 w/w). The samples were then bloated with paper towels before frying.

(c) Soaking in 3% NaCl solution at 25°C for 5 min (Pedrichi et al., 2007)

The rinsed slices were soaked in 3% NaCl solution at 25°C for 5 min (NaCl-to-water ratio ~0.03 w/w). The samples were then bloated with paper towels before frying.

Table 3.1: Experimental design – temperature effects – no pre-treatment

FOT* [°C]	**FT [s]**	**CTMP [°C]**	**FMC [w.b.]**	**CS [RCF]**	**CT [s]**
145	300	125	0.02	0	0
145	300	125	0.02	8.1	0
145	300	125	0.02	8.1	60
145	300	125	0.02	8.1	120
145	300	125	0.02	13.8	0
145	300	125	0.02	13.8	60
145	300	125	0.02	13.8	120
165	210	142	0.02	0	0
165	210	142	0.02	8.1	0
165	210	142	0.02	8.1	60
165	210	142	0.02	8.1	120
165	210	142	0.02	13.8	0
165	210	142	0.02	13.8	60
165	210	142	0.02	13.8	120
185	150	157	0.02	0	0
185	150	157	0.02	8.1	0
185	150	157	0.02	8.1	60
185	150	157	0.02	8.1	120
185	150	157	0.02	13.8	0
185	150	157	0.02	13.8	60
185	150	157	0.02	13.8	120

*FOT = frying oil temperature; FT = frying time; CTMP = cooling temperature; FMC = final moisture content; CS = Centrifuge Speed; CT = cooling time. All de-oiling steps were done for 1 min.

Table 3.2: Experimental design – pre-treatment effects

Pre-Treatment	**FOT* [°C]**	**FT [s]**	**CTMP [°C]**	**FMC [%]**	**CS [RCF]**	**CT [s]**
N, B, S	165	210	142	0.02	0	0
N, B, S	165	210	142	0.02	8.1	0
N, B, S	165	210	142	0.02	8.1	15
N, B, S	165	210	142	0.02	8.1	30
N, B, S	165	210	142	0.02	8.1	45
N, B, S	165	210	142	0.02	8.1	60
N, B, S	165	210	142	0.02	13.8	0
N, B, S	165	210	142	0.02	13.8	0
N, B, S	165	210	142	0.02	13.8	15
N, B, S	165	210	142	0.02	13.8	30
N, B, S	165	210	142	0.02	13.8	45
N, B, S	165	210	142	0.02	13.8	60

*FOT = frying oil temperature; FT = frying time; CTMP = cooling temperature; FMC = final moisture content; CS = Centrifuge Speed; CT = cooling time. -N = no pre-treatment; B = blanching in hot water at 85°C for 3.5 min; S = soaked in 3% NaCl at 25°C for 5 min. All de-oiling steps were done for 1 min..

3.1.2 Frying Process

A commercial deep-fat fryer (George Foreman Spin Fryer –GSF026B) was used in this study. The fryer has a capacity of 2.6 l of oil and has a centrifuge system that consists of a basket which rotates at two different speeds. The radius of the basket is about 8.57 cm and the length 7.62 cm. A tachometer (Laser Photo/Contact Tachometer with IR Thermometer - Model RPM Extech Instruments) was used to determine the rotational speed of the centrifuge. The basket can rotate at two speeds (loaded with potatoes and sample holder), 350+1 rpm and 457+1 rpm. The relative centrifugal force (RCF), commonly referred to as "g-force" or "times g", is acceleration constant between centrifuges. Thus, it is much more precise to duplicate a procedure reported using RCF than one using RPMs. The relative centrifugal force (RCF) was calculated as:

$$RCF = 0.000011 \times r \times N^2 \qquad (2.1)$$

where *r* is the radius [8.57 cm– 2.54 cm (radius of the potato slice) = 6.03 cm] of rotation and N is the rotational speed in [rev/min]. Therefore, the RFC values were 8.1 and 13.8 for 350 rpm and 457 rpm, respectively. Figure 3.1 shows the centrifuge dimensions used to calculate RCF.

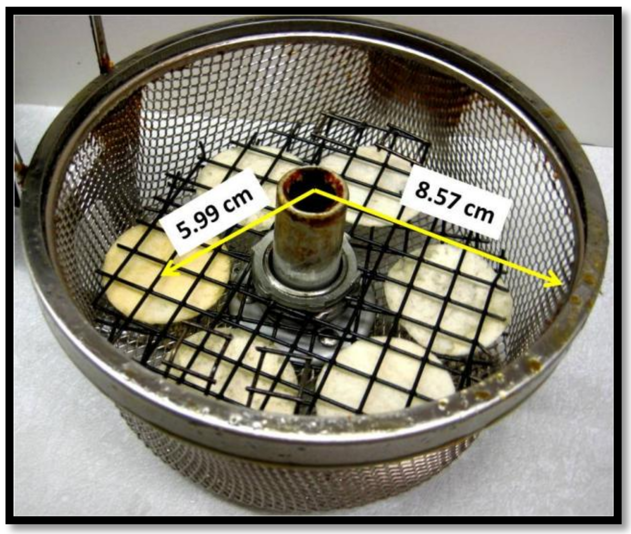

Figure 3.1: Centrifuge dimensions to calculate the relative centrifugal force.

Once the temperature of frying oil (canola) reached the target value, the samples were placed inside a double layer Teflon mesh (25 cm diameter by 15 cm depth) inside the frying basket and then immersed in the hot oil. About 6 slices of potatoes were fried each time. The samples were fried at 145 ^{o}, 165 ^{o}, and 185ºC for 300, 210, and 150 s, respectively, which resulted in final moisture content around 2% (w.b.) (AACC, 1986). The samples were fried at 165ºC for 210 s to determine effect of the pre-treatments on the fried product quality. After the de-oiling process, potato chips were allowed to cool down for 2 minutes at room temperature and the oil on the chips' surface was removed by blotting with paper towels. The samples were then enclosed in zip-lock plastic bags and placed in a desiccator for further analysis. Figure 3.2 shows the different components of the de-oiling process.

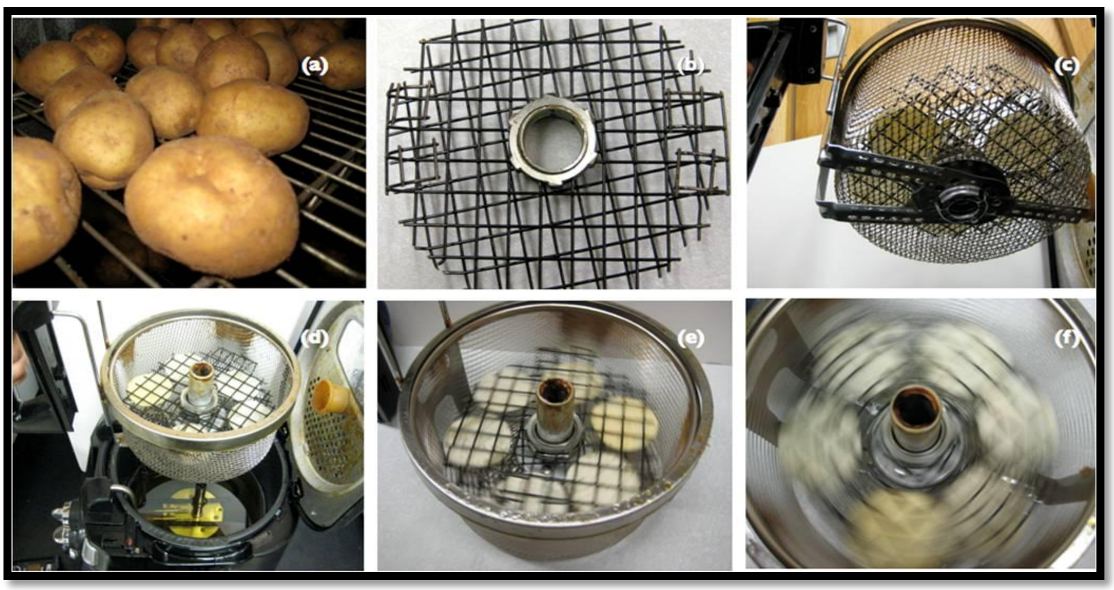

Figure 3.2: (a) Raw potato used for frying; (b) slices holding net; (c) basket with potato slices; (d) basket being placed inside the fryer; (e) potato slices being de-oiled; (f) high speed centrifuge de-oiling the chips.

3.1.3 De-oiling Setup

After the frying process was conducted, the chips, still inside the fryer, but out of the oil, were de-oiled by a centrifuge process (8.1 and 13.8 RCF) for 60 s after cooling the product for 0, 15, 30, 45, 60 s, and 120 s in the fryer.

3.1.4 Analytical Methods

3.1.4.1 Moisture Content of Raw Potatoes

Potato tubers have noticeable variability in moisture content. The initial moisture content of the raw potato was determined by weight loss after drying 5g of chopped samples for 72 hours at 105°C (AACC, 1986). The experiments were done at least in triplicate.

3.1.4.2 Moisture Content of Potato Chips

Potato chips were ground and the moisture content determined by weight loss after drying 5g of ground chips for 24 hours at 105°C (AACC, 1986). The test was done at least in triplicate. Moisture content on wet basis (MC_{wb}) was be defined as:

$$MC_{wb} = \frac{\text{mass of water [kg]}}{\text{mass of product [kg]}} \times 100 \tag{2.2}$$

and moisture content on a dry basis (MC_{db}) was be defined as:

$$MC_{db} = \frac{\text{mass of water [kg]}}{\text{mass of dry matter [kg]}} \times 100 \tag{2.3}$$

3.1.4.3 Oil Content

Total oil content of potato chips was measured by using a Soxtec System HT (Pertorp, Inc., Silver Spring, Maryland) extraction unit with petroleum ether (AACC, 1986) by measuring the weight differences as:

$$OC = \frac{W_2 - W_1}{W_i} \times 100 \tag{2.4}$$

where OC = oil content (% w.b.), W_i = initial weight of aluminum cup (g), W_1 = weight of aluminum cup with extracted oil(g), and W_2 = initial weight of sample (g). The test was done at least in triplicate.

3.1.5 Product Characteristics in Frying

3.1.5.1 Shrinkage

The direct measurements of the potato chips dimensions were used in obtaining the degree of shrinkage (Kawas & Moreira, 2001):

$$D_i = \frac{D_o - D(t)}{D_o} \times 100 \tag{2.5}$$

$$L_i = \frac{L_o - L(t)}{L_o} \times 100 \tag{2.6}$$

where D_0 (diameter) and L_0 thickness are the original dimensions of the raw potato slices (m) and $D(t)$ and $L(t)$ are the dimensions of the sample at time t in (m), and D_i and L_i are the % changes in small diameter, large diameter, and thickness respectively. Degree of shrinkage in volume (S_v), was evaluated by:

$$S_v = \frac{V_o - V(t)}{V_o} \times 100 \tag{2.7}$$

where V_0 is the original volume of the sample (m^3) and $V(t)$ is the volume (m^3) of the sample at time t. The volume of the sample at any given time can be calculated by:

$$V = \frac{\pi D^2 L}{4} \tag{2.8}$$

The diameter (*D*), and thickness (*L*) of samples were measured with a digital caliper (Instant SAE-Metric Conversion). Fifteen samples were taken to determine shrinkage for each batch.

3.1.5.2 Color

The color of the potato chips was measured using a Hunter Lab Colorimeter Labscan XE (Hunter Associates Laboratory, Reston, VA). The colorimeter records and interprets readings in *L-a-b* Hunter Scale using the Universal Software. The Commission Interpretation de l'Eclarirage (CIE) 1976 *L*a*b** Scale is the standard scale to indicate color readings. *L* and *L** values exhibit lightness with a range of zero for black to 100 for white as the human eyes recognize the intensity of light. The *a* and *a** values describe red-green chromaticity and *b* and *b** measures yellow-blue chromaticity of the sample. A white calibration plate was used to standardize the colorimeter, and the samples were placed against the same background to measure the color value in a glass plate. Fifteen samples were taken to measure color by rotating the chip with a 180°angle.

3.1.5.3 Texture

A rupture test was performed on potato chips obtained at different treatments using a TA-XT2 Texture Analyzer (Texture Technologies Corporation, Scarsdale, New York). The test was conducted applying a direct force using a ¼" ball prove to a sample placed at the base of an 18 mm hollow cylinder. The instrument setting was maintained with 10 mm/s of test speed, 5.0 mm of rupture test, 0.666N of force and 10 points/second in resolution. The peak force value of each sample through the rupture test was recorded to measure hardness and work, defined as the force (N) at maximum compression and area under the curve before rupture, respectively. Fifteen samples were taken for the experiment. Tests were conducted at room temperature.

3.1.5.4 Sensory Analysis

Sensory evaluation of potato chips was achieved with a 30-member consumer panel (randomly selected faculty, students, and staff) at Texas A&M University. The quality attributes evaluated were color, odor, texture, flavor, and overall quality. Panelists scored the samples using a nine-hedonic scale (Meilgaard and others 1999), where a score of 1 represented attributes most disliked and a score of 9 represented attributes most liked. Scores higher or equal to 5 were considered acceptable. Five different kinds of potato chips, both pretreated before frying and de-oiled by a centrifuge process (8.1 and 13.8 RCF) for 60 s after cooling down for 0, 30 and 60 s was evaluated. Pre-treatment methods were classified as non-pretreatment, blanching in hot water (85°C/3.5min), soaking in 3% NaCl solution (25°C/5min), respectively for each treatment. The samples in capped-glass-labeled containers were served to each panelist at once. The containers were coded with a random three digits number to identify the sample.

3.2 Statistical Analysis

Data analysis was performed using SPSS software for Windows, v. 11.5.1 (SPSS, 2002). The effect of frying temperature, cooling time, and centrifuge speed were evaluated. Differences between variables were tested for significance by one-way ANOVA. Significant different means ($P \leq 0.05$) were separated by the Tukey test.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Oil Absorption of Potato Chips

4.1.1 De-oiled Chips without Pre-treatment

Figure 4.1 and Table 4.1 represent the oil content of potato slices fried at different conditions (cooling temperatures, centrifuge speeds, and cooling times). Potato chips without de-oiling were considered controls. Oil uptake was influenced significantly ($P>0.05$) by the centrifuge speed and cooling time. Higher centrifuge speed and 0 s cooling time usually resulted in the lowest oil uptake in potato chips (0.17±0.01 w.b). Frying at higher temperature (185^{o}C) and de-oiling at low centrifuge speed (8.1 RCF) resulted in the highest oil uptake values (0.44±0.01 w.b).

Most oil-uptake happens during cooling (Moreira and Barrufet, 1998). Once most of the moisture evaporates from the chips, the temperature of the chips begins to increase, and the rate of oil absorption decreases due to decreasing interfacial tension and capillary pressure. Once the chips are removed from the fryer, the chips start cooling and as the temperature of the chips decreases the pressure within the pore space decreases. In addition, as the temperature is reduced, the interfacial tension between oil and air increases and the oil on the surface begins to flow rapidly into the porous chip resulting in an increase in the internal oil content of the chips.

Gamble et al. (1987) thought oil entered the slice during frying, and the oil was pulled into the slice due to condensation of steam producing a vacuum when the chips

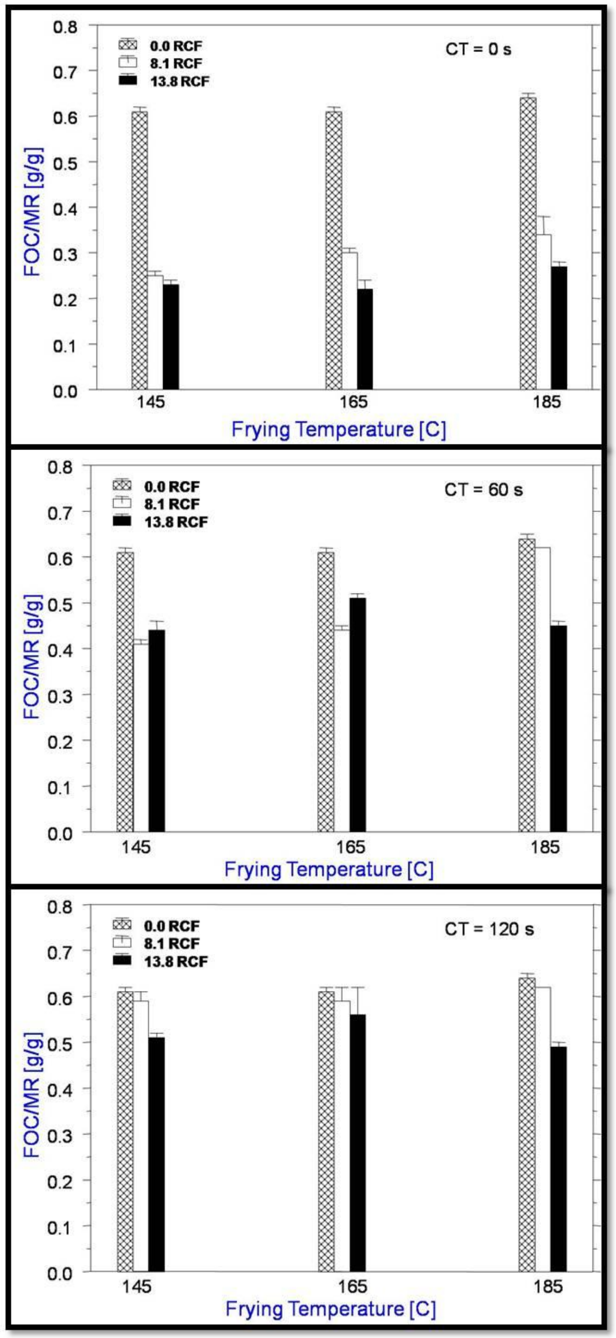

Figure 4.1: Final oil content/moisture removed for potato chips (without pre-treatment) fried at different temperatures, and de-oiled under various centrifuge speeds for (a) 0 s cooling time; (b) 60 s cooling time; and (c) 120 s cooling time.

were removed from the fryer. Moreira, Sun, & Chen (1997) noted that during frying, tortilla chips absorbed only 20% of the oil and 80% stayed on the chip's surface. They also observed that during cooling the chips absorbed 64% of the total oil content, and the rest of it remained on the chip's surface. According to Kawas et al. (1995), tortilla chips absorb about 34% of the total oil content (i.e., 9.5 ± 0.2% w.b.) during frying, and about 69% of the total oil (i.e., 17.6 ± 0.2% w.b.). The rest (8.9% w.b) of the oil remains on the chip's surface. For foods like French fries, a major reduction of frying oil is accomplished by immediate drainage of the fried product after removal from the frying medium, i.e. by shaking (Mellema et al., 2003). Therefore, the outer edge of the slice is the most susceptible in substituting oil for moisture during both the frying and cooling periods. In this study, it was that the de-oiling process, using centrifuge, would efficiently help reduce oil uptake on the surface of the chips by promoting an immediate drainage of oil.

According to Gamble et al. (1987), the moisture loss and the oil uptake are interrelated and linear functions of the square root of the frying time. To adequately explain the effect of moisture loss and oil uptake in this study, the final oil content of chips divided by moisture reduction (FOC/RM) was calculated (Table. 4.1). The final oil content of the chips with respect to moisture reduction from the raw slices (FOC/RMI) had slightly greater values than the final oil content of the chips with respect to moisture reduction from the rinsed slices (FOC/RMR) as is shown in the APPENDIX since the slices absorbed the moisture during rinsing. In this study we used the FOC/RMI results were used to analyze the process and it is referred as FOC/RM.

Table 4.1 Effect of frying oil temperature, centrifuge speed, and cooling time on the oil content of potato chips processed without pre-treatment.

T_{oil} (°C)	CS (RCF)	CT (s)	IMC (w.b.)	FMC (w.b.)	FOC (w.b.)	FOC/RMI (g/g)
145	0	0	0.72±0.00	0.02±0.00	$_{a}$0.43±0.00 ^{a}	$_{a}$0.61±0.01 ^{a}
145	8.1	0	0.73±0.00	0.02±0.00	$_{a}$0.17±0.00 ^{b}	$_{a}$0.25±0.01 ^{b}
145	8.1	60	0.70±0.00	0.02±0.00	$_{a}$0.28±0.01 ^{c}	$_{a}$0.41±0.01 ^{c}
145	8.1	120	0.72 ±0.01	0.02±0.00	$_{a}$0.41±0.02 ^{d}	$_{a}$0.59±0.02 ^{d}
145	13.8	0	0.77±0.04	0.02±0.00	$_{a}$0.17±0.00 ^{b}	$_{a}$0.23±0.01 ^{e}
145	13.8	60	0.75±0.03	0.02±0.00	$_{a}$0.32±0.00 ^{e}	$_{a}$0.44±0.02 ^{f}
145	13.8	120	0.78±0.01	0.02±0.00	$_{a}$0.39±0.00 ^{f}	$_{a}$0.51±0.01 ^{g}
165	0	0	0.75±0.01	0.02±0.00	$_{b}$0.44±0.00 ^{a}	$_{a}$0.61±0.01 ^{a}
165	8.1	0	0.69±0.00	0.02±0.00	$_{b}$0.20±0.00 ^{b}	$_{b}$0.30±0.01 ^{b}
165	8.1	60	0.75±0.00	0.02±0.00	$_{b}$0.32±0.00 ^{c}	$_{b}$0.44±0.01 ^{c}
165	8.1	120	0.74±0.00	0.02±0.00	$_{a}$0.42±0.02 ^{d}	$_{a}$0.59±0.03 ^{d}
165	13.8	0	0.73±0.00	0.02±0.00	$_{b}$0.16±0.01 ^{e}	$_{a}$0.22±0.02 ^{e}
165	13.8	60	0.72±0.00	0.02±0.00	$_{b}$0.36±0.01 ^{f}	$_{b}$0.51±0.01 ^{f}
165	13.8	120	0.75±0.00	0.02±0.00	$_{a}$0.41±0.04 ^{d}	$_{b}$0.56±0.06 ^{g}
185	0	0	0.76±0.00	0.02±0.00	$_{c}$0.47±0.01 ^{a}	$_{b}$0.64±0.01 ^{a}
185	8.1	0	0.75±0.00	0.02±0.00	$_{c}$0.25±0.03 ^{b}	$_{c}$0.34±0.04 ^{b}
185	8.1	60	0.76±0.00	0.02±0.00	$_{c}$0.46±0.00 ^{c}	$_{c}$0.62±0.00 ^{c}
185	8.1	120	0.72±0.00	0.01±0.00	$_{b}$0.44±0.00 ^{d}	$_{c}$0.62±0.00 ^{d}
185	13.8	0	0.74±0.00	0.02±0.00	$_{c}$0.19±0.00 ^{e}	$_{c}$0.27±0.01 ^{e}
185	13.8	60	0.73±0.00	0.02±0.00	$_{a}$0.32±0.01 ^{f}	$_{c}$0.45±0.01 ^{f}
185	13.8	120	0.74±0.00	0.01±0.00	$_{a}$0.35±0.01 ^{g}	$_{c}$0.49±0.01 ^{c}

Tests were performed in triplicate.
a-gMeans within a column with different superscript letters are significantly different ($P<0.05$) a-cMeans within a column with different subscript letters are significantly different ($P<0.05$)
Toil = oil temperature, CS = Centrifuge Speed, CT = cooling time, IMC = initial moisture content, FMC = final moisture content, FOC = final oil content and FOC/RMI = final oil content/moisture removed from IMC. 0 s cooling = no cooling time, a no cooling allowed in right after frying.

4.1.1.1 Effect of Frying Temperature

Figure 4.1 shows that FOC/RM usually increases as frying temperature increases for 0 s cooling. Due to the greater pressure gradient inside the chip's pores, the potato chip fried in oil with a higher temperature led to higher internal oil content. As expected, increasing the frying temperature and increasing the centrifuge force usually resulted in decreasing values of the FOC/RM (Fig. 4.1a and 4.1c). Unexpectedly, the potato chips fried at 145° and 165°C, cooled for 60 s, and de-oiled at 8.1 RCF had less value of FOC/RM than the chips de-oiled at 13.8 RCF (Figure 4.1b). In this case, the de-oiling process at 13.8 RCF would promote decreasing the temperature of the chip's pores due to cooling by rotation so that oil uptake accelerated, compared to chips de-oiled at 8.1 RCF. On the other hand, Yamsaengsung et al. (2002b) observed that the higher frying temperature led to a faster drying rate and a faster increase in the temperature and pressure of the product. They found also that even though the chips fried at a higher temperature results in a larger crust, it had lower total oil saturation. Therefore, the early crust formation of potato chips fried at 185°C inhibited oil uptake, which was attributed to cooling itself during de-oiling in this study.

4.1.1.2 Effect of Centrifuge Speed

The de-oiling process using a centrifuge may reduce the movement of oil from the surface into the inner parts of the chips because of the pressure gradient in the chip's pore. The centrifuge may also force the surface oil out of the slices. As expected, increasing the centrifuge force usually decreased the values of FOC/RM (Fig. 4.2a -

4.2c). However, the values of FOC/RM for the chips de-oiled at 13.8 RCF and fried at 145° and 165°C for 60 s of cooling (Fig. 4.2b) showed larger values than those for the chips de-oiled at 8.1 RCF. It is proposed that the de-oiling process at 13.8 RCF would promote the decrease of the temperature of the chips due to cooling by rotation of the chips, which resulted in the acceleration of oil uptake compared to de-oiling at 8.1 RCF.

At 120 s cooling time (Fig 4.2c), the FOC/RMs decreased with increased centrifuge force. The FOC/RMI values in all de-oiling processes, compared to the controls (no de-oiling), decreased for all frying temperatures. However, compared to the control samples, the reduction in FOC/RM values decreased slightly (2-3%) for the chips fried at all frying temperatures and de-oiled at 8.1 RC; and varied between 8%, and 23 % for the chips fried de-oiled at 13.8 RCF.

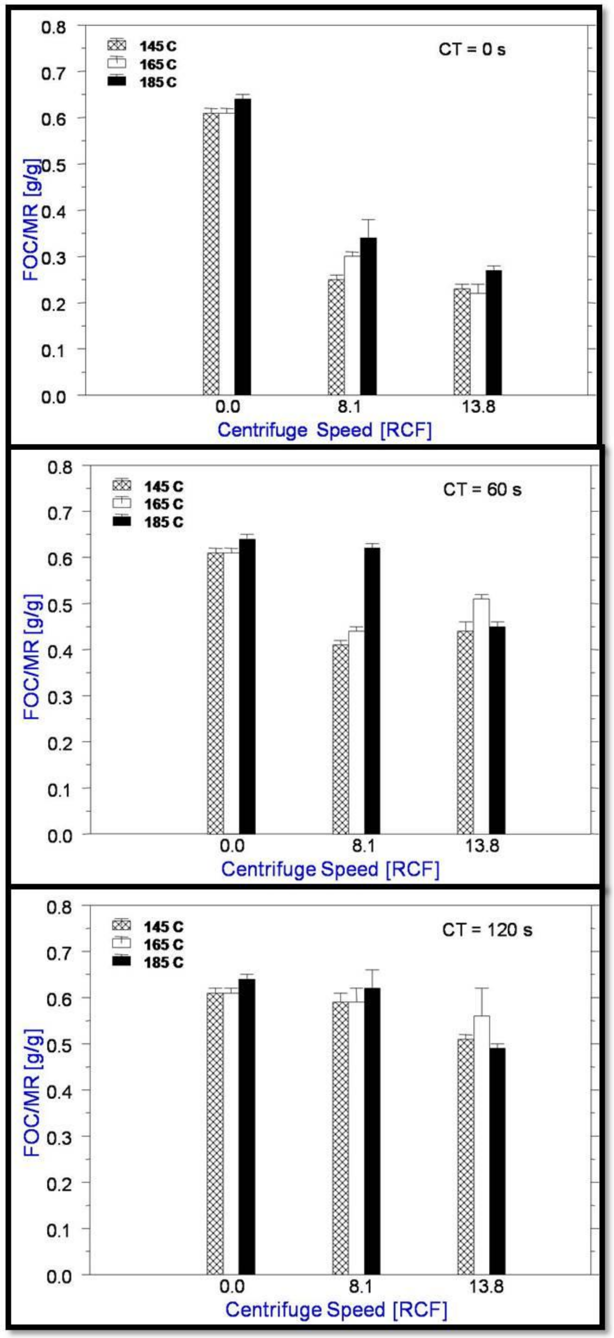

Figure 4.2: Final oil content/moisture removed as a function of the centrifuge speed for potato chips (without pre-treatment) de-oiled under various frying temperatures for (a) 0 s cooling time; (b) 60 s cooling time; and (c) 120 s cooling time.

4.1.1.3 Effect of Cooling Time

Figure 4.3 shows that FOC/MR values increased with increasing cooling time, regardless of centrifuge speed.

Moreira, Sun, & Chen (1997) reported that the internal oil content increased rapidly during the first 15 s of cooling then slowly thereafter in the frying of tortilla chips. The chips might absorb most of the 64% of oil content during the first 15 s of cooling. The rest of the surface oil might migrate continuously after the initial 15 s of cooling time, and 36% of the total oil content might remain on the surface of the chip. In this study, potato chips were cooled in the fryer with the lid cover (the chips were out of the oil). The chips in the fryer were cooled to around 125°, 142°, and 157°C where fried at 145°, 165°, and 185°C, respectively. These cooling temperatures led to a decrease in the pressure gradient and resulted in slowing the oil-uptake rate from the surface. It was difficult to observe the equivalent concept of the first 15 s cooling time in this study since the chips were cooled in the fryer so that the internal oil content increased gradually.

During de-oiling without cooling (Fig. 4.3a – 4.3c), the surface oil did not migrate easily to the inside of the chips since there was not enough residence time to reduce the chips temperature and capillary pressure. As soon as the chips were removed from the oil, the centrifuge forced the removal of the surface oil of the chips. It resulted in less oil content for the chips de-oiled at 13.8 RCF than those at 8.1 RCF. The reduction in FOC/RM values for the chips fried at 165°C and de-oiled at 13.8 RCF and those fried at 185°C and de-oiled at 8.1 RCF from the FOC/RMI values of controls were maximized at 64% and minimized at 47%, respectively (Table 4.1).

For 60 s of cooling time, the FOC/RM values for the chips de-oiled at 8.1 RCF, for all frying temperatures, except at 185°C, were less than those de-oiled at 13.8 RCF (Fig. 4.3a to 4.3c). For the 60 s cooling time, the potato chip would have time to absorb the surface oil due to the temperature gradient (thus capillary pressure) between the pore and ambient. In addition, the de-oiling process at 13.8 RCF would promote decreasing the temperature of the chip's surface during rotation so that oil uptake continued, whereas the de-oiling process at 8.1 RCF did not influence the temperature change and just drained the oil from the surface. Pedrishci et al. (2005) reported that when potato chips were fried at 120°, 150°, and 180°C, the higher frying temperature showed a faster softening of the tissue and hardening of the crust. The crust microstructure development (mean pore size, connectedness, and permeability) resulted in a significant effect in oil absorption (Bouchon, 2004). Most of the oil is limited to the surface of the fried product while the core region is virtually oil-free (Moreira et al., 1997; Aguilera & Gloria, 1997; 1997; Pedreschi et al., 1999; Bouchon & Aguilera, 2001; Bouchon et al., 2001). Therefore, it is expected that potato chips fried at 185°C (Fig. 4.3c) formed a crust faster, compared to potato chips fried at 145° and 165°C so that most of the oil was limited to the surface. Therefore, it agreed that the greater the centrifuge force, the less the oil on the surface of the chip.

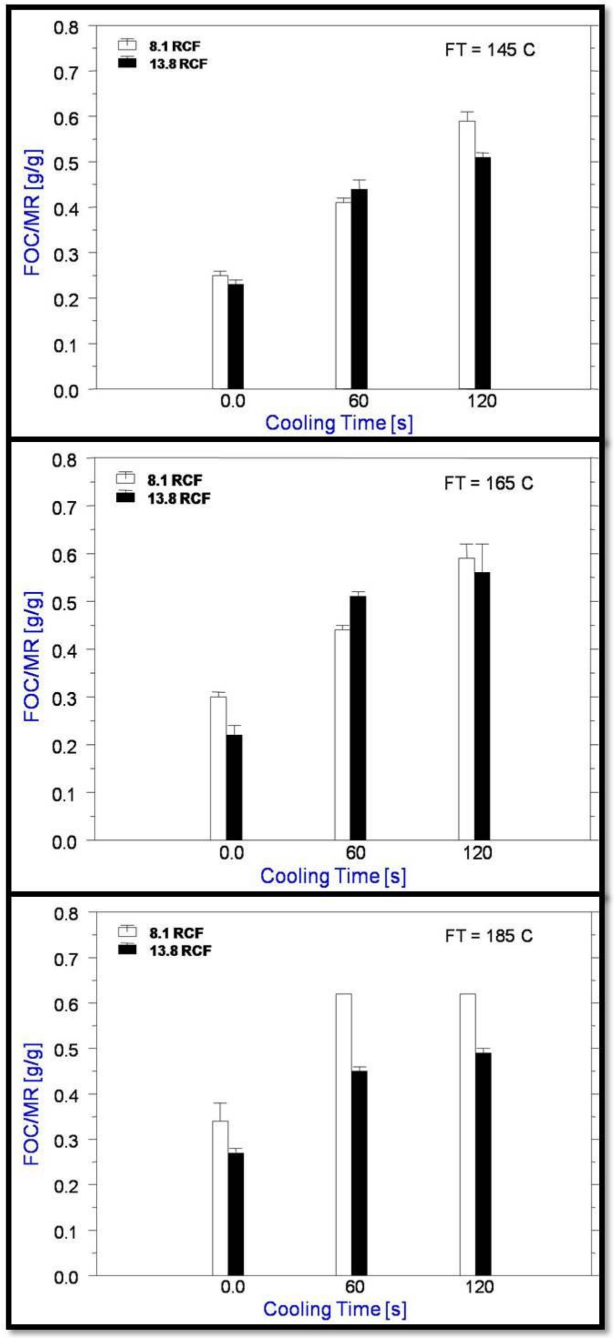

Figure 4.3: Final oil content/moisture removed as a function of the cooling time for potato chips (without pre-treatment) de-oiled under various centrifuge speeds and fried at (a) 145°C; (b) 165°C; and (c) 185°C.

4.1.2 De-oiled Chip with Pre-treatments

Tables 4.2 through 4.4 show initial and final moisture content, final oil content and final oil uptake with respect to moisture removal for fried potato slices under various experimental conditions (pre-treatment, centrifuge speed, and cooling times). Table 2 shows pre-treatment, centrifuge speed, and cooling time influenced significantly ($P>0.05$) oil uptake of the chips. The chips without pre-treatment showed a simple trend in that the higher the centrifuge speed and the less cooling time, the less oil uptake. Pre-treatments improved oil uptake of the chips. The chips blanched in hot water (85°C) (Table 4.3) usually resulted in a slight decrease in oil uptake, compared to the non-pretreated samples. The chips soaked in a 3% NaCl solution (Table 4.4) usually resulted in the reduction of oil uptake by at least 10% compared to the non-pre-treated samples. The two pre-treatments showed temperature decreases through centrifuge speed itself, with the application of cooling time before de-oiling causing the reversal of oil uptake at 13.8 RCF, where FOC/RM values were greater than at 8.1 RCF in specific cooling times.

Figure 4.4a shows oil uptake with respect to moisture removal for no pre-treated samples fried in various experimental conditions (temperatures, centrifuge speeds, and cooling times). Potato chips without the de-oiling process were considered controls.

Moreira, Sun, & Chen (1997) emphasized the cooling period in which to analyze the mechanism of the oil-uptake process in tortilla chips. They found that the internal oil content of the chip increased rapidly during the first 15 s of cooling since starch gelatinizes and moisture evaporates at a fast rate resulting in expansion of the capillary pores. The internal oil content increased slowly thereafter. The chips absorbed 20%, 51.2%

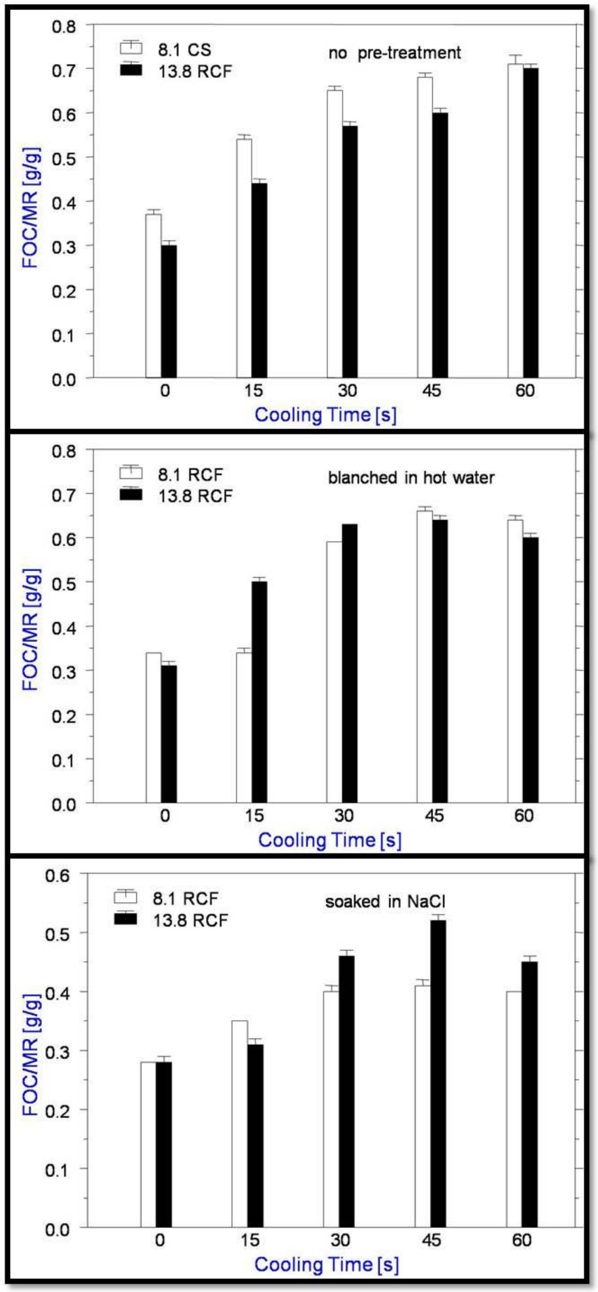

Figure 4.4: Final oil content/moisture removed as a function of cooling time for potato chips fried at 165°C, de-oiled under various centrifuge speeds, and with (a) no pre-treatment; (b) blanched in hot water at 85°C for 3.5 min; and (c) soaked in 3% NaCl solution at 25°C for 5 min.

and 28.8% of the total final oil content inside the chip during frying, cooling, and at the surface of the chips during cooling, respectively. In this study, since the potato chips were cooled inside the fryer (closed lid), we could not observe a fast rate of oil uptake as was done with the tortilla chip experiment.

The reduction in FOC/RM values for the chips cooled for 0 s at 13.8 RCF and for 60 s at 8.1 RCF for the no pre-treated samples were maximized at 62% and minimized at 9%, respectively (Table 4.2). In other words, the chips absorbed less oil with a higher centrifuge and faster cooling time.

4.1.2.1 No Pre-treatment

Table 4.2 Effect of centrifuge speed and cooling time on the final oil content of potato chips fried at 165°C without pre-treatment.

CS (RCF)	CT (s)	IMC (w.b.)	FMC (w.b.)	FOC (w.b.)	FOC/RMI (g/g)
0	0	0.73±0.00	0.02±0.00	$_{a}$0.56±0.00^{a}	0.78±0.01^{a}
8.1	0	0.73±0.01	0.02±0.00	$_{a}$0.26±0.00^{b}	$_{a}$0.37±0.01^{b}
8.1	15	0.78±0.01	0.02±0.00	$_{a}$0.41±0.01^{c}	$_{a}$0.54±0.01^{c}
8.1	30	0.74±0.00	0.02±0.00	$_{a}$0.47±0.00^{d}	$_{a}$0.65±0.01^{d}
8.1	45	0.75±0.01	0.02±0.00	$_{a}$0.50±0.01^{e}	$_{a}$0.68±0.01^{e}
8.1	60	0.74±0.02	0.02±0.01	$_{a}$0.51±0.01^{f}	$_{a}$0.71±0.02^{f}
13.8	0	0.75±0.01	0.02±0.00	$_{a}$0.22±0.00^{g}	$_{b}$0.30±0.01^{g}
13.8	15	0.75±0.01	0.02±0.00	$_{a}$0.32±0.00^{h}	$_{b}$0.44±0.01^{h}
13.8	30	0.74±0.01	0.02±0.00	$_{a}$0.41±0.01^{c}	$_{b}$0.57±0.01^{i}
13.8	45	0.75±0.00	0.02±0.00	$_{a}$0.44±0.01^{i}	$_{b}$0.60±0.01^{j}
13.8	60	0.74±0.01	0.02±0.00	$_{a}$0.50±0.01^{d}	$_{a}$0.70±0.01^{k}

Tests were performed in triplicate.
a-gMeans within a column with different superscript letters are significantly different (P<0.05) a-cMeans within a column with different subscript letters are significantly different (P<0.05)
CS = Centrifuge Speed, CT = cooling time, IMC = initial moisture content, FMC = final moisture content, FOC = final oil content and FOC/RMI = final oil content/moisture removed from IMC.

Table 4.3 Effect of centrifuge speed and cooling time on the final oil content of potato chips fried at 165°C and pre-treated by blanching in hot water at 85°C for 3.5 min.

CS (RCF)	**CT (s)**	**IMC (w.b.)**	**FMC (w.b.)**	**FOC (w.b.)**	**FOC/RMI (g/g)**
0	0	0.76±0.00	0.02±0.00	$_{a}$ 0.55±0.00 ^{a}	0.75±0.01 ^{a}
8.1	0	0.74±0.00	0.02±0.00	$_{b}$ 0.24±0.00 ^{b}	$_{a}$ 0.34±0.00 ^{b}
8.1	15	0.73±0.00	0.02±0.00	$_{b}$ 0.24±0.00 ^{b}	$_{a}$ 0.34±0.01 ^{c}
8.1	30	0.75±0.00	0.02±0.00	$_{b}$ 0.43±0.00 ^{c}	$_{a}$ 0.59±0.00 ^{d}
8.1	45	0.74±0.00	0.02±0.00	$_{b}$ 0.47±0.00 ^{d}	$_{a}$ 0.66±0.01 ^{e}
8.1	60	0.71±0.00	0.02±0.00	$_{b}$ 0.44±0.01 ^{e}	$_{a}$ 0.64±0.01 ^{f}
13.8	0	0.74±0.01	0.02±0.00	$_{a}$ 0.22±0.00 ^{f}	$_{b}$ 0.31±0.01 ^{g}
13.8	15	0.72±0.00	0.02±0.00	$_{b}$ 0.35±0.01 ^{g}	$_{b}$ 0.50±0.01 ^{h}
13.8	30	0.72±0.00	0.02±0.00	$_{b}$ 0.44±0.00 ^{e}	$_{b}$ 0.63±0.00 ^{i}
13.8	45	0.72±0.00	0.02±0.00	$_{b}$ 0.44±0.00 ^{h}	$_{b}$ 0.64±0.01 ^{J}
13.8	60	0.72±0.00	0.02±0.00	$_{b}$ 0.42±0.01 ^{i}	$_{b}$ 0.60±0.01 ^{k}

Tests were performed in triplicate. a-gMeans within a column with different superscript letters are significantly different ($P<0.05$) a-cMeans within a column with different subscript letters are significantly different ($P<0.05$) - Toil = oil temperature, CS = Centrifuge Speed, CT = cooling time, IMC = initial moisture content, FMC = final moisture content, FOC = final oil content and FOC/RMI = final oil content/moisture removed from IMC.

Table 4.4 Effect of centrifuge speed and cooling time on the final oil content of potato chips fried at 165°C and pretreated by soaking in 3% NaCl solution at 25°C for 5 min.

CS (RCF)	**CT (s)**	**IMC (w.b.)**	**FMC (w.b.)**	**FOC (w.b.)**	**FOC/RMI (g/g)**
0	0	0.75±0.00	0.02±0.00	$_{b}$0.47±0.01^{a}	$_{c}$0.64±0.01^{a}
8.1	0	0.71±0.00	0.02±0.00	$_{c}$0.19±0.00^{b}	$_{c}$0.28±0.00^{b}
8.1	15	0.77±0.00	0.02±0.00	$_{c}$0.26±0.00^{c}	$_{c}$0.35±0.00^{c}
8.1	30	0.73±0.00	0.02±0.00	$_{c}$0.29±0.00^{d}	$_{c}$0.40±0.01^{d}
8.1	45	0.70±0.02	0.02±0.00	$_{c}$0.28±0.00^{e}	$_{c}$0.41±0.01^{e}
8.1	60	0.71±0.00	0.02±0.00	$_{c}$0.28±0.00^{e}	$_{c}$0.40±0.00^{f}
13.8	0	0.73±0.01	0.02±0.00	$_{b}$0.20±0.00^{f}	$_{c}$0.28±0.01^{b}
13.8	15	0.75±0.00	0.02±0.00	$_{c}$0.23±0.00^{g}	$_{c}$0.31±0.01^{g}
13.8	30	0.76±0.00	0.02±0.00	$_{c}$0.34±0.00^{h}	$_{c}$0.46±0.01^{h}
13.8	45	0.74±0.00	0.02±0.00	$_{c}$0.38±0.00^{i}	$_{c}$0.52±0.01^{i}
13.8	60	0.75±0.01	0.02±0.00	$_{c}$0.33±0.00^{j}	$_{c}$0.45±0.01^{j}

Tests were performed in triplicate.
a-gMeans within a column with different superscript letters are significantly different (P<0.05) a-cMeans within a column with different subscript letters are significantly different (P<0.05)
CS = Centrifuge Speed, CT = cooling time, IMC = initial moisture content, FMC = final moisture content, FOC = final oil content and FOC/RMI = final oil content/moisture removed from IMC.

4.1.2.1.1 Effect of Centrifuge Speed

As expected, all values of the FOC/RM decreased with increased centrifuge speed resulting in the draining of more oil from the surface of the chip (Figure 4.4a). The higher the centrifuge speed, the more oil removal. The chip cooled for 60 s and de-oiled at 8.1 and 13.8 RCF absorbed 71% and 70% of the surface oil, respectively, close to the control of 78%. In other words, once the oil is absorbed into the chip during cooling, it is difficult to remove it.

4.1.2.1.2 Effect of Cooling Time

As cooling time increased, the reduction in oil uptake decreased due to the accelerating pressure gradient resulting from the decreasing temperature of the chip. This resulted in increased oil absorption during cooling (Figure 4.4a). The difference in the oil-uptake reduction between 8.1 and 13.8 RCF decreased as cooling time increased, and at 60 s of cooling the results showed similar values to each other. The chip de-oiled at 8.1 RCF reached FOC/RM equilibrium (68%) at around 45 s of cooling, which was faster than the chips de-oiled at 13.8 RCF, which continued to increase even at 60 s of cooling. If the chips had cooled for longer time, it is expected that the chips de-oiled at 13.8 RCF would had resulted in a higher FOC/MR value than those de-oiled at 8.1 RCF due to the decrease of temperature by the centrifuge itself.

4.1.2.2 Blanching in Hot Water at 85°C for 3.5 min

Figure 4.4 a and Table 4.3 show oil uptake to moisture removal ratio for the chips blanched at 85°C for 3.5 min before frying under various experimental conditions (temperatures, centrifuge forces, and cooling times). Potato chips without the de-oiling were considered controls.

Blanching potato slices prior to frying has been reported to not only improve the color and texture of the final product, but also reduce the oil uptake by causing gelatinization of the starch on the surface (Califano & Calvelo, 1987).

Chips de-oiled at 8.1 and 13.8 RCF for 30 to 45 s had similar FOC/MR values. The oil uptake for the chips processed for 0 s/8.1 RCF was slightly higher than those de-oiled at 13.8 RCF, as expected. However, the trend was reversed due to temperature decrease by the centrifuge itself so that the oil uptake of the chips de-oiled at 13.8 RCF resulted in higher values until between 30 and 45 s of cooling time. The chips de-oiled at 8.1 RCF reached equilibrium (64%) at around 45 s (Table 4.3 and Figure 4.4b). The reduction in FOC/RM values for 0 s/13.8 RCF and 45 s/8.1 RCF from the control samples were maximized at 59% and minimized at 12%, respectively. In other words, the blanched chips also absorbed less oil with a higher centrifuge speed and faster cooling time.

4.1.2.2.1 Effect of Centrifuge Speed

Figure 4.4b shows the effect of centrifuge speed on the FOC/RM of blanched chips fried at 165°C and de-oiled after cooling in the fryer for 0 through 60 s.

As expected, the FOC/MR values usually decreased with increasing centrifuge speed except for the chips cooled for 15 s and 30 s. The centrifuge force at 13.8 RCF influenced the decline of the chip’s temperature resulting in the reduction of the FOC/MR values.

4.1.2.2.2 Effect of Cooling Time

Oil uptake increased with increasing cooling time, as expected (Figure 4.4b). However, between 0 s and 45 s of cooling time, the FOC/RM values for the chips de-oiled at 13.8 RCF were greater than those de-oiled at 8.1 RCF. During the period reaching about 45 s, this trend was reversed, i.e., the higher the centrifuge speeds the less oil uptake. It seems that at a point between 30 to 45 s of cooling time, temperature gradient between inside the pore space and outside was greater so that the slower centrifuge speed of 8.1 RCF resulted in more oil up take.

4.1.2.3 Soaking in 3% NaCl Solution at 25°C for 5 min

Figure 4.4c and Table 4.4 show oil uptake with respect to moisture removal for the chips soaked in 3% NaCl at 25°C in various experimental conditions (temperatures, centrifuge forces, and cooling times). Potato chips without the de-oiling process were considered controls.

4.1.2.3.1 Effect of Centrifuge Speed

Figure 4.4c shows the effect of centrifuge speed on the FOC/RM on chips soaked in a 3% NaCl solution, fried at 165°C, and de-oiled for different cooling times.

Santis el al. (2007) selected the low level of salt concentration (3%w/w) since an appropriate saltiness of the product is of great significance to its overall sensory quality. Soaking potato strips in an NaCl solution before frying has been reported as a simple pretreatment to improve the texture and reduce the oil uptake in French fries (Bunger, Moyano, & Rioseco, 2003). Soaking in a NaCl solution significantly improved oil uptake, which was reduced by 19% at 45 s s/13.8 RCF to 56% at 0 s/13.8 RCF when each value of the FOC/RM was compared to the control. Bunger et al. (2001) explained that soaking potato strips in a NaCl solution before frying is a simple pre-treatment to control their surface so that the solution penetrates into the potato surface and prevents water loss through osmotic dehydration.

As expected, the FOC/MR values increased with increasing centrifuge speed except for the chips cooled for 0 s and 15 s and increased with increasing cooling time. The centrifuge force of 13.8 RCF influenced the decline of the chip's temperature resulting in an increased FOC/MR values.

4.1.2.3.2 Effect of Cooling Time

The FOC/RM values for the chips processed for 0 s/8.1 and 13.8 RCF were close which means that centrifuge force does not influence oil uptake during the de-oiling process due to the surface changes by the NaCl solution as described by Bunger et al. (2001) (Figure 4.4c). Most of the oil on the surface did not penetrate into the chip's pores but remained on the surface. However, after 30 s of cooling time, the FOC/RM values for the chips de-oiled at 13.8 RCF were greater than those at 8.1 RCF due to the decrease of temperature by the centrifuge itself as described before.

4.1.2.4 Comparison between Controls and Pre-treated Chips

Figure 4.5 shows the relationship between FOC/MR and centrifuge speed for potato chips processed under different pre-treatments, fried at 165^{o}C, and cooled for 0 s. The chips without pre-treatment showed a simple trend in that the higher the centrifuge speed the less oil uptake. The chips blanched in hot water resulted in a slight decrease in oil uptake with increased centrifuge speed. Pedreschi et al. (2005) observed that blanching potato slices caused starch gelatinization resulting in a microstructure with no significant influence in drying profiles and increase in oil uptake after frying at 180°C. Besides, some authors reported that blanching in low-temperature water (55-70°C) before frying activates the pectinesterase enzyme and the resulting reactions decrease porosity and hence reduce oil uptake (Aguilar, Anzaldúa-Morales, Talamás, & Gastélum, 1997). On the other hand, Alvarez, Morillo, and Canet (2000) found that blanching potato strips before frying at lower temperatures for a short time (97°C, 2 min) resulted in higher oil content than the control strips. In this study, centrifuge speeds for de-oiling of blanched chip influenced the oil uptake, which led to a decrease in the FOC/RM values in the range from 3% at 45 s/8.1 RCF to 37% at 0 s and 15 s/8.1 RCF and an increase in FOC/RM values in the range from 3% at 0 s/13.8 RCF to 14% at 15 s, 10% at 30 s and 6% at 45 s/13.8 RCF when each value was compared with the no pre-treated samples (Tables 4.2 and 4.3).

Soaking in a 3% NaCl solution improved the reduction in FOC/MR by at least 6% with the highest reduction (44%) for the chips processed at 60 s/8.1 RCF when compared to the no pre-treated samples. The samples soaked in 3% NaCl solution showed temperature decreases through centrifuge speed itself with the application of cooling time before de-oiling resulting in the reversal of oil uptake at 13.8 RCF where FOC/RM values are greater than at 8.1 RCF in specific cooling times.

So, in terms of oil uptake, the best process consisted of pre-treating the samples with 3% NaCl at 25°C for 5 min, frying at 165°C, cooling for 0 s at 13.8 RCF.

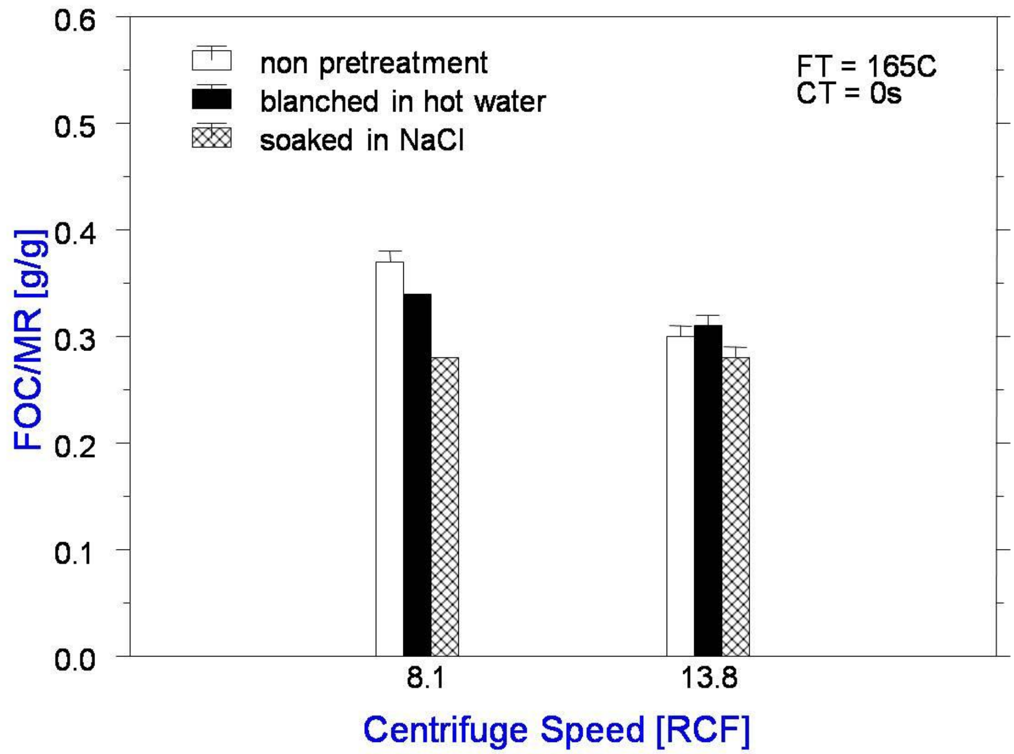

Figure 4.5: Final oil content/moisture removed as a function of centrifuge speed for potato chips non pretreated, blanched in hot water at 85°C for 3.5 min, and soaked in 3% NaCl solution at 25°C for 5 min, fried at 165^{o}C, and cooled for 0 s.

4.2 Texture

Table 4.5 shows the values for texture (hardness and work) for potato chips processed under different experimental conditions. The results were in agreement with the work of Pedreschi et al (2005) that neither the frying temperature nor the pre-treatments had a significant effect (P>0.05) over the final texture of the potato chips. However, de-oiling led to increased hardness of the chips fried at 145° and 165°C for 0 s cooling time (by 13% and 41%), respectively, and the hardness decreased as cooling time increased, (by 25% and 21%) (Table 4.5). The amount of work shows a trend similar to hardness in terms of frying temperature, except for the controls (0 s of cooling and no de-oiling).

The gelatinization of starch in potatoes during frying primarily influences the texture of the potato chips (Andersson, Gekas, Lind, Oliveira, & Oste, 1994). The changes at the cellular and sub-cellular levels in the outermost layer of potato chips during frying result in the crispy structure of the product. These chemical and physical changes include physical damage produced when the product is cut and a rough surface is formed with release of intracellular material; starch gelatinization and consequent dehydration; protein denaturation; breakdown of adhesive forces between the cells; water evaporation; rapid dehydration; expansion and browning of the tissue; and finally oil uptake itself (Bouchon, Hollins, Pearson, Pyle, & Tobin, 2001). When potato chips were fried at 120°, 150°, and 180°C, the higher frying temperature showed a faster softening of the tissue and hardening of the crust (Pedrishci et al., 2005). Neither the frying temperature nor the pre-treatment had any significant effect over the final texture of the potato chips (Pedreschi, 2005).

Table 4.5 Changes in texture (hardness (N) and work (N*mm)) of the potato chip fried at varying frying temperature, cooled at different times, and de-oiled at different centrifuge speeds (without pre-treatment).

T_{oil} (°C)	CS (RCF)	CT (s)	Hardness (N)	Work (N*mm)
145	0	0	$_{a}$3.16±0.53^{a,b}	$_{a}$10.00±1.98^{a}
145	8.1	0	$_{a}$3.58±1.16^{b}	$_{a}$8.27±2.02^{b}
145	8.1	60	$_{a}$3.39±0.68^{a,b}	$_{a}$5.34±1.18^{c}
145	8.1	120	$_{a}$2.59±0.54^{c,d}	$_{a}$4.08±1.55^{c}
145	13.8	0	$_{a}$3.61±0.76^{b}	$_{a}$8.96±2.28^{a,b}
145	13.8	60	$_{a}$2.95±0.40^{a,d}	$_{a}$4.83±1.44^{c}
145	13.8	120	$_{a}$2.37±0.53^{c}	$_{a}$4.50±1.77^{c}
165	0	0	$_{b}$2.64±0.42^{a}	$_{b}$5.32±1.64^{a,d}
165	8.1	0	$_{a}$3.46±1.08^{b}	$_{b}$4.46±1.18^{a,b}
165	8.1	60	$_{b}$2.56±0.52^{a}	$_{b}$3.77±1.40^{b,c}
165	8.1	120	$_{a}$2.56±0.81^{a}	$_{a}$4.00±1.64^{b,c}
165	13.8	0	$_{a}$3.73±1.05^{b}	$_{b}$5.53±1.04^{d}
165	13.8	60	$_{a,b}$2.53±0.90^{a}	$_{b}$3.41±1.00^{b,c}
165	13.8	120	$_{a}$2.10±0.23^{a}	$_{b}$3.19±1.04^{c}
185	0	0	$_{b}$2.60±0.40^{a,d}	$_{b}$6.44±1.74 a
185	8.1	0	$_{b}$2.54±0.74^{a,b,d}	$_{b}$3.33±1.06^{b,c}
185	8.1	60	$_{c}$2.13±0.44^{b,c}	$_{c}$2.88±0.71^{b}
185	8.1	120	$_{a}$2.19±0.62^{a,b,c}	$_{a}$2.90±1.33^{b}
185	13.8	0	$_{b}$2.04±0.67^{c}	$_{c}$2.60±0.88^{b}
185	13.8	60	$_{b}$2.18±0.52^{a,b,c}	$_{b}$3.31±1.27^{b,c}
185	13.8	120	$_{b}$2.72±0.31^{c}	$_{a,b}$3.84±0.59^{c}

Tests were performed in triplicate.
$^{a-g}$Means within a column with different superscript letters are significantly different (P<0.05) $_{a-c}$Means within a column with different subscript letters are significantly different (P<0.05)
CS = Centrifuge Speed, CT = cooling time

4.2.1 De-oiled Chips without Pre-treatment

4.2.1.1 Effect of Temperature

While the frying temperature did not have a significant effect (P>0.05) over the final texture of the potato chips, it influenced the textural properties slightly. At a low temperature (145°C) of hardness and work, the chips became harder to break. Values were 3.61 ±0.76 N and 8.96±2.28 N*mm, respectively, at 13.8 RCF without cooling (Figure 4.6). At a high temperature (185°C), the chips became brittle, with decreased hardness and work. Values of hardness and work were 2.04 ± 0.67 N and 2.60 ±0.88 N*mm, respectively, at 13.8 RCF without cooling. As the temperature increased, hardness and work decreased so that the chips became softer.

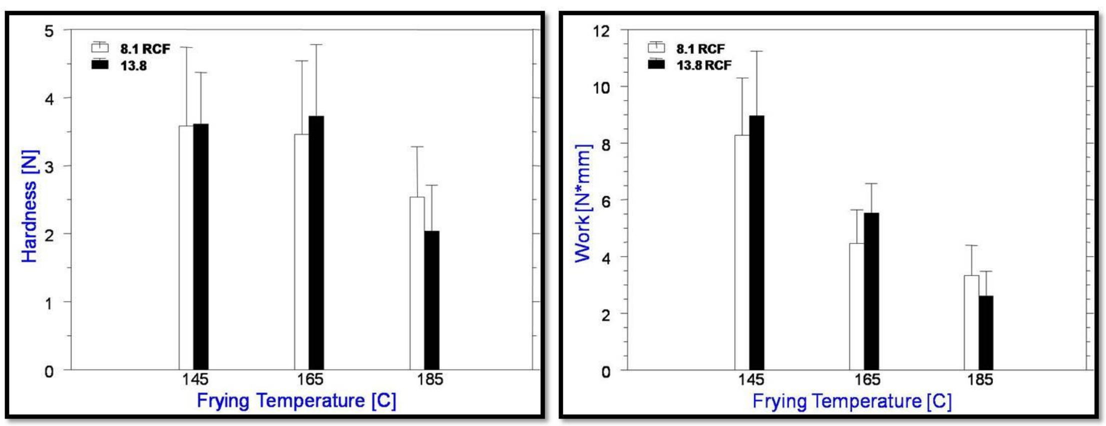

Figure 4.6: Effect of frying temperature on the hardness and work of potato chips (without pre-treatment) cooled for 0 s and de-oiled under various centrifuge speeds.

4.2.1.2 Effect of Centrifuge Speed

As centrifuge speed increases, hardness increases except for the samples fried at 185°C for 0 s, and 60 s, and those fried at 145° and 165° C for 120 s (Fig. 4.7). As soon as the potato chips were removed from the fryer, the chips start simultaneously cooling and de-oiling at different cooling times. A method using a de-oiling centrifuge removed surface oil resulting in reduced oil content in the final product and an increased hardness of the chips. In the case of potato chips fried at 185°C for 0 s and 60 s, the centrifuge more effectively decreased temperature, compared to chips fried at 145° and 165°C for 0 s and 60 s. Since after cooling, oil was located either on the surface of the chip or sucked into the porous crust microstructure (Kawas et al, 2002), and an increase in the oil temperature caused the crust thickness (Singh, 1995), the potato chips fried at a higher temperature resulted in more oil content in the crust region. Therefore, hardness decreased as centrifuge speed increased. The amount of work shows a trend similar to hardness in relation to centrifuge speed except for the samples fried at 145°C for 120 s.

4.2.1.3 Effect of Cooling Time

The hardness of potato chips is affected by cooling time. Figure 4.7 shows the effect of oil temperature on the hardness profile of potato chips fried at 145°, 165°, and 185°C for 0 s, 60 s, and 120 s, respectively.

As cooling time increased, hardness decreased except for the chips fried at 185°C. Work showed a trend similar to hardness, except to the control samples (Table 4.5). De-oiled chips without cooling contained less oil content, and oil absorption increased as the products cooled after frying. However, the control sample had greater values of work than any of the other products fried at different temperatures. In other words, the oil in the chips would spread uniformly during the de-oiling process so that less work was required to break the chips. Therefore, during rupture, the chips except for the chips fried at 185°C resulted in a decrease of crunchiness, and the chips except to the control samples resulted in a decrease of firmness as cooling time increases. The control sample resulted in greater firmness than any of the other products fried at different temperatures.

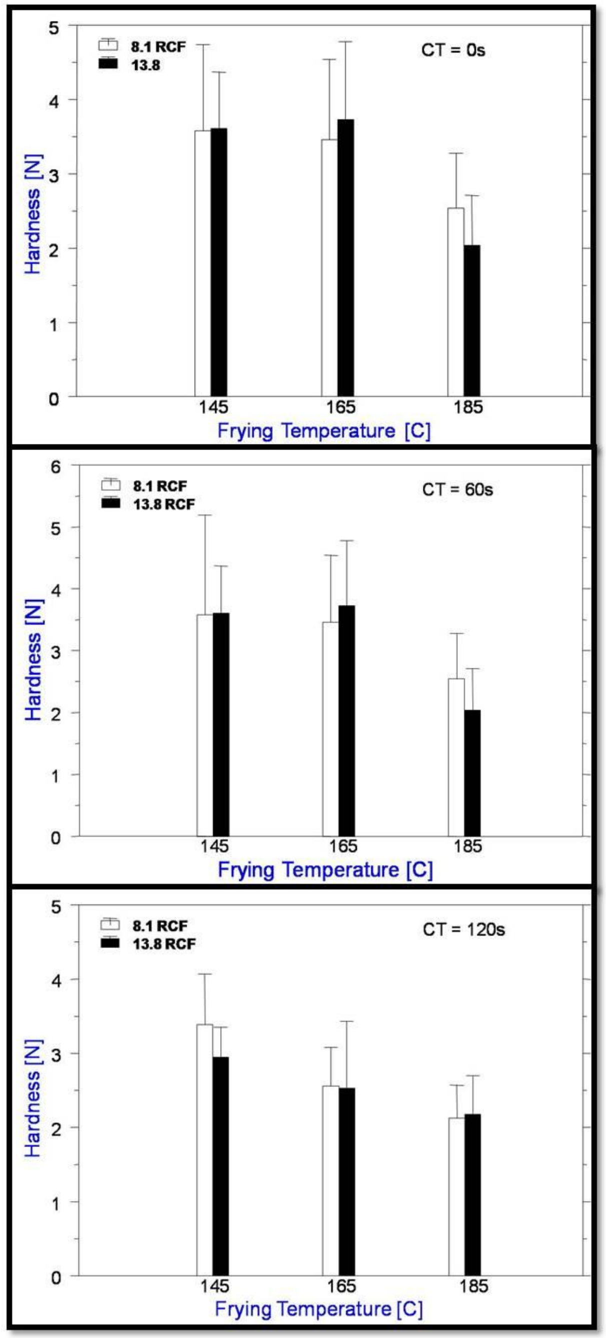

Figure 4.7: Effect of frying temperature on the hardness of potato chips (without pre-treatment), cooled for (a) 0 s; (b) 60 s; (c) 120 s and de-oiled at different centrifuge speeds.

4.2.2 De-oiled Chips with Pre-treatments

The results of this study were in agreement with the work of Pedreschi et al (2005) that pre-treatment did not have a significant effect (P>0.05) over the final texture of the potato chips. However, pre-treatments influenced the textural properties slightly.

Blanching in hot water and soaking in 3% NaCl solution usually resulted in increased hardness by about 10% and 51%, respectively, when compared for the chips fried at the same temperature (165^{o}C) without pre-treatment (Table 4.6). In other words, during rupture, the pre-treated chips required less work than the untreated chips so that the firmness decreased.

During the pre-treatments, structural changes took place. Also, the reduced oil uptake resulted in increasing hardness and work. For the work results, blanching shows a trend similar to the control, and soaking in NaCl decreased the value of work by 11% compared to the control.

4.2.2.1 No Pre-treatment

Table 4.6 Effect of centrifuge speed and cooling time on the final oil content of potato chips fried at 165°C without pre-treatment.

CS (RCF)	CT (s)	Hardness (N)	Work (N*mm)
0	0	$_{a}2.34\pm0.29^{a,c}$	$_{a}4.14\pm0.48^{a,d}$
8.1	0	$_{b}2.75\pm0.38^{b,e}$	$_{b}5.03\pm0.64^{b}$
8.1	15	$_{a}2.56\pm0.35^{b,c,d}$	$_{a}3.90\pm0.48^{a,c}$
8.1	30	$_{a}2.62\pm0.32^{b,c,d}$	$_{a}5.40\pm0.67^{b}$
8.1	45	$_{a}2.47\pm0.32^{a,c,d}$	$_{a}4.46\pm0.64^{d}$
8.1	60	$_{a}2.21\pm0.26^{a}$	$_{a}4.02\pm0.56^{a}$
13.8	0	$_{c}2.94\pm0.32^{e}$	$_{c}3.32\pm0.29^{e}$
13.8	15	$_{a}2.55\pm0.34^{b,c,d}$	$_{b}2.81\pm0.38^{f}$
13.8	30	$_{a}3.01\pm0.38^{e}$	$_{b}3.38\pm0.45^{e}$
13.8	45	$_{b}2.83\pm0.34^{b,e}$	$_{b}3.59\pm0.50^{c,e}$
13.8	60	$_{a}2.65\pm0.36^{b,d}$	$_{b}3.58\pm0.46^{c,e}$

Tests were performed in triplicate. - a-gMeans within a column with different superscript letters are significantly different ($P<0.05$) a-cMeans within a column with different subscript letters are significantly different ($P<0.05$) - CS = centrifuge speed, CT = cooling time.

4.2.2.1.1 Effect of Centrifuge Speed

As expected, the values of hardness were not affected significantly ($P<0.05$) by the centrifuge speed (Table 4.6). Work values seemed to be lower at higher centrifuge speed. The chips were not affected (cracked or broken) by the speed of the centrifuge indicating that they did not have any damage during the de-oiling process. Hardness increased by 18% and 26% for the chips centrifuged by 8.1 and 13.8 RCF, respectively, compared to the control (0 s CS and 0 s CT). Work values increased by 21% and decreased by 20% for the chips de-oiled at 8.1 and 13.8 RCF, respectively.

In general, as centrifuge speed increases, hardness increases, and work decreases so that the chips resulted in more crunchiness and firmness (Table 4.6). In other words, the centrifuge enhances the quality of chips fried at 165°C without pre-treatment. The de-oiling process using a centrifuge reduced oil absorption on the chips' surface during cooling and resulted in an increased hardness of the chips. Higher centrifuge speed efficiently helped reduce oil uptake on the surface of the chips by promoting immediate drainage of oil.

4.2.2.1.2 Effect of Cooling Time

Hardness did not changed significantly ($P<0.05$) with cooling time (Table 4.6). Compared with the control, the highest changes occurred for the chips de-oiled at 13.8 RCF for 30 s of cooling. Work values increased by 30% for the chips de-oiled at 8.1 RCF and cooled for 30 s. The lowest value was obtained for the chips de-oiled at 13.8 RCF and cooled for 15 s.

The chips cooled for 30 s resulted in the least thickness and volume shrinkage and were harder due to greater thickness compared to other chips cooled for different times. In other words, the chips cooled for 30 s needed more force to puncture the chips and more work required to travel by probe to the puncture. The amount of work shows a trend similar to hardness in terms of cooling time.

4.2.2.2 Blanching in Hot Water at 85°C for 3.5 min

Table 4.7 Effect of centrifuge speed and cooling time on the final oil content of potato chips blanched in hot water at 85°C for 3.5 min before frying at 165°C.

CS (RCF)	CT (s)	Hardness (N)	Work (N*mm)
0	0	$_{a}2.57\pm0.26^{a,e}$	$_{a}4.06\pm0.42^{a}$
8.1	0	$_{b}3.34\pm0.34^{b,c}$	$_{a}4.03\pm0.40^{b}$
8.1	15	$_{a}2.78\pm0.29^{a}$	$_{a}2.67\pm0.23^{a,c}$
8.1	30	$_{a}2.48\pm0.04^{b,c}$	$_{b}3.10\pm0.32^{a}$
8.1	45	$_{a}2.52\pm0.23^{c,d}$	$_{a}2.97\pm0.31^{d}$
8.1	60	$_{b}3.39\pm0.33^{d}$	$_{a}3.57\pm0.32^{a}$
13.8	0	$_{a}2.56\pm0.27^{a,e}$	$_{b}2.42\pm0.17^{c}$
13.8	15	$_{a}3.08\pm0.31^{b,e}$	$_{b}3.80\pm0.37^{c}$
13.8	30	$_{a}2.32\pm0.21^{b,e}$	$_{b}3.52\pm0.04^{d}$
13.8	45	$_{a}2.59\pm0.26^{b,e}$	$_{b}3.52\pm0.36^{d}$
13.8	60	$_{b}2.95\pm0.33^{e}$	$_{a}3.98\pm0.40^{d}$

Tests were performed in triplicate. - a-gMeans within a column with different superscript letters are significantly different (P<0.05) a-cMeans within a column with different subscript letters are significantly different (P<0.05) - CS = centrifuge speed, CT = cooling time.

4.2.2.2.1 Effect of Centrifuge Speed

The centrifuge speed did not affect significantly (P<0.05) the hardness values for the chips de-oiled at 0 and 13.8 RCF. For the chips de-oiled at 8.1 RCF, the chip hardness increased by 30% (Table 4.7). Work values were not affected by centrifuge speed for 0 and 8.1 RCF; however, the work value for the chip de-oiled at 13.8 RCF was 40% lower than those for the control samples.

In general, as centrifuge speed increases, hardness decreases except for the sample de-oiled for 45 s (Table 4.7). Hardness is related to the thickness of the chips, and as mentioned before, the thicker the chips the harder they are. As shown in Table 4.14, the thickness shrinkage decreases as the centrifuge speed increases. The centrifuge helped prevent the shrinking of the thickness of the chips except for those de-oiled at 0 s, which puffed and increased in thickness (Table 4.14). Therefore, hardness decreased as centrifuge speed increased. The trend of the work was reversed, i.e., the higher the centrifuge speed the less amount of work. As centrifuge speed increased, the thickness and volume shrinkage rate decreased so that the density at the in intercellular level decreased and resulted in a decreased hardness, except for chips de-oiled at 45 s, and increased work, except for chips de-oiled at 0 s.

4.2.2.2.2 Effect of Cooling Time

No clear trend (Table 4.7) was observed between cooling time and hardness or work values. Compared to the control, the highest change (32% increases) was observed for the chips cooled for 60 s and de-oiled at 8.1 RCF. The work values showed lower values than the control for each cooling time.

For chips cooled before de-oiling, hardness decreased as cooling time increased at 8.1 RCF, except for 60 s, and increased at 13.8 RCF, except for 30 s, compared to the samples cooled for 0 s (Table 4.7). As previously mentioned, hardness is related to the thickness of the chips and the thicker the chips the harder they are. As cooling time increased, the thickness shrinkage at 8.1 RCF increased and resulted in a decreased hardness of the chips (Table 4.7). At 45 s, the hardness of the chip slightly increased due to a decreased shrinkage in thickness. At 13.8 RCF, the trend was reversed, the longer the cooling time the greater the hardness. The thickness of samples cooled for 0 s at 8.1 RCF increased rather than shrank like others and resulted in an increased hardness of the chips. The trend of the work was reversed, the longer the cooling time at 8.1 RCF the less work and at 13.8 RCF the more work compared to the samples cooled for 0 s.

4.2.2.3 Soaking in 3% NaCl Solution at 25°C for 5 min

Table 4.8 Effect of centrifuge speed and cooling time on the final oil content of potato chips treated by soaked in 3% NaCl solution at 25°C for 5 min before frying at 165°C.

CS (RCF)	**CT (s)**	**Hardness (N)**	**Work (N*mm)**
0	0	$_{a}3.54\pm0.45^{a,c}$	$_{a}3.69\pm0.33^{a}$
8.1	0	$_{b}4.01\pm0.05^{b}$	$_{b}4.15\pm0.06^{a}$
8.1	15	$_{a}3.33\pm0.04^{c,f}$	$_{a}3.54\pm0.05^{b}$
8.1	30	$_{a}4.03\pm0.06^{a,d}$	$_{a}3.67\pm0.06^{c}$
8.1	45	$_{a}4.28\pm0.45^{a,d}$	$_{a}3.02\pm0.53^{c}$
8.1	60	$_{a}4.57\pm0.61^{b}$	$_{a}3.71\pm0.16^{d,f}$
13.8	0	$_{a}3.53\pm0.44^{a}$	$_{a}3.36\pm0.62^{e}$
13.8	15	$_{a}3.72\pm0.51^{e}$	$_{a}3.33\pm0.27^{a,f}$
13.8	30	$_{a}3.78\pm0.66^{d}$	$_{b}2.92\pm0.24^{d}$
13.8	45	$_{b}3.71\pm0.08^{a,c}$	$_{a}2.90\pm0.36^{d}$
13.8	60	$_{b}3.67\pm0.33^{e,f}$	$_{b}2.80\pm0.18^{a}$

Tests were performed in triplicate. - a-gMeans within a column with different superscript letters are significantly different ($P<0.05$) a-cMeans within a column with different subscript letters are significantly different ($P<0.05$) - CS = centrifuge speed, CT = cooling time.

4.2.2.3.1 Effect of Centrifuge Speed

The chips hardness increased by 13% for the chips de-oiled at 8.1 RCF compared to the control samples (Table 4.8). Work values increased by 12% for the chips de-oiled at 8.1 RCF and decreased by 9% at 13.8 RCF, although not significantly ($P<0.05$).

As the centrifuge speed increased, hardness decreased except for the sample de-oiled for 15 s (Table 4.8). Hardness is related to the thickness of the chip. However, it is not applicable in the case of the sample soaked in a 3% NaCl solution. Soaking in a NaCl solution as a pre-treatment penetrates into the surface preventing water loss by osmotic dehydration (Bunger, Moyano, & Rioseco, 2002). The solute increased the thickness of chips, and the temperature decreased through the centrifuge speed itself so that the oil content of the chip increased. Due to an increased oil content of the chips (Table 4.4), hardness decreased with increasing centrifuge speed (Table 4.8). Since the solute increased the thickness of the chip, the amount of work shows a trend similar to hardness in terms of centrifuge speed.

4.2.2.3.2 Effect of Cooling Time

Compared with 0 s cooling time (Table 4.8), hardness values increased for all cooling times, except for the chips cooled for 15 s and de-oiled at 8.1 RCF. Compared to the control, the highest change (29%) was obtained for the chips cooled for 60 s and de-oiled at 8.1 RCF.

The work values showed a decrease values for the chips cooled for different times compared to the chips cooled for 0 s. The highest change (24%) was observed for the chips cooled for 60 s and de-oiled at 13.8 RCF, when compared to the control samples.

As cooling time increased, the thickness of the chip increased so that hardness increased. In other words, the hardness shows a pattern similar to shrinkage in thickness. However, the amount of work shows a trend that was reversed due to an increased thickness and volume at 8.1 RCF and a stable thickness and increased volume at 13.8 RCF. Therefore, the density of the intercellular level of the chip decreased so that the amount of work decreased compared to the chips cooled for 0 s.

4.2.2.4 Comparison between Controls and Pre-treated Chips

Blanching in hot water and soaking in NaCl usually led to an increase in hardness. The control samples that showed the highest value in hardness were those soaked in 3% NaCl for 5 min before frying. i.e., and 51% increase compared to the no pre-treated samples. Soaking in NaCl also resulted in less work (about 11%) to break the chips compared with the blanched and no pre-treated samples.

The results of this study were in agreement with the work of Pedreschi et al. (2005) in that pre-treatment did not have a significant effect (P>0.05) over the final texture of the potato chips.

However, pre-treatments influenced the textural properties slightly. Blanching and soaking in an NaCl solution increased hardness and decreased work values (Table 4.8). In other words, during rupture, the pre-treated chips required less work than the untreated chips. During the pre-treatments, structural changes took place. Also, the reduced oil uptake resulted in increasing hardness and work. Blanching in hot water and soaking in a 3% NaCl solution usually led to an increase in hardness.

Foams were also observed to be more stable with concentrations of NaCl, causing densifying of protein and increasing ionic strength (Akintayo, 1999). In other words, sodium chloride enhances the ionic strength of the structure that possibly creates stability in foam. As moisture evaporates during frying in the oil medium, the protein of chips increases because a potato tuber is composed of approximately 77.5% water and about 22.5% dry matter that consists 18.9% starch, 1.95% starch, 0.97% ash, 0.58% fiber and 0.1% fat (Smith, 1987). Akintayo (1999) reported that the protein has a good gelation capacity, which is the process of forming a gel, with at least a gelation concentration of 6% (w/v). Therefore, protein in the chips plays a key role in increasing the thickness of chips rather than shrinking it (Figure 4.23c) and using sodium chloride results in an increased hardness of the chips (Table 4.8). The puffed structure was not restored due to increased foam stability caused by the protein in the chip.

4.3 Color

Potato chips' color developed during frying results from the nonenzymatic browning related to the Maillard reaction. It is the result of the reaction of amino acids with reducing sugars, primarily D-glucose, which accumulates during low-temperature storage (Jankwski, Parkin, & Von Elbe, 1997; Marquez & Anon, 1986; Weaker & Reeve, 1975). High reducing sugar content causes excessive darkening and off-flavor development that is unacceptable for processed potato products (Sahin, 2000). Frying conditions, thickness of slices, and the length of the frying period have an effect on the chip's color (Talburt & Smith, 1987).

The lightness ($L*$) and redness ($a*$) of the potato chips when they were de-oiled were significantly influenced (P>0.05) by the frying temperature (Table 4.7). Potato chips showed less lightness and redness when fried at 145°C and more lightness and red when fried at 185°C. Potato chips fried at 165°C did not show significant (P<0.05) color characteristics, compared to both the frying temperatures, 145° and 165°C. Frying temperature also significantly influenced (P>0.05) yellowness ($b*$) resulting in increasing $b*$ values as temperature increased.

De-oiling using a centrifuge influenced significantly ($P>0.05$) the increase in the lightness (L^*) of the chips without cooling. However, the centrifuge speed did not significantly affect ($P<0.05$) the lightness of the chips so that the L^* of those values were close. As cooling time increased, the lightness of the chips decreased. The chips had the highest value of L^* (65.23±2.84) at a 165°C frying temperature and de-oiled at 13.8 RCF (Table 4.9).

The de-oiling process using a centrifuge did not influence significantly ($P<0.05$) the redness (a^*) of the chips, except for the products fried at 185°C (Table 4.9). However, higher centrifuge speed resulted in a slight increase in the redness of the de-oiled chips. As cooling time increased, the redness of the chips increased. The chips had the lowest value of a^* (2.34±0.30) at a frying temperature of 165°C and de-oiled at 8.1 RCF.

The centrifuge influenced significantly ($P>0.05$) the yellowness (b^*) of the chips (Table 4.9). Also, as cooling time increased, the yellowness of the chips increased.

Pre-treatments before frying significantly influenced ($P>0.05$) the lightness and yellowness of the final products. All the products (non-pretreated, blanched in hot water, and soaked in NaCl), compared to the controls (0 s cooling tome and no de-oiled) of each pre-treated sample, resulted in increasing in lightness (L^*) and yellowness (b^*), whereas the redness (a^*) values of the final products fluctuated. Blanching in hot water usually decreased the yellowness of the final products, compared to non-pretreated samples.

Table 4.9 Effect of de-oiling after frying on color (*L**, *a**, *b**) for potato chips subjected to varying frying temperature, centrifuge speed, and cooling time (without pre-treatment).

T_{oil} (°C)	CS (RCF)	CT (s)	L*	a*	b*
145	0	0	$_a$ 55.99± 3.93 ^{a,d}	$_a$ -1.77±0.72 ^{a,b}	$_a$ 16.40 ±0.61 ^{a}
145	8.1	0	$_a$ 60.66 ±3.13 ^{b}	$_a$ -2.21 ±0.32 ^{a}	$_a$ 14.86 ±1.28 ^{b}
145	8.1	60	$_a$ 56.72 ±1.53 ^{d}	$_a$ -1.35 ±0.86 ^{b,c}	$_a$ 16.84 ±1.67 ^{a}
145	8.1	120	$_a$ 52.87 ±2.92 ^{c}	$_a$ -1.02 ±0.59 ^{c}	$_a$ 18.03 ±1.31 ^{c}
145	13.8	0	$_a$ 60.15 ±2.39 ^{b}	$_a$ -1.76 ±0.38 ^{a,b}	$_a$ 16.50 ±1.23 ^{a}
145	13.8	60	$_a$ 59.20 ±2.44 ^{b}	$_a$ -1.24 ±0.55 ^{b,c}	$_a$ 18.59 ±0.46 ^{c,d}
145	13.8	120	$_a$ 54.00 ±2.41 ^{a,c}	$_a$ -0.00 ±1.09 ^{d}	$_a$ 19.33 ±2.19 ^{d}
165	0	0	$_a$ 55.66 ±2.87 ^{a}	$_a$ -1.64 ±0.85 ^{a,b,d}	$_b$ 18.11 ±2.14 ^{a}
165	8.1	0	$_b$ 65.11 ±2.88 ^{b}	$_a$ -2.34 ±0.30 ^{a}	$_b$ 17.71 ±1.70 ^{a}
165	8.1	60	$_a$ 58.19 ±3.07 ^{c}	$_{a,b}$ -0.75 ±1.62 ^{b,c}	$_b$ 20.26 ±2.72 ^{b}
165	8.1	120	$_a$ 52.96 ±3.25 ^{d}	$_b$ 0.23 ±1.65 ^{e}	$_b$ 22.02 ±1.09 ^{c}
165	13.8	0	$_b$ 65.23 ±2.84 ^{b}	$_a$ -1.95±0.49 ^{a,d}	$_b$ 18.84 ±1.72 ^{a}
165	13.8	60	$_a$ 60.77 ±3.03 ^{c}	$_a$ -1.07 ±0.82 ^{b,d}	$_b$ 20.44 ±0.58 ^{b}
165	13.8	120	$_a$ 54.11 ±4.63 ^{a,d}	$_a$ 0.74 ±2.64 ^{e}	$_b$ 20.67 ±0.48 ^{b}
185	0	0	$_b$ 51.73 ±3.94 ^{a}	$_b$ -0.00 ±1.22 ^{a,b,c}	$_b$ 19.50 ±2.73 ^{a}
185	8.1	0	$_b$ 62.92 ±2.61 ^{b}	$_b$ -1.07 ±1.24 ^{a}	$_c$ 22.91 ±0.85 ^{b}
185	8.1	60	$_b$ 54.34 ±3.60 ^{a}	$_b$ 0.17 ±1.12 ^{b,c}	$_c$ 23.70 ±0.23 ^{b}
185	8.1	120	$_a$ 54.49 ±2.23 ^{a}	$_a$ -0.89 ±1.28 ^{a,b}	$_b$ 22.93 ±2.03 ^{b}
185	13.8	0	$_c$ 62.98 ±1.26 ^{b}	$_b$ 0.38 ±1.20 ^{c}	$_c$ 22.83 ±1.87 ^{b}
185	13.8	60	$_a$ 58.70 ±4.69 ^{c}	$_b$ 1.72 ±2.40 ^{d}	$_c$ 25.43 ±2.60 ^{c}
185	13.8	120	$_b$ 58.50 ±5.65 ^{c}	$_a$ -0.43 ±0.45 ^{a,b,c}	$_c$ 22.44 ±0.87 ^{b}

Tests were performed in triplicate.
a-gMeans within a column with different superscript letters are significantly different (P<0.05) a-cMeans within a column with different subscript letters are significantly different (P<0.05)
Toil = oil temperature, CS = Centrifuge Speed, CT = cooling time

4.3.1 De-oiled Chips without Pre-treatment

4.3.1.1 Effect of Temperature

The effect of oil temperature on the color of potato chips is presented in Table 4.9.

The frying temperature significantly influenced (P>0.05) the lightness (L*) and redness (a*) of the chips fried at 145° and 185°C and de-oiled. Potato chips fried at 165°C exhibit the color description of the potato chips fried at both of the temperatures, 145° and 185°C. Therefore, potato chips fried at 145°C showed less lightness and redness, and the product fried at 185°C show more lightness and redness than any of the products fried at different temperatures. Frying temperature influenced significantly (P>0.05) the yellowness (b*) of the products resulting in increasing values as temperature increased. Color depends upon the formation of brown pigments during the frying of the potato slices in oil, resulting from the reaction between sugars and amino acids (Marquez et al., 1986). Therefore, the potato chips fried at a higher temperature (185°C) contain more brown pigments resulting in increasing the values of a* and b*.

Figure 4.8 (d-f)) shows the image of potato chips fried at different temperature. As discussed above, potato chips fried at 185^{o}C (Fig. 4.8f) looks darker than the chips fried at 145^{o} or 165^{o}C.

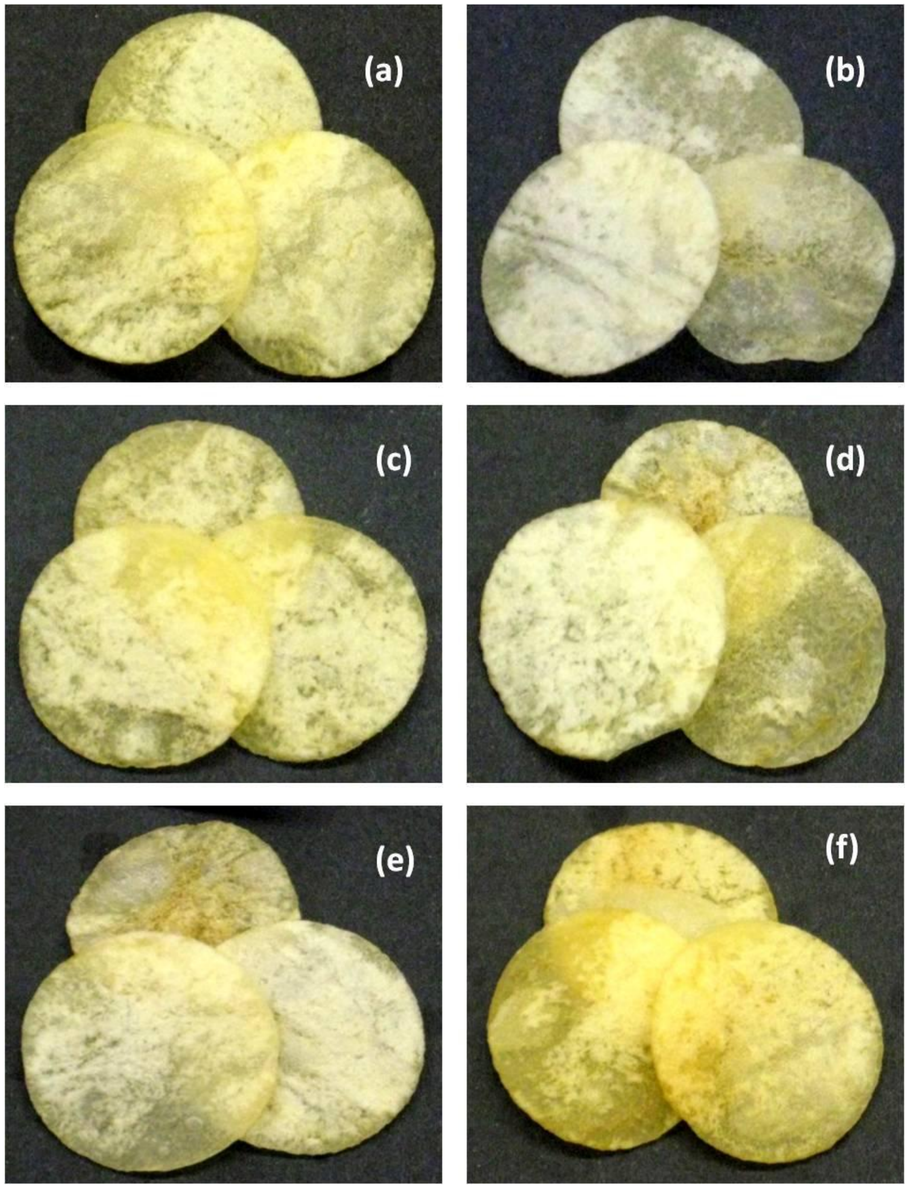

Figure 4.8: Comparison of potato chips fried at 165°C, 0 s cooling time, without de-oiling, and with the following pre-treatments (a) no pre-treatment (b) blanched in hot water at 85°C for 3.5min and (c) soaked in 3% NaCl solution for 5 min. No pre-treated potato chips, 0 s cooling time, without de-oiling and fried at the following temperatures (d) 145°C (e) 165°C (f) 185°C.

4.3.1.2 Effect of Centrifuge Speed

De-oiling significantly influenced (P>0.05) the increase of lightness (L*) values of the chips without cooling (Table 4.9). On the other hand, centrifuge speed did not significantly affect (P<0.05) the lightness of the chips. The chip had the highest value of L*(65.23±2.84) at 165°C frying temperature and de-oiled at 13.8 RCF.

The de-oiling process using a centrifuge did not influence significantly (P<0.05) the redness (a*) of the chips except for the products fried at 185°C. The a* values of the potato chips fried at 185°C and de-oiled without cooling were slightly less than with cooling. The yellowness (b*) of the chips fried at 145°, 165° and 185°C was influenced significantly (P>0.05) by the centrifuge speed. As frying temperature increased, the b* values increased due to the formation of brown pigments during the frying of the potato slices in oil, as mentioned in Section 4.2.2.1.1.

Figures 4.9 to 4.11 show the images of potato chips processed at different temperature and de-oiling speed. Chips de-oiled were lighter in color than the chips not de-oiled (Fig. 4.8d-f) which looks oily. The chips de-oiled at different RCF did not show difference in color for each frying temperature (Fig. 4.9-4.11).

4.3.1.3 Effect of Cooling Time

Cooling time influenced significantly (P>0.05) the lightness (*L**) and redness (*a**) of the chips fried at 145° and 185°C and de-oiled, and potato chips fried at 165°C produced the color description of the potato chips fried at both of the temperatures, 145° and 185°C (Table 4.9). The yellowness (b*) of the chips fried at 145°, 165°, and 185°C was influenced significantly (P>0.05) by cooling.

As cooling time increased, the lightness (*L**) of the chips decreased and the redness (*a**) and yellowness (*b**) of the chips increased. However, the lightness (*L**) and redness (*a**) of potato chips fried at 165°C and de-oiled showed the characteristics of the frying temperatures, 145° and 185° C. As the products cool, oil absorption increased and it resulted in the change of color of the final products.

Figures 4.9 to 4.11 show the images of potato chips processed at different temperature and cooling times. Chips look oilier, thus more yellow, as cooling time frying time increased for all temperatures.

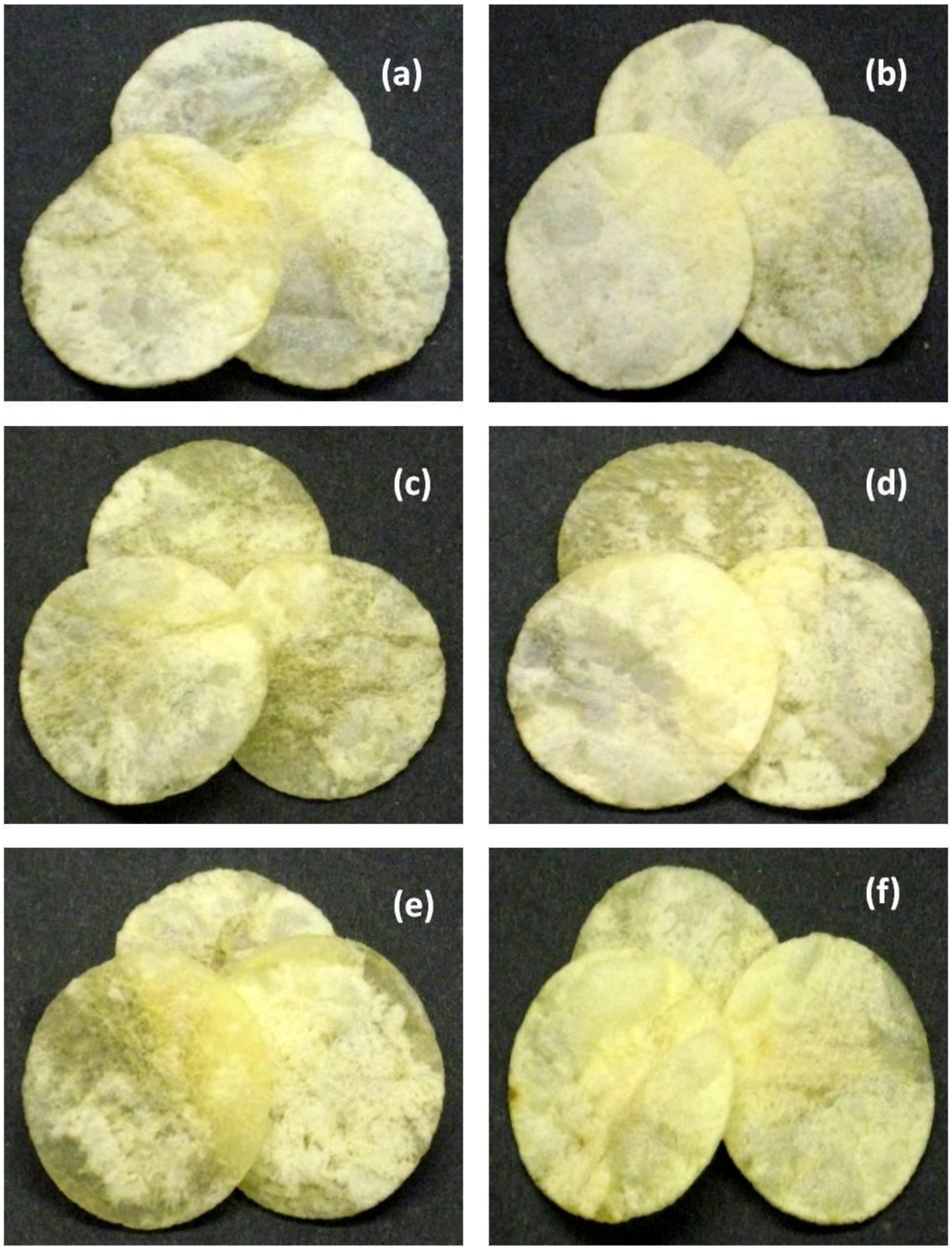

Figure 4.9: Comparison of no pre-treated potato chips fried at 145°C and (a) 0 s cooling time/8.1 RCF, (b) 0 s cooling time/13.8 RCF, (c) 60 s cooling time/8.1 RCF, (d) 60 s cooling time/13.8 RCF, (e) 120 s cooling time/8.1 RCF and (f) 120 s cooling time/13.8 RCF.

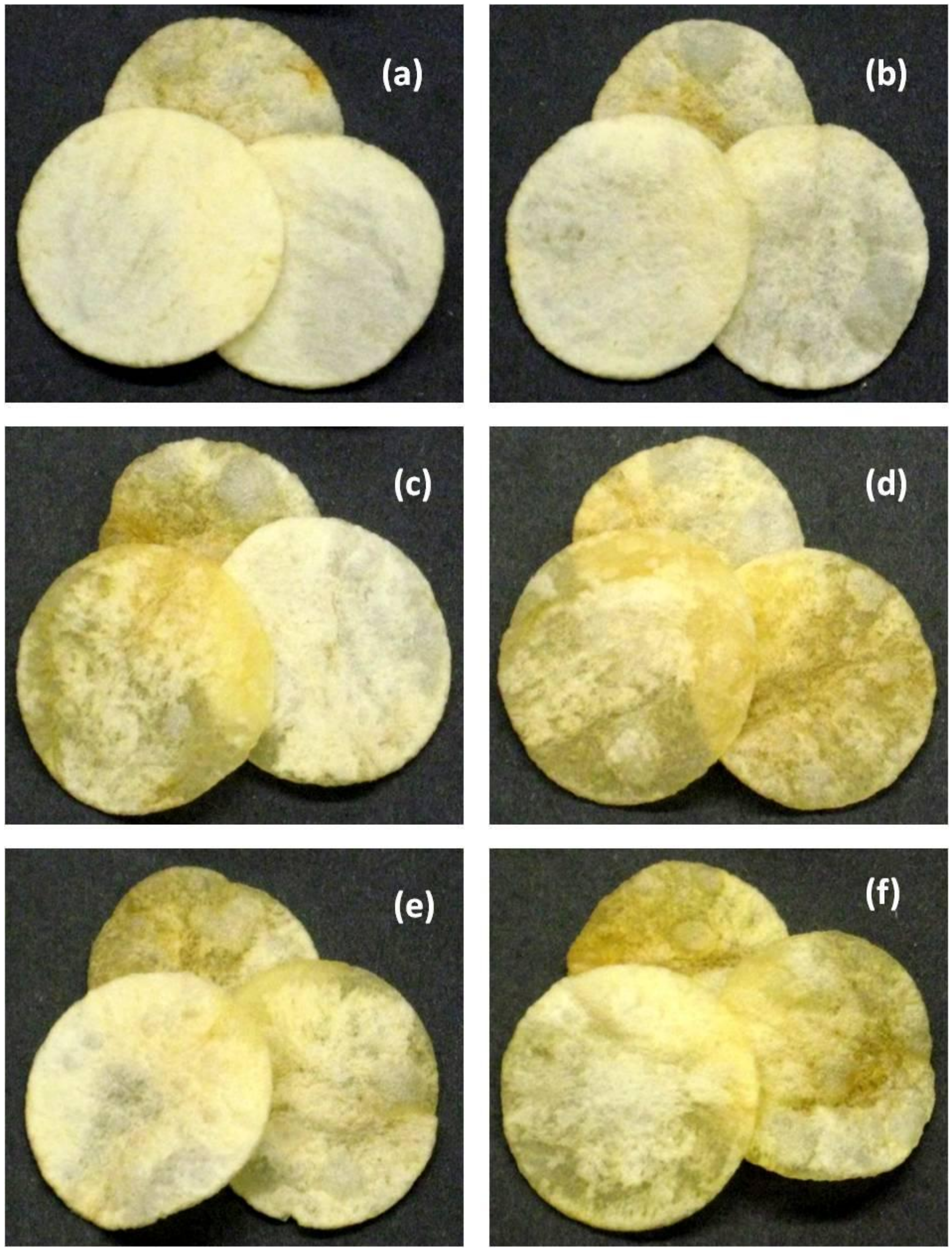

Figure 4.10: Comparison of no pre-treated potato chips fried at 165°C and (a) 0 s cooling time/8.1 RCF, (b) 0 s cooling time/13.8 RCF, (c) 60 s cooling time/8.1 RCF, (d) 60 s cooling time/13.8 RCF, (e) 120 s cooling time/8.1 RCF and (f) 120 s cooling time/13.8 RCF.

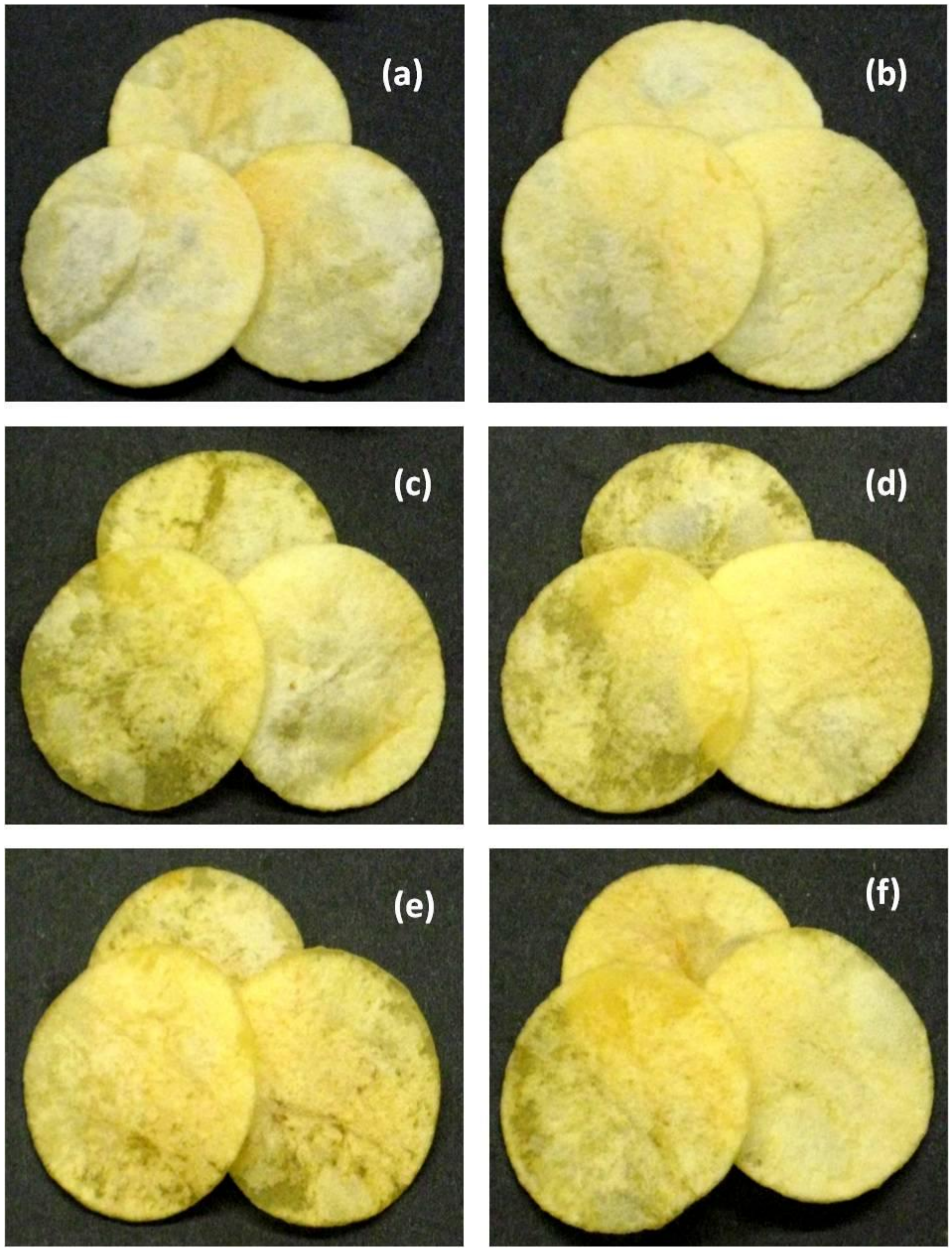

Figure 4.11: Comparison of no pre-treated potato chips fried at 185°C and (a) 0 s cooling time/8.1 RCF, (b) 0 s cooling time/13.8 RCF, (c) 60 s cooling time/8.1 RCF, (d) 60 s cooling time/13.8 RCF, (e) 120 s cooling time/8.1 RCF and (f) 120 s cooling time/13.8 RCF.

4.3.2 De-oiled Chips with Pre-treatments

Pre-treatments before frying affected significantly (P>0.05) the lightness (L^*) and yellowness (b^*) of the final products (Tables 4.10-4.12). All products (without-pretreatment, blanching in hot water, and soaking in NaCl), compared to the controls of each pre-treated samples, led to an increase in lightness (L^*) and yellowness (b^*), whereas redness (a^*) values of the final products did not show the same trend. Blanching in hot water usually reduced the yellowness of the final products, compared to the no pre-treated samples. Blanching is used when the reducing sugar level of the raw potatoes is high and could result in an undesirable dark color after frying (Andersson, 1994). The color is improved by blanching (Califano & Calvelo, 1987). Also, Santis et al. (2007) reported that soaking in NaCl led to potato chips that were lighter in color.

Figures 4.12 to 4.16 show the effect of pre-treatment conditions on the color of potato chips fried at 165^{o}C and cooled at different times and de-oiled at different centrifuge speeds. It is clear that the products that were blanched before frying are less dark that the other pre-treated and no pre-treated samples.

4.3.2.1 No Pre-treatment

Table 4.10 Effect of centrifuge speed and cooling time on the final oil content of potato chips fried at 165°C without pre-treatment.

CS (RCF)	CT (s)	L*	a*	b*
0	0	$_a$ 50.52±0.52 ^{a}	$_a$ -1.51±0.02 ^{a}	$_a$ 19.90±0.20 ^{a}
8.1	0	$_b$ 62.68±0.87 ^{b}	$_b$ -1.72±0.02 ^{b}	$_b$ 20.47±0.26 ^{b}
8.1	15	$_a$ 58.03±0.64 ^{c}	$_a$ -1.38±0.02 ^{c}	$_a$ 21.80±0.31 ^{c}
8.1	30	$_a$ 55.64±0.77 ^{d}	$_a$ -1.47±0.02 ^{d}	$_a$ 21.31±0.29 ^{d}
8.1	45	$_a$ 52.80±0.28 ^{e}	$_a$ -1.17±0.02 ^{e}	$_a$ 21.62±0.24 ^{c}
8.1	60	$_a$ 52.48±0.73 ^{e}	$_a$ -1.06±0.05 ^{f}	$_a$ 21.82±0.30 ^{c}
13.8	0	$_b$ 62.78±0.89 ^{b}	$_c$ -1.48±0.02 ^{b}	$_a$ 19.56±0.26 ^{a}
13.8	15	$_b$ 60.14±0.86 ^{c}	$_b$ -1.83±0.02 ^{c}	$_b$ 19.81±0.22 ^{a}
13.8	30	$_b$ 59.17±0.71 ^{c}	$_b$ -1.53±0.02 ^{a}	$_b$ 20.44±0.27 ^{b}
13.8	45	$_b$ 54.48±0.63 ^{d}	$_a$ -1.16±0.01 ^{d}	$_b$ 20.84±0.27 ^{c}
13.8	60	$_a$ 52.65±0.72 ^{e}	$_b$ -1.44±0.02 ^{e}	$_b$ 20.39±0.24 ^{b}

Tests were performed in triplicate. a-gMeans within a column with different superscript letters are significantly different ($P<0.05$) a-cMeans within a column with different subscript letters are significantly different ($P<0.05$). CS = Centrifuge Speed, CT = cooling time.

4.3.2.1.1. Effect of Centrifuge Speed

Lightness values (L^*) increased with centrifuge speed (Fig. 4.18a). Compared to the control, L^* values increased by 24% (Table 4.10) indicating that removal of the surface oil result in lightness changes. Color a^* increased by 14% for the chips de-oiled at 8.1 RCF and did not change very much (2%) for those de-oiled at 13.8 RCF when compared the control chips. Color b^* of the chips de-oiled at 8.1 RCF only increased by 3% compared to the control.

In other words, the chips showed more lightness and less redness and yellowness as cooling time increased. As centrifuge speed increased, the oil content of the chips decreased (Table 4.2). The increased centrifuge speed resulted in the draining of more oil from the surface of the chip so that reduced oil content resulted in more lightness and less redness and yellowness. Also, de-oiling resulted in the draining of the brown pigment in the chips.

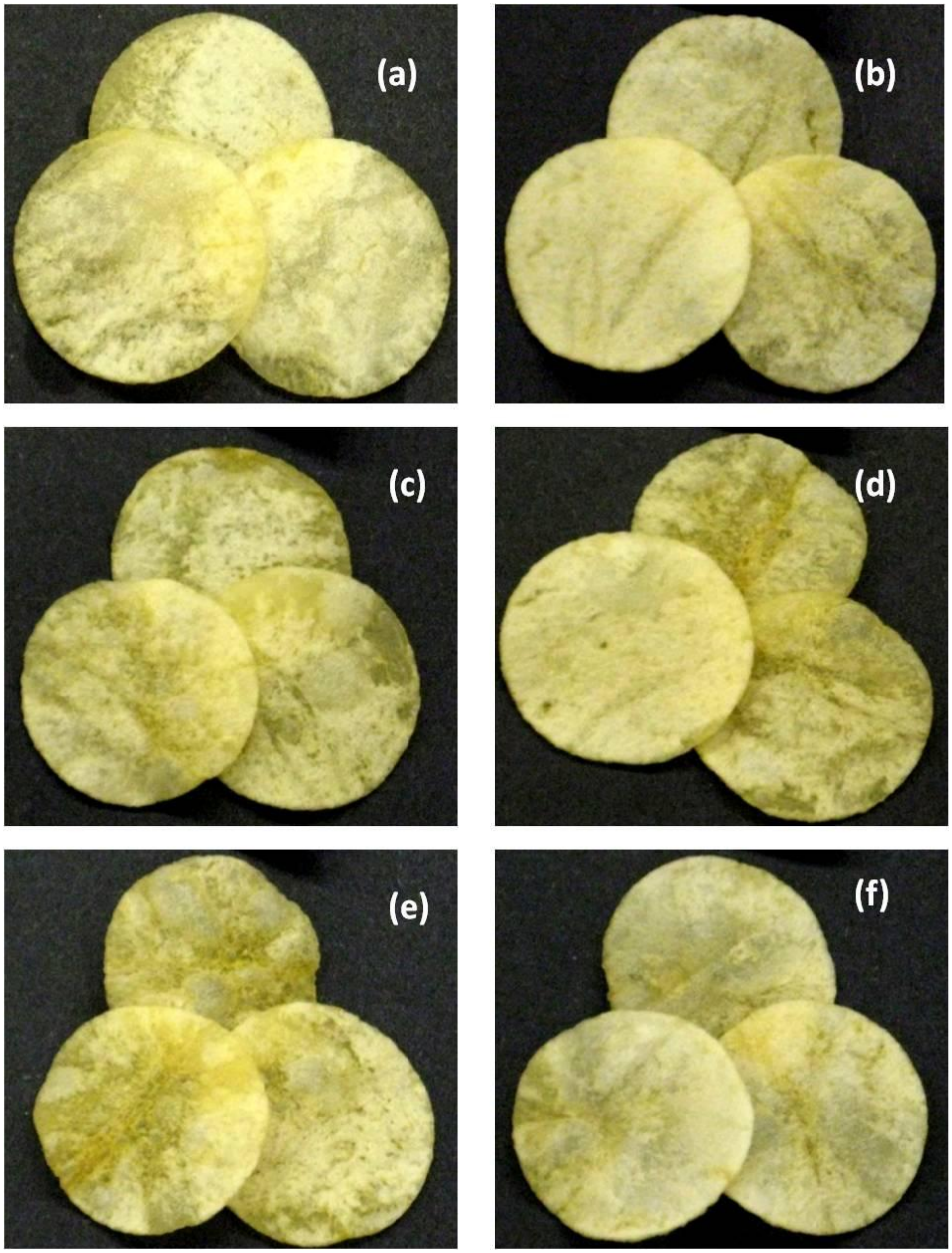

Figure 4.12: Effect of cooling time after de-oiling (8.1 RCF) for no pre-treated potato chips fried at 165^{o}C (a) no de-oiling and 0 s cooling time, (b) 0 s, (c) 15 s, (d) 30 s, (e) 45 s, and (f) 60 s.

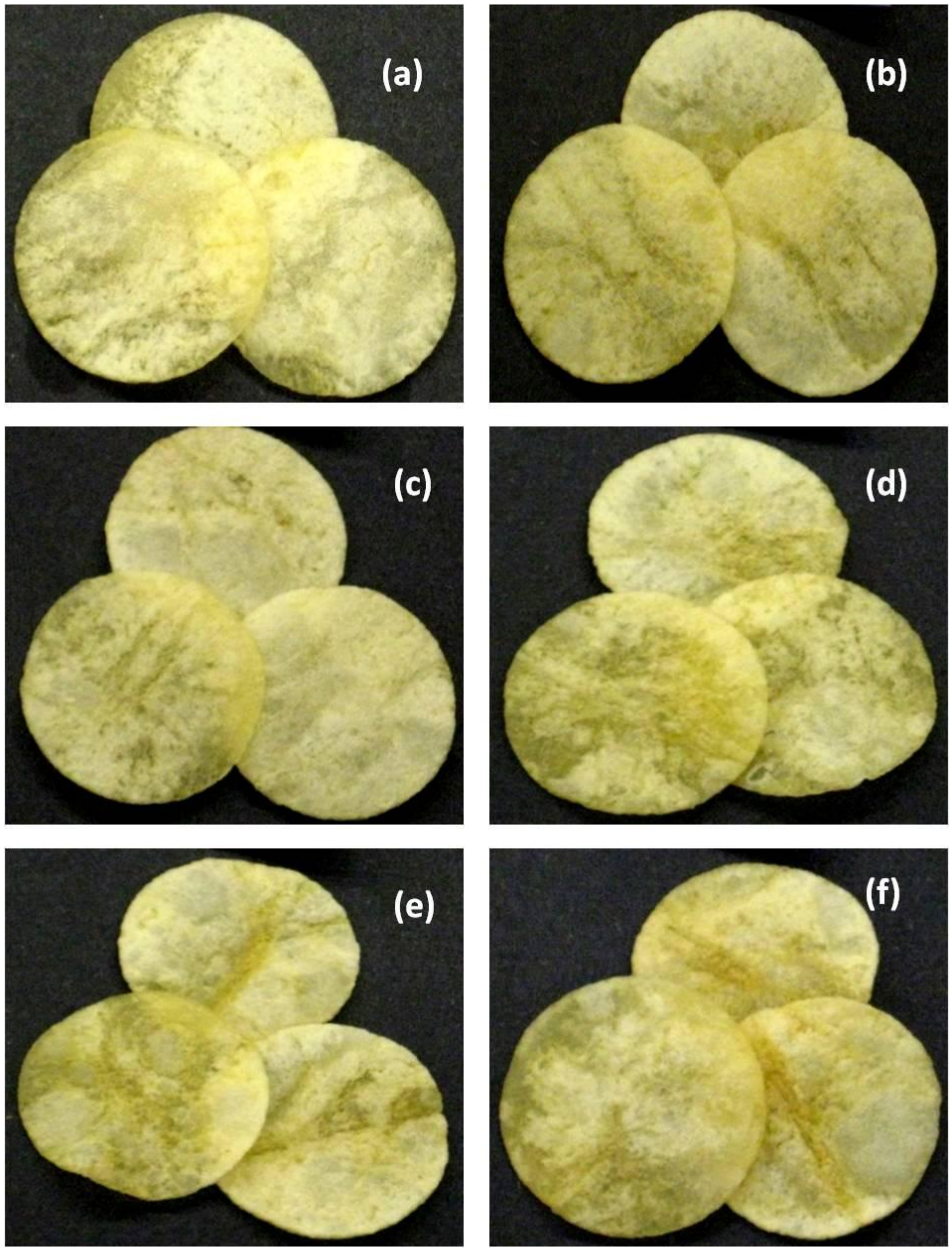

Figure 4.13: Effect of cooling time after de-oiling (13.8 RCF) for no pre-treated potato chips fried at 165°C (a) no de-oiling and 0 s cooling time (b) 0 s, (c) 15 s, (d) 30 s, (e) 45 s and (f) 60 s.

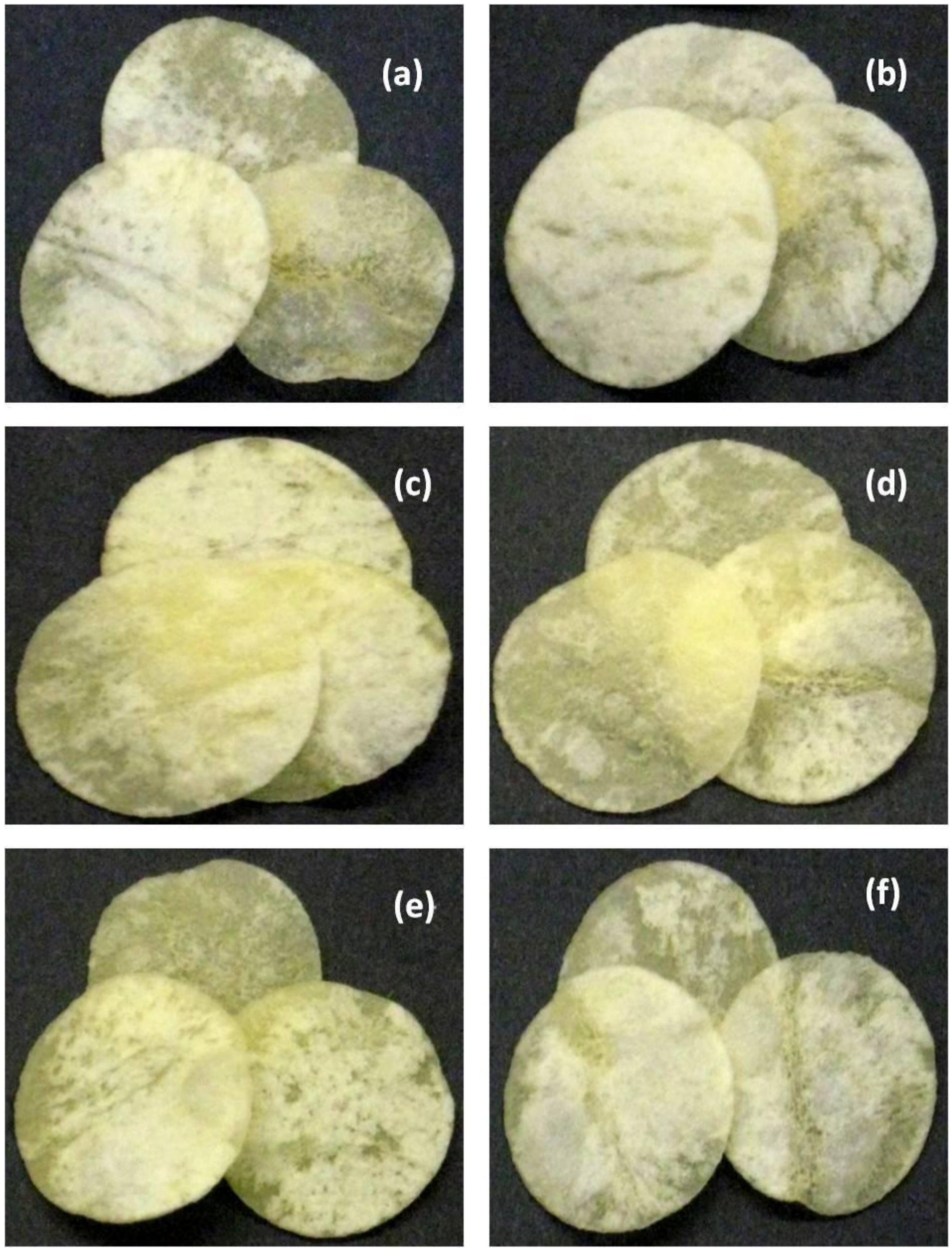

Figure 4.14: Effect of cooling time after de-oiling (8.1 RCF) for potato blanched in hot water at 85^{o}C for 3.5 min and fried at 165^{o}C (a) no de-oiling and 0 s cooling time (b) 0 s, (c) 15 s, (d) 30 s, (e) 45 s, and (f) 60 s.

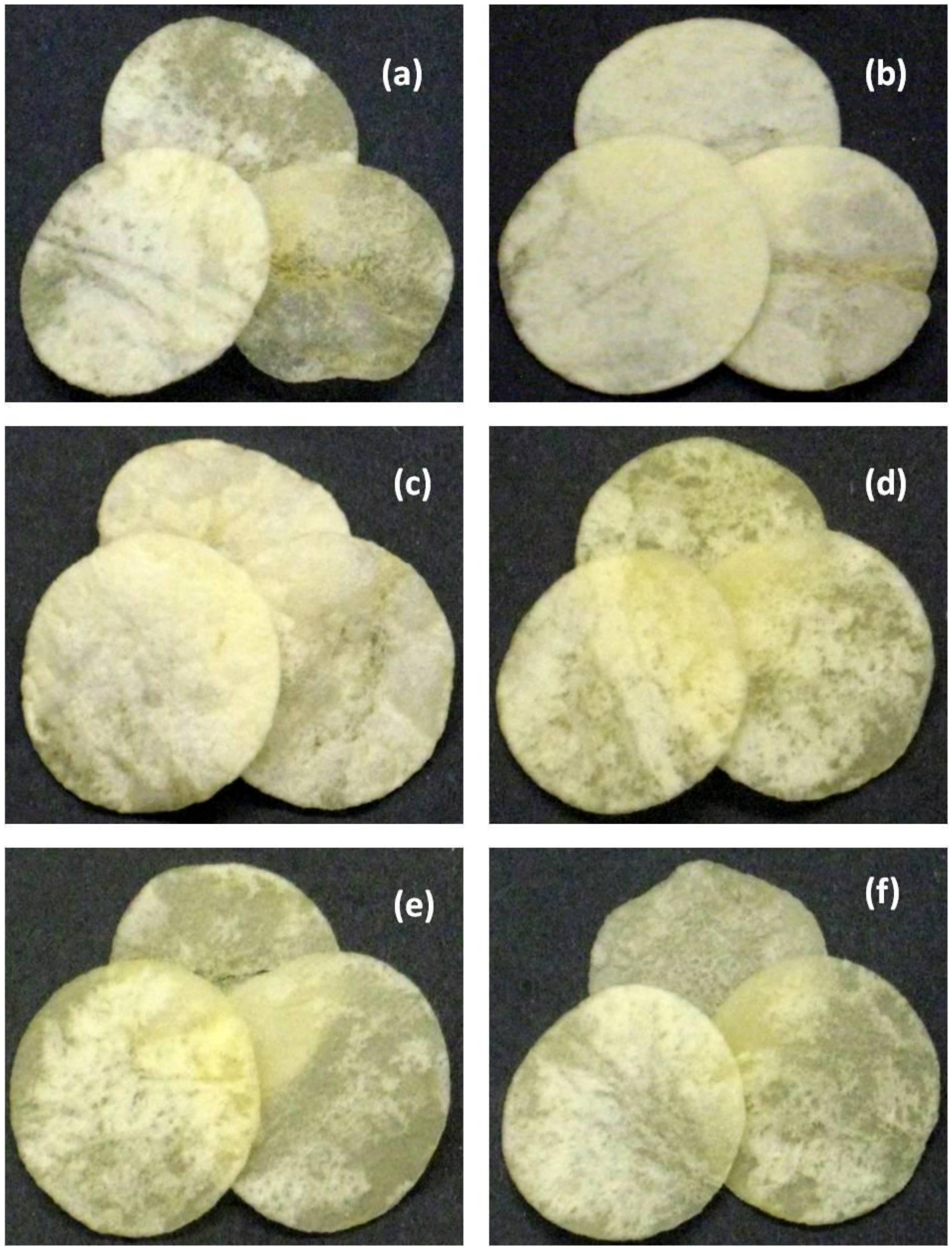

Figure 4.15: Effect of cooling time after de-oiling (13.8 RCF) for potato blanched in hot water at 85^{o}C for 3.5 min and fried at 165^{o}C (a) no de-oiling and 0 s cooling time, (b) 0 s, (c) 15 s, (d) 30 s, (e) 45 s, and (f) 60 s.

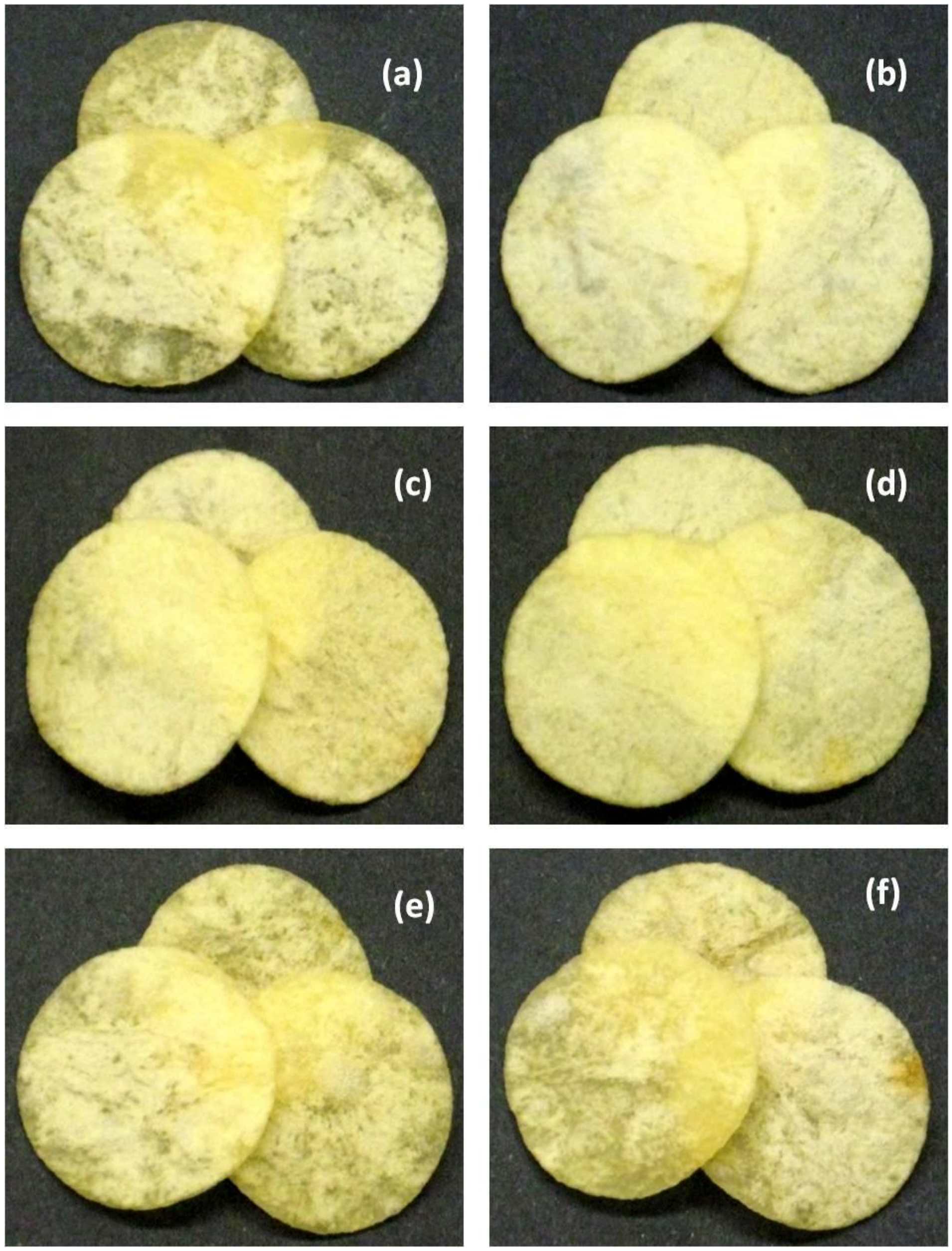

Figure 4.16: Effect of cooling time after de-oiling (8.1 RCF) for potato soaked in 3% NaCl at 25°C for 5 min and fried at 165°C (a) no de-oiling and 0 s cooling time, (b) 0 s, (c) 15 s, (d) 30 s, (e) 45 s, and (f) 60 s.

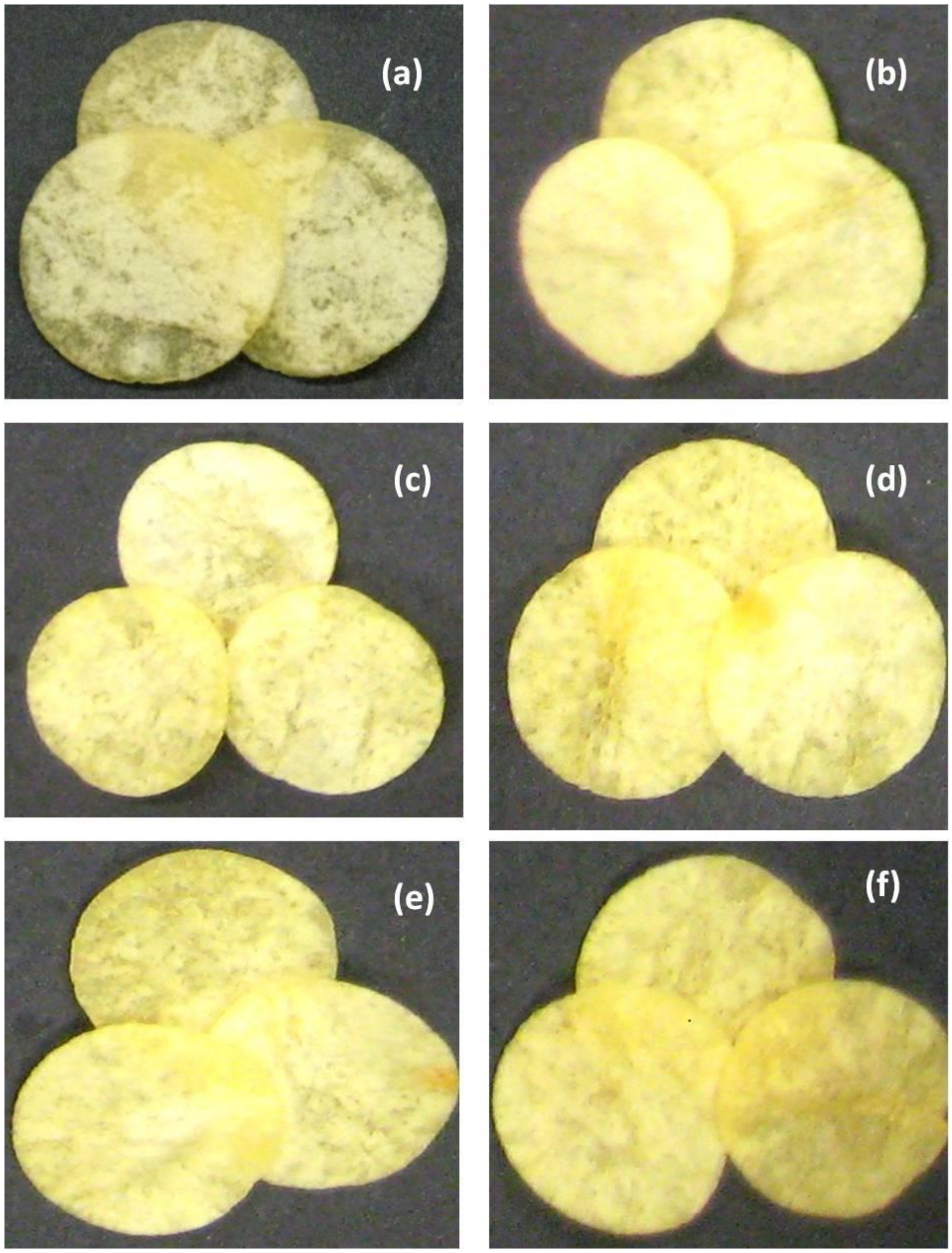

Figure 4.17: Effect of cooling time after de-oiling (13.8 RCF) for potato soaked in 3% NaCl at 25^{o}C for 5 min and fried at 165^{o}C (a) no de-oiling and 0 s cooling time, (b) 0 s, (c) 15 s, (d) 30 s, (e) 45 s, and (f) 60 s.

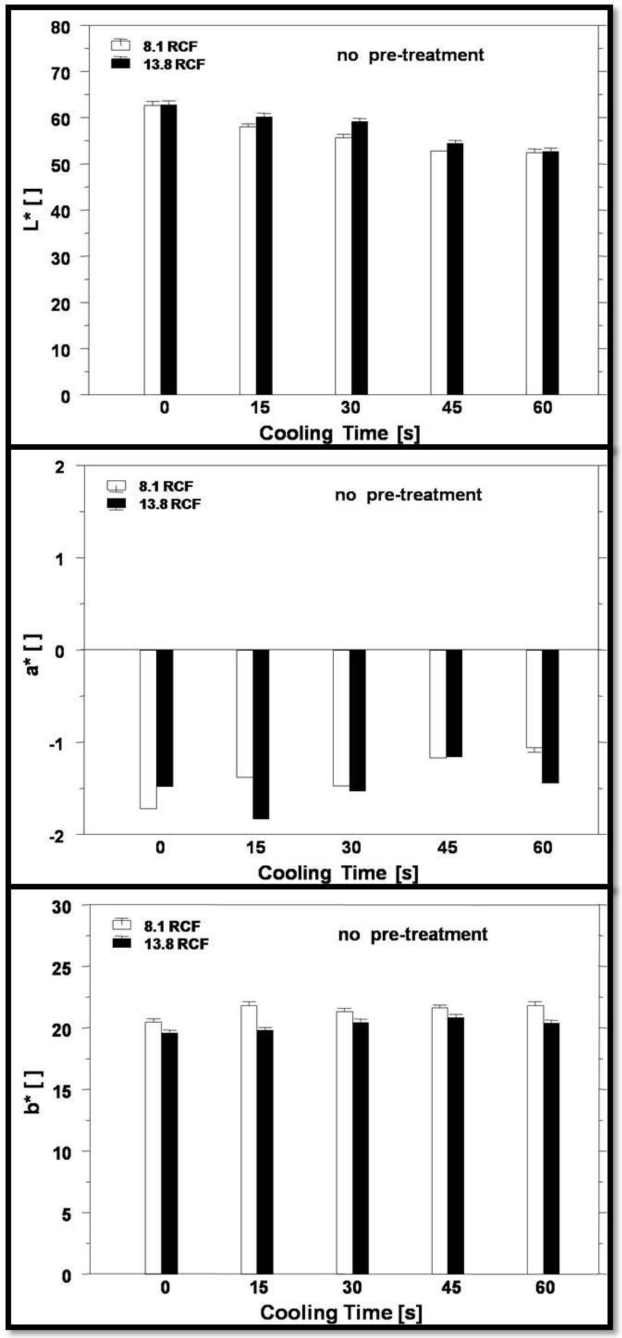

Figure 4.18 Effect of cooling time and centrifuge speed on the color changes of potato chips fried at 165°C without pre-treatment: (a) lightness, *L**; (b) redness, *a**; and (c) yellowness; *b**.

4.3.2.1.2 Effect of Cooling Time

Lightness values (*L**) of the no pre-treated chips decreased with an increase of cooling time for both centrifuge speeds (Fig. 4.18a). The same trend was observed with color *a** for the chips de-oiled at 8.1 RCF (Fig. 4.18b), with exception for the chips cooled for 30 s, which the redness was closer to the control sample. Color *b** did not show any specific trend with cooling time (Fig. 4.18c) with no significant changes (Table 4.10).

4.3.2.2 Blanching in Hot Water at 85^{o}C for 3.5 min

Table 4.11 Effect of centrifuge speed and cooling time on the final oil content of potato chips blanched in 85^{o}C water for 3.5 min before frying at 165^{o}C.

CS (RCF)	CT (s)	*L**	a*	b*
0	0	$_{a}$52.85±0.63^{a}	$_{a}$-2.37±0.24^{a}	$_{a}$15.17±0.21^{a}
8.1	0	$_{b}$59.48±0.82^{b}	$_{b}$-2.11±0.27^{a}	$_{b}$17.46±0.16^{b}
8.1	15	$_{a}$57.57±0.79^{c}	$_{a}$-1.71±0.47^{b}	$_{a}$18.49±0.21^{c}
8.1	30	$_{a}$58.99±0.77^{b}	$_{a}$-2.31±0.08^{a}	$_{a}$16.81±0.20^{d}
8.1	45	$_{a}$53.54±0.70^{d}	$_{a}$-1.57±0.20^{b}	$_{a}$18.96±0.09^{e}
8.1	60	$_{a}$55.44±0.65^{e}	$_{a}$-0.96±0.51^{c}	$_{a}$19.20±0.22^{f}
13.8	0	$_{c}$62.57±0.83^{f}	$_{c}$-1.55±0.40^{b}	$_{c}$18.63±0.23^{c}
13.8	15	$_{b}$59.00±0.65^{b}	$_{b}$-1.05±0.91^{c}	$_{b}$19.32±0.25^{f}
13.8	30	$_{b}$56.44±0.69^{g}	$_{b}$-1.63±0.27^{b}	$_{b}$17.51±0.22^{b}
13.8	45	$_{b}$59.52±0.76^{b}	$_{b}$-1.74±0.04^{b}	$_{b}$17.13±0.21^{g}
13.8	60	$_{b}$57.14±0.81^{c}	$_{b}$-0.78±0.50^{c}	$_{b}$20.88±0.29^{h}

Tests were performed in triplicate. a-gMeans within a column with different superscript letters are significantly different (P<0.05) a-cMeans within a column with different subscript letters are significantly different (P<0.05). CS = Centrifuge Speed, CT = cooling time

4.3.2.2.1 Effect of Centrifuge Speed

Compared with the control samples (Table 4.11), lightness values increased by 13% and 18% for the chips de-oiled at 8.1 RCF and 13.8 RCF, respectively. Color a* decreased by 11% and 35% and color b* decreased by 15% and 23% for the chips de-oiled at 8.1 RCF and 13.8 RCF, respectively. In general, L* and b* values were higher, while a* values were lower, for the chips de-oiled at 13.8 RCF than at 8.1 RCF (Fig. 4.19).

In other words, the chips showed more lightness and less redness and yellowness. As centrifuge speed increased, the oil content of the chips decreased (Table 4.2). The increased centrifuge speed resulted in the draining of more oil from the surface of the chip. Also, de-oiling resulted in the draining of the brown pigment in the chips.

4.3.2.2.2 Effect of Cooling Time

No significant changes ($P<0.05$) were observed for the values of L* when the chips were cooled from 0-30 s (8.1 RCF). The chips lightness values were closer to the control after cooling from 45 to 60 s (Fig. 4.19a). The value of a* was higher for the chips cooled for 30 s and de-oiled at 8.1 RCF and the lowest value for the chips cooled for 60 s at 13.8 RCF (Fig. 4.19b). The b* values were lower for the chips cooled for 30 s (Fig. 4.19c).

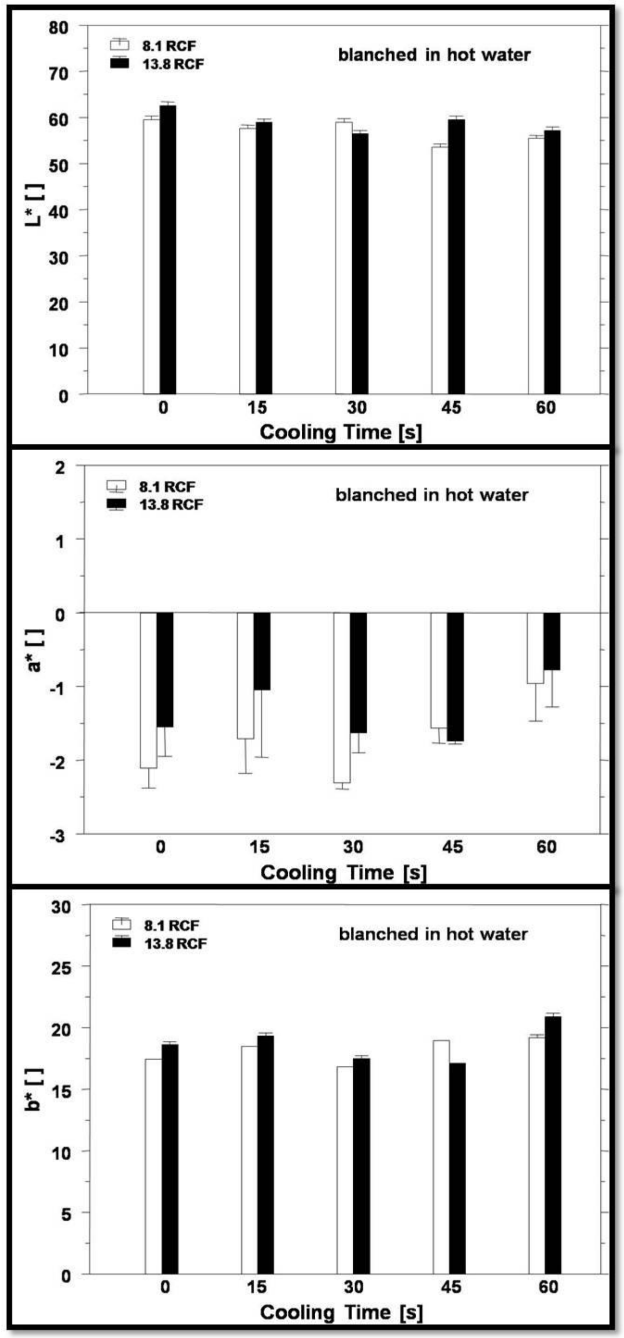

Figure 4.19 Effect of cooling time and centrifuge speed on the color changes of potato chips blanched at 85^{o}C for 3.5 min before frying at 165^{o}C: (a) lightness, L*; (b) redness, a*; and (c) yellowness; b*.

4.2.2.3 Soaking in 3% NaCl Solution at 25^{o}C for 5 min

Table 4.12 Effect of centrifuge speed and cooling time on the final oil content of potato chips blanched in 85^{o}C water for 3.5 min before frying at 165^{o}C.

CS (RCF)	CT (s)	L*	a*	b*
0	0	$_{c}$ 51.27±0.74 ^{a}	$_{c}$ -2.50±0.04 ^{a}	$_{c}$ 17.18±0.25 ^{a}
8.1	0	$_{c}$ 60.72±0.80 ^{b}	$_{b}$ -1.81±0.03 ^{b}	$_{c}$ 20.86±0.25 ^{b}
8.1	15	$_{b}$ 56.55±0.80 ^{c}	$_{c}$ -2.02±0.03 ^{c}	$_{c}$ 21.55±0.27 ^{c}
8.1	30	$_{a}$56.01±0.71 ^{c,d}	$_{c}$ -1.79±0.03 ^{b}	$_{c}$ 22.79±0.31^{d}
8.1	45	$_{c}$ 57.59±0.64 ^{e}	$_{c}$ -2.44±0.08 ^{d}	$_{c}$ 21.25±0.30 ^{e}
8.1	60	$_{c}$ 60.37±0.72 ^{b}	$_{b}$ -2.14±0.04 ^{e}	$_{c}$ 21.32±0.30 ^{f}
13.8	0	$_{b}$ 60.26±0.82 ^{b}	$_{b}$ -2.61±0.04 ^{f}	$_{b}$ 18.45±0.25 ^{g}
13.8	15	$_{c}$ 61.35±0.83 ^{f}	$_{c}$ -2.36±0.04 ^{g}	$_{c}$ 20.80±0.28 ^{b}
13.8	30	$_{c}$ 55.75±0.74 ^{d}	$_{a}$ -1.60±0.02 ^{h}	$_{c}$ 24.39±0.20 ^{h}
13.8	45	$_{c}$ 55.46±0.76 ^{d}	$_{a}$ -1.54±0.02 ^{i}	$_{c}$ 25.47±0.36 ^{i}
13.8	60	$_{c}$ 57.79±0.72 ^{e}	$_{c}$ -1.63±0.02 ^{j}	$_{c}$ 22.22±0.29 ^{j}

Tests were performed in triplicate. a-gMeans within a column with different superscript letters are significantly different ($P<0.05$) a-cMeans within a column with different subscript letters are significantly different ($P<0.05$). CS = Centrifuge Speed, CT = cooling time

4.2.2.3.1 Effect of Centrifuge Speed

The lightness (*L**) values of the chips de-oiled for 8.1 RCF and 13.8 RCF decreased by 18% compared to the control samples (Table 4.12). The *L** values were higher for the chips de-oiled at the lower speed (Fig. 4.20a) with exception for the chips cooled at 15 s. Color values *a** (Fig. 4.20b) decreased by 28% and increased by only 4% when the chips were centrifuged at 8.1 RCF and 13.8 RCF, respectively. Yellowness (*b**) values (Fig. 4.20c) increased by 21% and 7% at 8.1 RCF and 13.8 RCF, respectively.

In other words, the chips showed less lightness, more redness and yellowness at 15 s and. Then, the chips showed less lightness and less redness and yellowness at 60 s. At 15 s of cooling, as centrifuge speed increased, oil uptake increased; however, after 30 s of cooling the trend was reversed due to temperature decrease through the centrifuge speed itself and the application of cooling time before de-oiling. Therefore, the color of the sample blanched in hot water was influenced by oil uptake.

4.3.2.3.2 Effect of Cooling Time

For the chips de-oiled at 8.1 RCF, lightness values (*L**) decreased by 10% from 0 to 15 s and then remained constant for the chips cooled between 15 and 45 s. For 60 s of cooling time, the *L** value was not significant different from that cooled for 0 s (Fig 4.20a). For the chips de-oiled at 13.8 RCF, the *L** values were lower between 30-60 s of cooling.

The *a** value was the highest for the chips cooled for 0 s and the lowest for chips cooled for 45 s and de-oiled for 13.8 RCF (Fig. 4.10b).

Color *b** values increased up to 32% from 0 to 30 s and for the chips de-oiled at 8.1 RCF and increased up to 48% from 0 to 45 s for the chips de-oiled at 13.8 RCF (Fig. 4.20c). These values correlated very well with the oil content results (Fig. 4.4), i.e., the higher the oil content the higher the *b** value.

4.3.2.4 Comparison between Controls and Pre-Treated Chips

The highest *L** value (Tables 4.10-4.12) was observed for the chips that were blanched before frying (control); the lowest *L** value was for the chips that were no pre-treated before frying. Also, the chips showed the lowest redness and yellowness. So, blanching cause the chips to be lighter in color, less yellow, and less dark than the other pre-treatments.

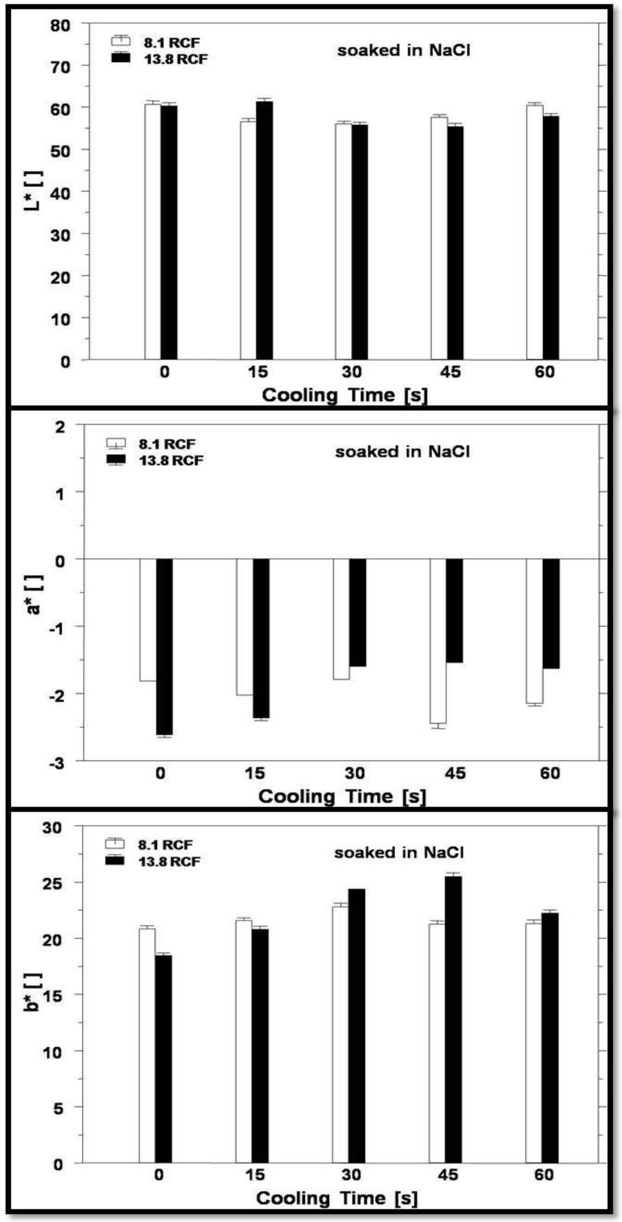

Figure 4.20 Effect of cooling time and centrifuge speed on the color changes of potato chips soaked in 3% NaCl solution at 25°C for 5 min before frying at 165°C: (a) lightness, $L*$; (b) redness, $a*$; and (c) yellowness; $b*$.

4.4 Shrinkage

Tables 4.13 and 4.14 show the values for shrinkage in thickness, diameter, and volume for potato chips processed under different experimental conditions. Higher frying temperature and centrifuge speed, and higher cooling time usually resulted in increasing shrinkage in thickness of potato chips (Table 4.13). Exceptionally, the chips fried at 165°C resulted in the negative number which means the thickness of chips increased during the process.

Blanching in hot water resulted in a decrease in volume shrinkage as a result of decreasing in thickness shrinkage with the same rate of diameter changes (Table 4.14). Shrinkage in thickness, diameter, and volume of the no pre-treated samples and blanched chips had similar trend to each other for the control samples. Chips pre-treated by soaking in NaCl resulted in more expansion than the other pre-treated samples; however, their shrinkage in diameter was similar to the control (0 s cooling and no de-oiling).

4.4.1 De-oiled Chip without Pre-treatment

The degree of shrinkage in thickness and volume of potato chips was significantly affected ($P>0.05$) by oil temperature, cooling time, and the centrifuge force for the non pre-treated samples while the degree of shrinkage in diameter was not significantly affected ($P<0.05$) (Table 4.13).

In French fries fried at 180°C with 1.5 mm thickness, crust started to form when the surface of the potato reached around 103°C in 45 s and 20 s, respectively at 140° and 180°C (Costa et al, 2000). Kawas et al. (2000) found that most diameter shrinkage of tortilla chips occurred in the first 5 s of frying, the thickness increased as a result of crust formation, and gas expansion on the surface caused some bubbles. According to Yamsaengsung et al. (2002a), shrinkage begins to stop, puffing commences due to gas pressure buildup inside the tortilla chip after all the bound water is eliminated and the moisture content of the chip is decreased. Puffing begins after about 20 s of frying at 190°C, or at about 10% moisture content (w.b.) and continues until equilibrium is reached at about 2% moisture content (w.b.). Yamsaengsung et al. (2002b) observed that the higher frying temperature led to a faster drying rate and a faster increase in the temperature and pressure of the product. In other words, shrinkage and puffing are significantly related to the removal of water at low moisture content accelerated by increasing the frying temperature.

According to Yamsaengsung et al. (2002), when a crust, defined as any region with moisture content less than 0.05 (w.b), starts forming at the surface of the tortilla chips, there is an excessive pressure buildup and the product expands and puffs. Bound water residing in the solid matrix of a hygroscopic material leads to shrinkage of the structure when it is removed. As frying continues, the crust region moves toward the center of the product increasing its thickness. During frying, the tortilla chip has both shrinkage in the radial and expansion in thickness due to gas bubble expansion inside the chip. After water has been removed to nearly equilibrium, the temperature at that particular region starts increasing up to the temperature of the oil medium. The temperature near the edges (crust) is already above 100°C, while the temperature at the product's center may still be in the proximity of 100°C. The edge region is the crust region with very little moisture and physical properties significantly different from the high moisture core region.

Table 4.13: Effect of frying temperature, centrifuge speed, and cooling time on the shrinkage in thickness, diameter, and volume of potato chips processed without pre-treatment.

Toil (°C)	CS (RCF)	CT (s)	Thickness (%)	Diameter (%)	Volume (%)
145	0	0	$_{a}14.400\pm2.084^{a}$	$_{a}9.802\pm3.522^{a}$	$_{a}30.034\pm4.832^{a}$
145	8.1	0	$_{a}4.061\pm1.417^{b}$	$_{a}9.075\pm2.302^{a}$	$_{a}21.963\pm2.854^{b}$
145	8.1	60	$_{a}0.960\pm0.319^{c}$	$_{a}10.194\pm1.473^{a}$	$_{a}18.818\pm2.368c$
145	8.1	120	$_{a}8.725\pm2.438^{d}$	$_{a}13.767\pm3.083^{a}$	$_{a}23.959\pm5.241^{d}$
145	13.8	0	$_{a}11.091\pm1.012^{e}$	$_{a}8.604\pm2.125^{a}$	$_{a}20.831\pm2.769^{d}$
145	13.8	60	$_{a}15.987\pm5.060^{e}$	$_{a}8.224\pm0.349^{a}$	$_{a}29.470\pm4.14^{a}$
145	13.8	120	$_{a}8.279\pm3.207^{e}$	$_{a}8.002\pm1.221^{a}$	$_{a}21.956\pm3.392^{b}$
165	0	0	$_{b}18.878\pm3.563^{a}$	$_{a}6.649\pm1.088^{a}$	$_{a}29.493\pm2.573^{a}$
165	8.1	0	$_{a}4.626\pm0.750^{b}$	$_{b}5.976\pm1.316^{a}$	$_{b}15.117\pm2.839^{b}$
165	8.1	60	$_{b}10.746\pm3.319^{c}$	$_{b}6.702\pm1.048^{a}$	$_{a}21.926\pm3.984^{c}$
165	8.1	120	$_{a}7.890\pm3.667^{c}$	$_{b}7.487\pm1.093^{a}$	$_{b}17.594\pm3.422^{b}$
165	13.8	0	$_{b}8.360\pm2.155^{c}$	$_{b}3.699\pm1.427^{b}$	$_{b}15.336\pm4.693^{b}$
165	13.8	60	$_{a}11.204\pm3.568^{c}$	$_{b}5.858\pm0.738^{a}$	$_{b}21.319\pm3.937^{c}$
165	13.8	120	$_{b}-3.845\pm1.997^{d}$	$_{a}8.208\pm1.994^{b}$	$_{b}14.296\pm1.993^{b}$
185	0	0	$_{c}9.942\pm2.515^{a}$	$_{a}6.219\pm1.529^{a}$	$_{c}16.575\pm1.869^{a}$
185	8.1	0	$_{b}11.579\pm2.992^{a}$	$_{b}6.817\pm1.785^{a}$	$_{a}23.517\pm3.422^{b}$
185	8.1	60	$_{b}13.403\pm2.275^{a,b}$	$_{b}5.749\pm1.528^{a}$	$_{a}23.514\pm2.275^{b}$
185	8.1	120	$_{a}7.805\pm2.966^{b}$	$_{b}6.010\pm1.391^{a}$	$_{b}18.379\pm2.381^{a}$
185	13.8	0	$_{b}10.735\pm2.695^{a}$	$_{c}5.742\pm1.485^{a}$	$_{b}17.082\pm3.941^{a}$
185	13.8	60	$_{a}14.780\pm2.876^{c}$	$_{b}6.176\pm1.386^{a}$	$_{c}25.001\pm2.703^{b}$
185	13.8	120	$_{a}17.467\pm4.032^{d}$	$_{b}5.576\pm0.691^{a}$	$_{c}26.444\pm3.343^{b}$

Tests were performed in triplicate.
a-gMeans within a column with different superscript letters are significantly different (P<0.05) a-cMeans within a column with different subscript letters are significantly different (P<0.05)
Toil = oil temperature, CS = Centrifuge Speed, CT = cooling time

Table 4.14: Shrinkage in thickness, diameter, and volume of potato fried at 165^{o}C and cooled at different times and de-oiled at different centrifuge speeds.

	CS (RCF)	CT (s)	Thickness (%)	Diameter (%)	Volume (%)
	0	0	${}_{a}12.492+1.144^{a}$	${}_{a}7.419+1.215^{a}$	${}_{a}24.973+2.485^{a}$
	8.1	0	${}_{a}9.549+1.819^{b}$	${}_{a}7.666+1.253^{a}$	${}_{a}22.867+2.765^{a}$
	8.1	15	${}_{a}9.026+1.534^{b}$	${}_{a}7.873+1.433^{a}$	${}_{a}22.774+2.588^{a}$
	8.1	30	${}_{a}7.343+1.154^{c}$	${}_{a}7.022+1.297^{a}$	${}_{a}19.984+2.160^{a}$
	8.1	45	${}_{a}7.238+1.616^{c}$	${}_{a}6.945+1.141^{a}$	${}_{a}19.991+2.026^{a}$
A	8.1	60	${}_{a}12.463+1.835^{d}$	${}_{a}7.573+1.232^{a}$	${}_{a}25.204+2.026^{b}$
	13.8	0	${}_{a}10.616+1.806^{b}$	${}_{a}7.230+1.418^{a}$	${}_{a}22.556+2.738^{c}$
	13.8	15	${}_{a}8.626+1.475^{c}$	${}_{a}7.328+0.783^{a}$	${}_{a}21.524+1.780^{c}$
	13.8	30	${}_{a}5.761+1.448^{c}$	${}_{a}7.365+1.485^{a}$	${}_{a}19.124+2.439^{c}$
	13.8	45	${}_{a}7.337+1.389^{c}$	${}_{a}6.601+0.751^{a}$	${}_{a}19.152+2.200^{c}$
	13.8	60	${}_{a}9.957+1.233^{b}$	${}_{a}7.177+1.038^{a}$	${}_{a}22.406+2.156^{c}$
	0	0	${}_{a}8.230+1.525^{a}$	${}_{a}6.802+1.726^{a}$	${}_{b}20.289+2.497^{a}$
	8.1	0	${}_{b}-4.661+2.242^{b}$	${}_{a}7.138+1.558^{a}$	${}_{b}10.234+3.316^{b}$
	8.1	15	${}_{b}5.209+1.606^{c}$	${}_{a}6.583+1.513^{a}$	${}_{b}17.267+2.730^{c}$
	8.1	30	${}_{b}9.184+1.594^{d}$	${}_{a}5.706+1.910^{a}$	${}_{a}19.875+3.612^{c}$
	8.1	45	${}_{b}1.364+0.878^{e}$	${}_{b}9.007+1.894^{b}$	${}_{a}18.401+2.131^{c}$
B	8.1	60	${}_{b}6.966+1.545^{c}$	${}_{b}4.325+1.516^{c}$	${}_{b}15.519+2.131^{d}$
	13.8	0	${}_{b}2.010+1.072^{e}$	${}_{a}7.498+1.748^{a}$	${}_{b}14.154+2.688^{d}$
	13.8	15	${}_{b}2.745+1.889^{e}$	${}_{a}6.434+1.371^{a}$	${}_{b}14.891+2.178^{d}$
	13.8	30	${}_{b}3.884+1.351^{e}$	${}_{a}6.649+1.051^{a}$	${}_{b}16.001+2.497^{c}$
	13.8	45	${}_{b}12.437+0.998^{f}$	${}_{a}6.649+1.958^{a}$	${}_{b}23.998+3.068^{e}$
	13.8	60	${}_{b}6.066+1.426^{c}$	${}_{a}7.098+1.717^{a}$	${}_{b}18.899+3.298^{c}$
	0	0	${}_{c}-10.105+2.059^{a}$	${}_{c}9.620+1.360^{a}$	${}_{c}10.055+2.746^{a}$
	8.1	0	${}_{c}-13.826+2.252^{b}$	${}_{c}9.202+0.692^{a}$	${}_{c}6.154+2.332^{b}$
	8.1	15	${}_{c}-10.791+2.185^{a}$	${}_{c}10.133+1.943^{a}$	${}_{c}11.760+2.599^{a}$
	8.1	30	${}_{c}-19.736+2.013^{c}$	${}_{c}12.513+1.371^{b}$	${}_{c}9.145+2.757^{a}$
	8.1	45	${}_{c}-19.279+2.175^{c}$	${}_{c}11.427+1.472^{b}$	${}_{c}7.708+2.532^{b}$
C	8.1	60	${}_{c}-14.506+2.732^{d}$	${}_{b}9.620+1.360^{a}$	${}_{c}7.092+2.532^{b}$
	13.8	0	${}_{c}-18.159+2.011^{c}$	${}_{c}10.436+1.317^{a}$	${}_{c}7.046+2.356^{b}$
	13.8	15	${}_{c}-19.397+2.841^{c}$	${}_{c}9.722+0.232^{a}$	${}_{c}3.438+1.655^{c}$
	13.8	30	${}_{c}-18.629+1.848^{c}$	${}_{c}12.220+1.425^{b}$	${}_{c}9.592+2.209^{a}$
	13.8	45	${}_{c}-14.467+1.885^{d}$	${}_{c}11.898+1.698^{b}$	${}_{c}11.750+2.866^{d}$
	13.8	60	${}_{c}-19.196+2.025^{c}$	${}_{c}13.343+1.384^{b}$	${}_{c}11.238+3.102^{d}$

Tests were performed in triplicate.
a-fMeans within a column with different superscript letters are significantly different ($P<0.05$) a-cMeans within a column with different subscript letters are significantly different ($P<0.05$) - A = no pre-treatment, B= blanched in hot water at 85°C for 3.5 min, C = soaked in 3% NaCl solution at 25oC for 5 min, CS = centrifuge speed, CT = cooling time

The control samples showed that shrinkage in thickness usually increased with increasing frying temperature (Table 4.13), except for the chips fried at 185°C, where shrinkage decreased. Shrinkage in diameter decreased for the chips fried at 145° and 165°C and stayed constant at about 6.5% from 165-185°C. Shrinkage in volume decreased with temperature.

4.4.1.1 Effect of Temperature

Figure 4.21 presents the effect of temperature on thickness change rate with respect to centrifuge speed for 0, 60, and 120 s of cooling time. Among these three variables, 0 s and 60 s of cooling time is the one that showed the trend that thickness in shrinkage increased as frying temperature increases for the chips de-oiled at 8.1 RCF (Fig. 4.21a and 4.22b). This observation was in agreement with the work of Costa et al. (2001) who reported that a higher temperature promoted faster shrinkage resulting in shrinkage increasing with an increase in temperature. Yamsaengsung et al (2002) observed this with chips fried at130°, 160°, and 190°C, the chips friend at 190°C began to form crust fastest, as expected.

For 120 s of cooling time with de-oiling at 8.1 RCF, the shrinkage of the chip in thickness was not depended on the frying temperature and remained constant at about 8 to 9% (Fig. 4.21c). However, at 13.8 RCF the shrinkage in thickness of the chips fried for 165°C had a 4% increase in expansion (negative value). The chips cooled for 0 s and 60 s remained constant at about 11% and 15% for the chips fried at 145° and 185°C, respectively at 13.8 RCF. Shrinkage increased to 8% and 11% for chips fried at 165°C for these cooling times.

Figure 4.22 presents the effect of temperature on shrinkage in volume with respect to centrifuge speed for 0 s, 60 s, and 120 s of cooling time. Shrinkage in volume for chips cooled for 0 s and 120 s usually decreased as frying temperature increased up to 165°C and increased at 185°C (Fig. 4.22a and 4.22c), while the shrinkage at 60 s of cooling time did not change significantly (with exception for the chips fried at 145°C and de-oiled at 13.8 RCF) (Fig. 4.22b).

4.4.1.2 Effect of Centrifuge Speed

Centrifuge speed decreased the shrinkage rate of the chips less at 8.1 RCF than at 13.8 RCF (Figure 4.21). In other words, shrinkage decreased with increasing centrifuge speed causing the movement of substances in the pores from the center to the edge of the chip. However, shrinkage of the chips fried at 165°C, cooled for 120 s and de-oiled at 13.8 RCF (Fig. 4.21c) changed the sign of the value to negative, which means there was an increase in thickness of the chip compared to the raw slice. Thickness increased as a result of crust formation, and gas expansion on the surface caused some bubbles during frying.

Kawas et al. (2000) reported that most diameter shrinkage of tortilla chips occurred in the first 5 s of frying, the thickness increased as a result of crust formation, and gas expansion on the surface caused some bubbles. During frying, the tortilla chip has both shrinkage in the radial and expansion in thickness due to gas bubble expansion inside the chip (Yamsaengsung, 2002). In other words, the shrinkage in the diameter of tortilla chips is much less than in the thickness resulting from puffing before cooling and de-oiling.

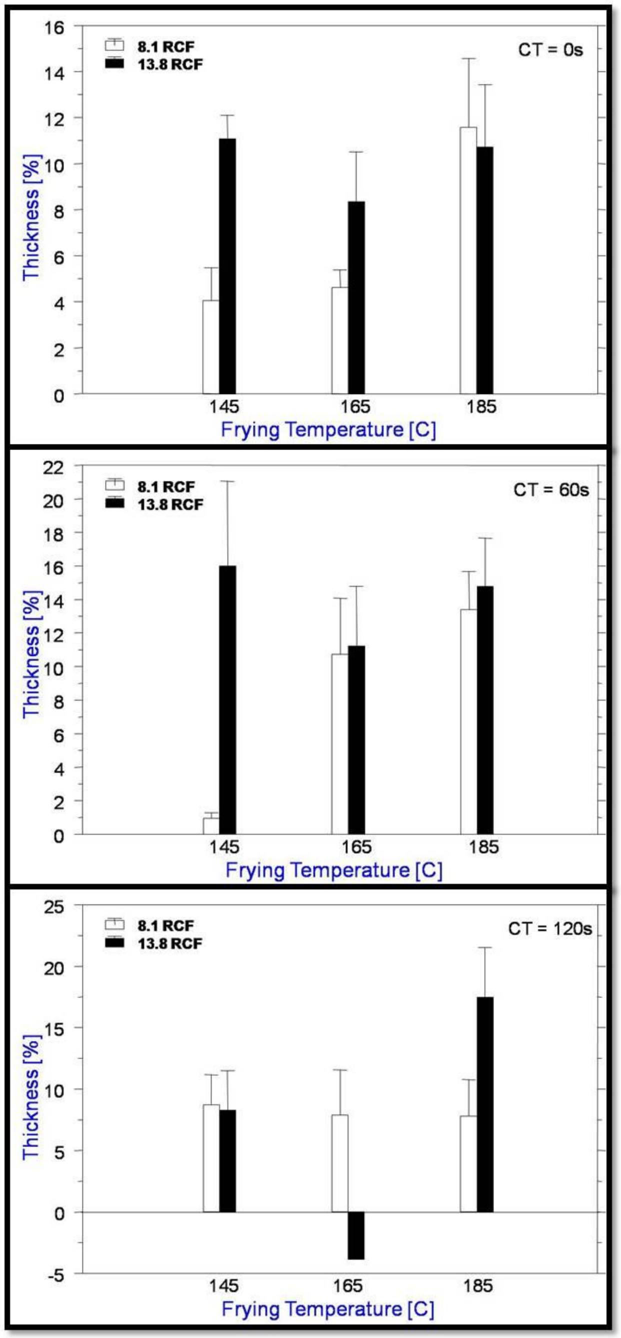

Figure 4.21: Shrinkage in thickness as a function of frying temperatures for potato chips (without pre-treatment) cooled for (a) 0 s; (b) 60 s; (c) 120 s and de-oiled at different centrifuge speeds.

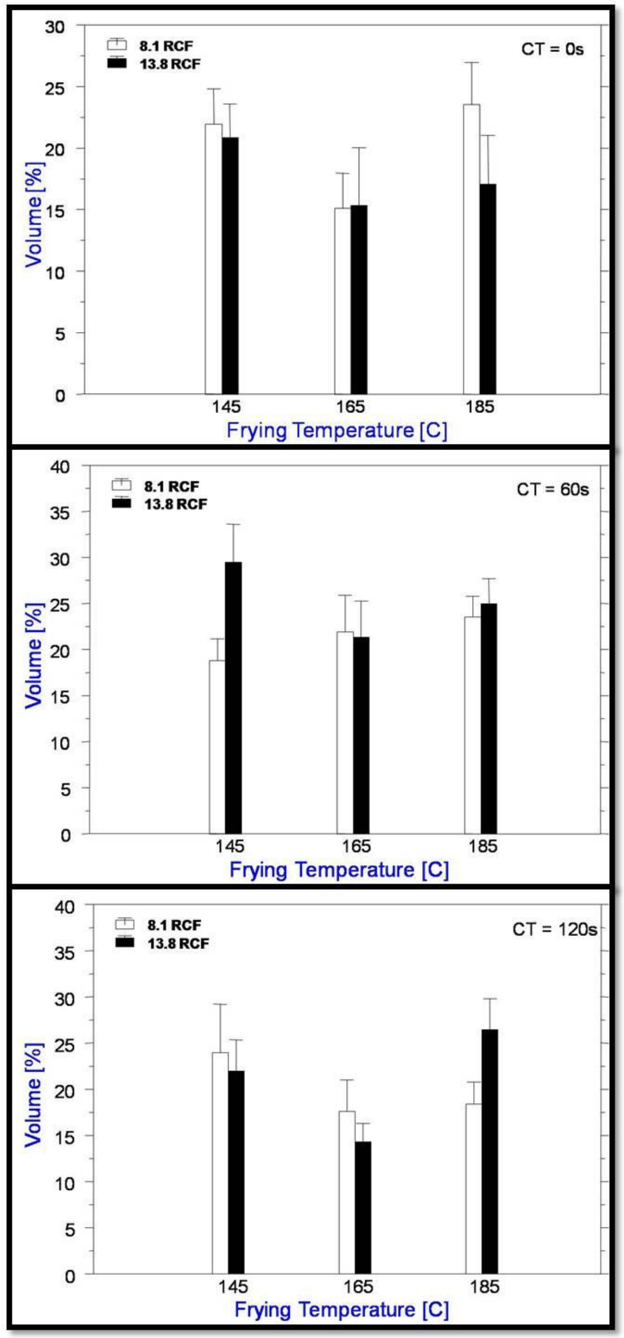

Figure 4.22: Shrinkage in volume as a function of frying temperatures for potato chips (without pre-treatment) cooled for (a) 0 s; (b) 60 s; (c) 120 s and de-oiled at different centrifuge speeds.

Shrinkage in diameter decreased with centrifuge force increase (Table 4.13). Since the higher the frying temperature, the faster the crust forms, the chips fried at higher temperatures resulted in less softness and decreased shrinkage. During de-oiling, the oil in the chips migrated to the edge of the chips and discharged from the chips. The speed of the centrifuge determined the position of the oil so that the faster the de-oiling process, the more oil discharged, resulting in an increased shrinkage rate.

Shrinkage in volume increased with increasing of centrifuge speed for the chips fried at 145°C (cooled for 60 s) or fried 185°C (cooled for 120 s) (Fig. 4.22b and 4.22c). Higher frying temperature promoted the faster formation of crust resulting in less flexibility in the crust, compared to lower frying temperatures. Therefore, centrifuge speed affected the shrinkage in volume at lower temperatures.

4.4.1.3 Effect of Cooling Time

Shrinkage in thickness usually resulted in an increase in shrinkage from 145-165°C then in a decrease from 165-185°C as cooling time increased (Fig. 4.21). This trend was different for the chips fried 185°C and de-oiled at 13.8 RCF where shrinkage in thickness increased with increased cooling time.

Generally, as cooling time increased, the shrinkage in diameter increased (145° and 165°C) (Table 4.13).

At each cooling time, the shrinkage in volume had the same trend (Fig.4.21a and 4.21c), showing a lower value at 165°C.

4.4.2 De-oiled Chip with Pre-treatments

The degree of shrinkage in thickness, diameter, and volume of potato chips blanched in hot water and soaked in 3% NaCl solution was significantly affected (P>0.05) by the cooling time and the centrifuge speed (Table 4.10). Those pre-treatments affect significantly (P>0.05) the shrinkage in thickness, diameter, and volume (Table 4.10).

4.4.2.1 No Pre-treatment

4.4.2.1.1 Effect of Centrifuge Speed

Figures 4.23a and 4.24a and Table 4.14 present the effect of centrifuge speed on shrinkage in thickness, diameter, and volume of no pre-treated potato chips from raw slices, respectively, for 0 s, 15 s, 30 s, 45 s, and 60 s of cooling time. Changing centrifuge speed and cooling time did not significantly influence (P>0.05) the shrinkage in thickness and volume (Table 4.14).

Shrinkage in thickness ranged from 7% to 12% with cooling time and centrifuge speed. Shrinkage in diameter (7% to 8%) did not change with centrifuge speed and cooling time. Shrinkage in volume ranged between 19% and 25%.

As centrifuge speed increased, shrinkage rate in thickness decreased except at 0 s of cooling time (Figure 4.23a). The de-oiling process moved the oil from the center of the chip to the edge resulting in increased thickness. During the de-oiling process, the vapor pressure in the chip's pores keeps the pores expanded in the center (puffing) attributed to vapor expansion by temperature gradients during frying.

Additionally, cooling is also in progress; however, the temperature change is slow because the chips are under the lid in the fryer. Therefore, the movement of oil in the chip is competing with the resistance of the structural change to shrink the center of the chip. In addition, at 0 s of cooling, the centrifuge force of 8.1 RCF is not enough to drain the oil out of the chip compared to 13.8 RCF. As a result, the chip de-oiled at 8.1 RCF holds more oil at the edge of the chip resulting in an increase in the thickness (Fig. 4.23a).

4.4.2.1.2 Effect of Cooling Time

Cooling time did not significantly influence (P>0.05) the shrinkage in thickness and volume (Table 4.14). As showing in Table 4.14 cooling time did not significantly influence (P>0.05) the shrinkage in diameter. Shrinkage in thickness ranged from 7% to 12% with cooling time and centrifuge speed. Shrinkage in diameter (7% to 8%) did not change with cooling time. Shrinkage in volume ranged between 19% and 25%.

As cooling time increases, the thickness of the chip continues to increase due to oil absorption until 30 s of cooling, and then the thickness of the chip starts decreasing due to an increase in the pressure gradient attributed to cooling.

Figure 4.24a shows a trend similar to the shrinkage in thickness since volume is a function of thickness and diameter, and only the thickness varied in the study.

4.4.2.2 Blanching in Hot Water at 85°C for 3.5 min

Figures 4.23b and 4.24b and Table 4.14 present the effects of centrifuge speed on shrinkage in thickness, diameter, and volume of potato chips blanched in hot water at 85^{o}C for 3.5 min before frying and cooled for 0 s, 15 s, 30 s, 45 s, and 60 s of cooling time.

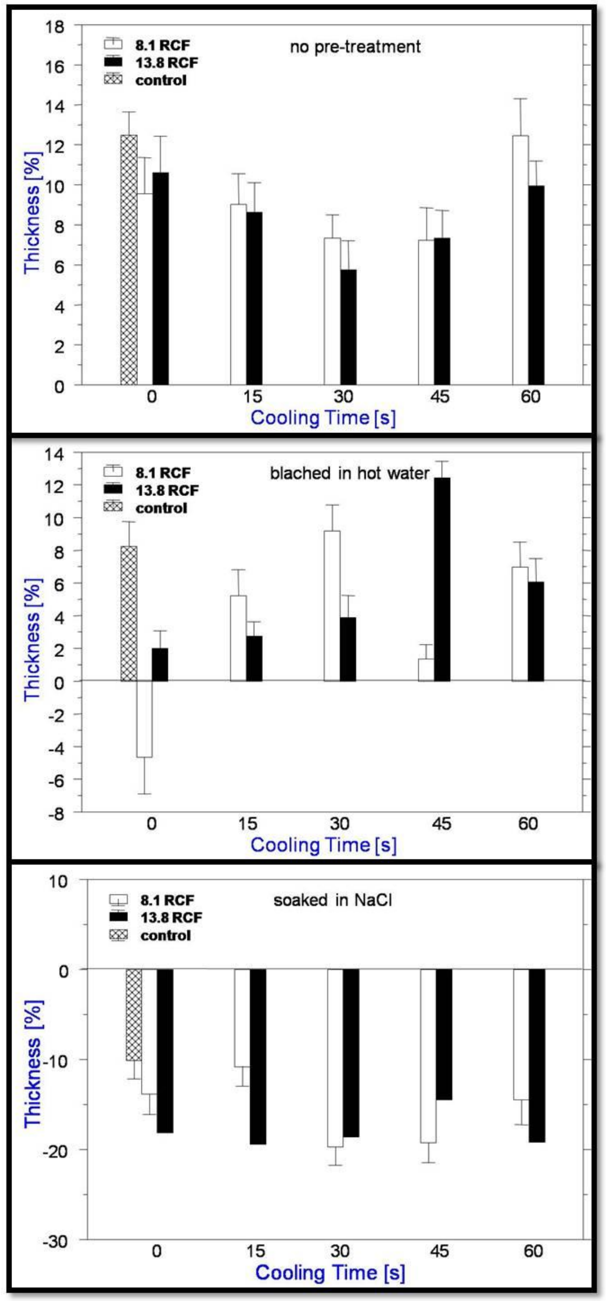

Figure 4.23: Shrinkage in thickness as a function of centrifuge speed for potato chips fried at 165°C, de-oiled under various centrifuge speeds, and with (a) no pre-treatment; (b) blanched in hot water at 85°C for 3.5 min; and (c) soaked in 3% NaCl solution at 25°C for 5 min.

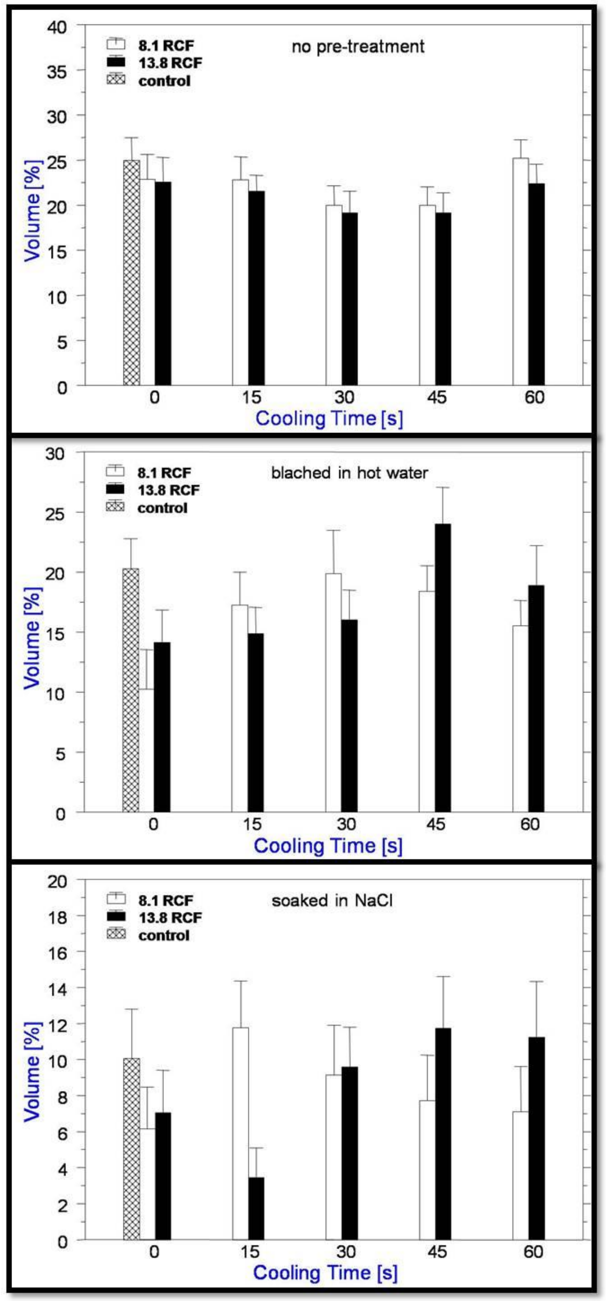

Figure 4.24: Shrinkage in volume as a function of the cooling time for potato chips at 165^{o}C, de-oiled under various centrifuge speeds, and with (a) no pre-treatment; (b) blanched in hot water at 85^{o}C for 3.5 min; and (c) soaked in 3% NaCl solution at 25^{o}C for 5 min.

4.4.2.2.1 Effect of Centrifuge Speed

Changing centrifuge speed and cooling time significantly influenced ($P<0.05$) the shrinkage in thickness (Fig. 4.23b). Shrinkage in diameter varied from 4% to 9% (Table 4.14). The shrinkage in volume was in the range of 10% to 24% (Table 4.14).

Shrinkage in thickness did not show a clear pattern (Figure 4.23b). Change in thickness at 8.1 RCF showed expansion by 5% for the chips cooled for 0 s. Studies reported that a blanched product with lower initial moisture content and higher initial porosity has a greater tendency to raise pressure within the chip's pores during frying, thus causing an expansion of the intercellular spaces (Barat et al., 2001; Moreira et al., 1997; Senadeera, Bhandari, Young, & Wijesinghe, 2005). These structural changes resulted in the increasing thickness of the product since during cooling and de-oiling the expanded pores increased the thickness of the sample. At 45 s of cooling time, the thickness shrinkage of the product de-oiled at 13.8 RCF was much greater than the product de-oiled at 8.1 RCF.

As shown in Table 4.14, the shrinkage in diameter (6% to 9%) did not change with the variables of centrifuge speed and cooling time except at 45 s of cooling time and at 8.1 RCF of centrifuge speed. More expansion occurred on the axial side while more shrinkage continued on the radial side compared to other samples.

Shrinkage in volume (Fig. 4.24b) showed the same trend as shrinkage in thickness since volume as a function of thickness and diameter, and only the thickness varied in study.

4.4.2.2.2 Effect of Cooling Time

Changing cooling time significantly influenced ($P<0.05$) the shrinkage in thickness (Fig. 4.23b). Shrinkage in diameter varied from 4% to 9% (Table 4.14). The shrinkage in volume was in the range of 10% to 24% (Table 4.14).

At 45 s of cooling time, the thickness shrinkage of the product de-oiled at 13.8 RCF was much greater than the product de-oiled at 8.1 RCF. As shown in Table 4.14, the shrinkage in diameter (4% to 9%) did not change with the variables of cooling time except at 45 s of cooling time and at 8.1 RCF of centrifuge speed. More expansion occurred on the axial side while more shrinkage continued on the radial side compared to other samples.

4.4.2.3 Soaking in 3% NaCl Solution at 25°C for 5 min

Figures 4.23c and 4.24c and Table 4.14 present the effect of centrifuge speed on shrinkage in thickness, diameter, and volume of potato chips soaked in 3% NaCl solution for 5 min before frying and cooled for 0 s, 15 s, 30 s, 45 s, and 60 s.

4.4.2.3.1 Effect of Centrifuge Speed

Changing centrifuge speed and cooling time significantly influenced ($P<0.05$) the shrinkage in thickness and in volume. Shrinkage in diameter was in the range between 9% and 13%.

As mentioned in section 4.2.2.4, protein in the chips played a key role in the structure that increased the thickness of chips rather than shrinking it (Figure 4.23c). As centrifuge speed increased, the thickness of the chip increased except for the sample cooled for 45 s, the shrinkage of volume increased except for the sample cooled for 15 s (Table 4.14). Ikoko et al. (2007) studied the effect of osmotic pre-treatment on soaking plantain slices in NaCl. They found that the total volume tended to increase with frying time. Soaking potato strips in a NaCl solution resulted in the penetration of the solute into the potato surface preventing water loss in terms of osmotic dehydration (Bunger, Moyano, & Rioseco, 2002). The solution in the pore reduced the effect of moisture evaporation that expanded the pores on the radial side during frying.

In this study, soaking in 3% NaCl solution prior to frying caused more expansion on the axial side and shrinkage on radial side during frying, cooling, and de-oiling. The thickness change of the slices soaked in an NaCl solution showed a similar pattern with the volume change (Fig. 4.23c and 4.24c). In other words, vapor pressure, shrinkage, and puffing, etc. during processing caused the structural change in the product rather than the change being caused by the centrifuge force. Compared to the control, the NaCl soaking pre-treatment accelerated the expansion on the axial side and shrinkage on radial side during the process (Table 4.14). The pre-treatment resulted in increasing the thickness and diameter shrinkage of the product due to greater force attributed to more expansion during frying. Eventually increasing the thickness compensated for the shrinkage in diameter, and the shrinkage in volume decreased, compared to the control (Fig.4.24c).

4.4.2.3.2. Effect of Cooling Time

Changing cooling time significantly influenced ($P<0.05$) the shrinkage in thickness and in volume. Shrinkage in diameter was in the range between 9% and 13%. In the period of 15 s cooling, thickness at 8.1 RCF decreased and shrinkage in diameter was constant (Table 4.14), while thickness at 13.8 RCF increased. In other words, the natural and mechanical effects were more effective during 15 s of cooling. As cooling time increased, the effect of the centrifuge speed on the product was balanced between 15 s and 30 s of cooling. Centrifuge speed did not significantly influence ($P>0.05$) the shrinkage in volume except at 15 s of cooling time (Figure 4.24c).

4.4.2.4 Comparison between Controls and Pre-treated Chip

All the fried and de-oiled products resulted in a decrease in thickness, diameter, and volume except for the thickness of the chip soaked in NaCl, compared to raw slices (Fig. 4.23 and 4.24). Shrinkage in thickness, diameter, and volume of the no pre-treated and blanched chips were similar to each other. Soaking in NaCl caused more expansion on the axial side and shrinkage on the radial side; however, its shrinkage in volume was similar to the blanched samples.

4.5 Sensory

The sensory analysis was conducted with three groups of potato chips: non-pre-treatment, blanching in hot water at 85°C for 3.5 min, and soaking in a 3% NaCl solution at 25°C for 5 min. The samples without the de-oiling process were considered controls.

Scores higher than or equal to 5 were considered acceptable, based on the nine-point hedonic scale used by Carr, Meilgaard & Civille (1999).

Table 4.15 shows the result for the sensory experiments. Most of the samples scored above 5; however, the samples that scored below 5 were the blanched chips that had higher in oil content and scored low in color and flavor. The samples usually scored higher values for chips cooled for 0 s, which were also the chips with the least oil content. The highest score in color was 7.09±0.10 for chips soaked in 3% NaCl solution, cooled for 0 s, and de-oiled at 13.8. The two highest scores for odor given by the panelist were 6.77±1.23 and 6.64±0.97 for the samples with no pre-treatment, de-oiled for 30 s at 13.8 and 0 s at 0 RCF, respectively. Based on the consumer comments, low scores for odor were for those chips with high oil content, except the chips with no pre-treatment. The highest score for texture was 6.82±0.89 for the samples that were blanched and de-oiled at 13.8 RCF with 30 s of cooling time. The two highest scores in flavor were 6.40±1.50 and 6.20±1.56 for the blanched samples de-oiled at 13.8 RCF for 0 s of cooling, and no pre-treated samples de-oiled at 13.8 RCF for 60 s of cooling, respectively. The two highest scores in overall quality were 6.57±1.36 and 6.55±1.36 for the samples soaked in 3% NaCl solution and de-oiled at 8.1 RCF for 0 s of cooling, and the samples blanched and de-oiled at 8.1 RCF for 0 s of cooling.

In summary, according to the consumer panelists, blanching and de-oiling without cooling enhanced texture and overall quality of the chip, soaking and de-oiling improved the color, flavor, and the overall quality, and the two pre-treatments did not influence the odor of the chip.

Table 4.15: Sensory attributes of potato chips fried at 165^{o}C and processed under different pre-treatments, centrifuge speeds, and cooling times.

	CS (RCF)	CT (s)	Color	Odor	Texture	Flavor	Overall
	0	0	$_{a}6.50\pm1.43^{a}$	$_{a}6.64\pm0.97^{a,b}$	$_{a}5.70\pm1.75^{a,b}$	$_{a,b}4.60\pm2.23^{a}$	$_{a}5.17\pm1.75^{a}$
	8.1	0	$_{a}6.40\pm1.43^{a}$	$_{a}6.00\pm1.24^{b}$	$_{a}6.19\pm1.52^{b,c}$	$_{a}5.67\pm0.36^{a,b}$	$_{a}5.70\pm1.86^{a,b}$
	8.1	30	$_{a}6.64\pm0.90^{a}$	$_{a}6.17\pm1.13^{a}$	$_{a}5.80\pm1.58^{a,b}$	$_{a}5.30\pm1.86^{a}$	$_{a}5.67\pm1.64^{a}$
A	8.1	60	$_{a}6.20\pm1.38^{a}$	$_{a}6.17\pm1.13^{a,b}$	$_{a}6.50\pm1.52^{a}$	$_{a}6.03\pm1.54^{a}$	$_{a}6.10\pm1.47^{a}$
	13.8	0	$_{a}6.47\pm0.87^{a}$	$_{a}5.97\pm1.08^{a,b}$	$_{a}6.07\pm1.86^{a,b,c}$	$_{a}5.87\pm1.67^{a,b}$	$_{a}6.00\pm1.48^{a}$
	13.8	30	$_{a}6.63\pm1.35^{a}$	$_{a}6.77\pm1.23^{a,b}$	$_{a}5.83\pm2.03^{b,c}$	$_{a}5.60\pm2.08^{a,b}$	$_{a}5.67\pm1.83^{a,b}$
	13.8	60	$_{a}6.57\pm1.31^{a}$	$_{a}6.57\pm1.17^{c}$	$_{a}6.07\pm1.79^{c}$	$_{a}6.20\pm1.56^{b}$	$_{a}6.17\pm1.42^{b}$
	0	0	$_{a}4.37\pm1.72^{a,b}$	$_{a}5.38\pm0.87^{a}$	$_{a}5.03\pm1.83^{a,b}$	$_{a}4.37\pm2.11^{a}$	$_{a}4.47\pm1.87^{a}$
	8.1	0	$_{a}6.70\pm1.55^{a}$	$_{a}6.23\pm1.56^{a,b}$	$_{a}6.70\pm0.75^{a,b}$	$_{a}6.10\pm1.70^{a,b}$	$_{a}6.55\pm1.36^{a}$
	8.1	30	$_{a}6.30\pm1.19^{a,b}$	$_{a}6.17\pm1.34^{a,b}$	$_{b}6.10\pm1.54^{b}$	$_{a}5.80\pm1.60^{a,b}$	$_{a}6.03\pm1.49^{a}$
B	8.1	60	$_{a}5.33\pm1.97^{a,b}$	$_{a}5.78\pm1.33^{a}$	$_{a}5.50\pm1.69^{a}$	$_{a}4.47\pm2.05^{b}$	$_{a}4.83\pm1.97^{a}$
	13.8	0	$_{a}6.37\pm1.62^{a,b}$	$_{a}6.13\pm1.18^{a,b}$	$_{a}6.44\pm0.72^{a,b}$	$_{a}5.50\pm2.26^{a}$	$_{a}6.05\pm1.67^{a}$
	13.8	30	$_{a}5.83\pm1.55^{b}$	$_{a}6.03\pm1.28^{a,b}$	$_{b}6.82\pm0.89^{a}$	$_{a}5.37\pm1.92^{a,b}$	$_{a}5.80\pm1.70^{a}$
	13.8	60	$_{b}5.63\pm1.74^{a,b}$	$_{b}5.83\pm1.53^{a,b}$	$_{b}5.87\pm1.69^{a}$	$_{b}4.83\pm1.90^{a,b}$	$_{b}5.27\pm1.71^{a}$
	0	0	$_{b}5.37\pm1.99^{a,b}$	$_{a}5.87\pm1.59^{a}$	$_{a}5.53\pm1.89^{a}$	$_{b}5.47\pm1.77^{a,b}$	$_{a}5.43\pm1.80^{a,b}$
	8.1	0	$_{a}6.77\pm1.26^{b,c}$	$_{a}6.23\pm1.36^{a}$	$_{a}5.97\pm1.83^{a}$	$_{a}5.80\pm1.78^{a,b}$	$_{a}6.26\pm0.69^{a,b}$
	8.1	30	$_{b}6.17\pm1.73^{b,c}$	$_{a}6.50\pm1.45^{a}$	$_{a}6.58\pm1.38^{a}$	$_{a}6.07\pm1.53^{a,b}$	$_{a}6.62\pm0.90^{a,b}$
C	8.1	60	$_{a}5.50\pm1.52^{c}$	$_{a}6.00\pm1.06^{a,b}$	$_{a}6.43\pm.38^{a}$	$_{a}5.64\pm0.88^{b}$	$_{a}5.73\pm0.91^{b}$
	13.8	0	$_{a}7.09\pm0.10^{a,d}$	$_{a}6.37\pm0.98^{a}$	$_{a}6.37\pm1.64^{a}$	$_{a}6.40\pm1.50^{a,b}$	$_{a}6.57\pm1.36^{a,b}$
	13.8	30	$_{b}5.90\pm1.49^{d}$	$_{b}5.93\pm1.18^{b}$	$_{b}6.13\pm1.61^{a}$	$_{b}5.43\pm1.82^{a}$	$_{b}5.77\pm1.41^{a}$
	13.8	60	$_{b}5.40\pm1.69^{a,d}$	$_{c}5.68\pm0.78^{b}$	$_{b}5.99\pm1.63^{a}$	$_{b}5.57\pm1.67^{a,b}$	$_{b}5.53\pm1.71^{a}$

Tests were performed in triplicate.
a-gMeans within a column with different superscript letters are significantly different ($P<0.05$) a-cMeans within a column with different subscript letters are significantly different ($P<0.05$)
A = no pre-treatment, B = blanched in hot water at 85°C for 3.5 min, C = soaked in 3% NaCl solution at 25oC for 5 min, CS = Centrifuge Speed, CT = cooling time

CHAPTER V

CONCLUSIONS

De-oiling process, with different pre-treatments (blanching in hot water (85°C/3.5min), rinsing in 3% NaCl solution (25°C/5min)) and at centrifuge speed (8.1 and 13.8 relative centrifugal force or RCF) and cooling time (0, 15, 30, 45 and 60 s or 0.60 and 120 s), was characterized in terms of product quality attributes (oil absorption, texture, color, shrinkage, and sensory):

The main results and conclusions in this study were:

- Lower frying temperature, higher centrifuge speed, and less cooling time usually resulted in the lowest oil uptake in potato chips; therefore, frying at higher temperature (145^{o}C), de-oiling at low centrifuge speed (13.8 RCF) and 0 s cooling time resulted in the highest oil uptake values.
- Pre-treatments improved oil uptake of the chips, the chips blanched in hot water (85°C) usually resulted in a slight decrease in oil uptake, and the chips soaked in a 3% NaCl solution usually resulted in the reduction of oil uptake by at least 10% compared to the non-pre-treated samples.
- The chips without pre-treatment showed a simple trend in that the higher the centrifuge speed the less oil uptake and the chips blanched in hot water resulted in a slight decrease in oil uptake with increased centrifuge speed.
- The samples soaked in 3% NaCl solution showed temperature decreases through centrifuge speed itself with the application of cooling time before de-oiling

resulting in the reversal of oil uptake at 13.8 RCF where FOC/RM values are greater than at 8.1 RCF in specific cooling times.

- In terms of oil uptake, the best process consisted of pre-treating the samples with 3% NaCl at 25oC for 5 min, frying at 165°C, cooling for 0 s at 13.8 RCF.
- Neither the frying temperature nor the pre-treatments had a significant effect ($P>0.05$) over the final texture of the potato chips.
- De-oiling led to increased hardness of the chips fried at 145° and 165°C (0 s cooling time), and the hardness decreased as cooling time increased.
- The amount of work shows a trend similar to hardness in terms of frying temperature, except for the controls (0 s of cooling and no de-oiling).
- Blanching and soaking in NaCl solution increased the hardness and decreased the work values.
- Potato chips showed less lightness and redness when fried at 145°C and more lightness and red when fried at 185°C. Potato chips fried at 165°C did not show significant ($P<0.05$) color characteristics, compared to both the frying temperatures, 145° and 165°C, and frying temperature also significantly influenced ($P>0.05$) yellowness (b^*) resulting in increasing b^* values as temperature increased.
- De-oiling using a centrifuge influenced significantly ($P>0.05$) the increase in the lightness (L^*) of the chips without cooling, and as cooling time increased, the lightness of the chips decreased.

- The de-oiling process using a centrifuge did not influence significantly ($P<0.05$) the redness (a^*) of the chips, except for the products fried at 185°C, and as cooling time increased, the redness of the chips increased.
- The centrifuge influenced significantly ($P>0.05$) the yellowness (b^*) of the chips, and as cooling time increased, the yellowness of the chips increased.
- Pre-treatments before frying significantly influenced ($P>0.05$) the lightness and yellowness of the final products.
- All the products (no pre-treated, blanched in hot water, and soaked in NaCl), compared to the controls (0 s cooling tome and no de-oiled) of each pre-treated sample, resulted in increasing in lightness (L^*) and yellowness (b^*), whereas the redness (a^*) values of the final products fluctuated.
- Blanching in hot water usually decreased the yellowness of the final products, compared to non-pretreated samples.
- Higher frying temperature and centrifuge speed, and higher cooling time usually resulted in increasing shrinkage in thickness of potato chips.
- Exceptionally, the chips fried at 165°C resulted in the negative number which means the thickness of chips increased during the process.
- Blanching in hot water resulted in a decrease in volume shrinkage as a result of decreasing in thickness shrinkage with the same rate of diameter changes.
- Chips pre-treated by soaking in NaCl resulted in more expansion than the other pre-treated samples; however, their shrinkage in diameter was similar to the control (0 s cooling and no de-oiling).

- Shrinkage in diameter decreased for the chips fried at 145^o and 165^{o}C and stayed constant at about 6.5% from 165-185^{o}C, and shrinkage in volume decreased with temperature.
- All the fried and de-oiled products resulted in a decrease in thickness, diameter, and volume except for the thickness of the chip soaked in NaCl, compared to raw slices.
- Soaking in NaCl caused more expansion on the axial side and shrinkage on the radial side; however, its shrinkage in volume was similar to the blanched samples.
- Most of the samples scored above 5; however, the samples that scored below 5 were the blanched chips that had higher in oil content and scored low in color and flavor.
- The samples usually scored higher values for chips cooled for 0 s, which were also the chips with the least oil content.
- According to the consumer panelists, blanching and de-oiling without cooling enhanced texture and overall quality of the chip, soaking and de-oiling improved the color, flavor, and the overall quality, and the two pre-treatments did not influence the odor of the chip.

CHAPTER VI

RECOMMENDATIONS FOR FURTHER STUDY

Recommendations for future research on de-oiling process of potato chips include:

- To conduct microscopic test to study textural changes of products.
- To measure the surface oil content of chips by dipping the chips in the solvent after process.
- To conduct pre-treatments, blanched in hot water after soaking in NaCl solution or soaked in NaCl solution after blanching in hot water.
- To study the effect of cooling temperature in the ambient rather than in the fryer.

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APPENDIX

Rinsed slices' moisture content and final oil content/moisture removed from rinsed slices' moisture content for non-pretreated potato chips.

T_{oil} (°C)	CS (RCF)	CT (s)	RMC (w.b.)	FOC/RMR (g/g)
145	0	0	0.81±0.00	0.54±0.01
145	8.1	0	0.81±0.02	0.22±0.01
145	8.1	60	0.79±0.02	0.37±0.02
145	8.1	120	0.80±0.00	0.52±0.02
145	13.8	0	0.82±0.03	0.21±0.01
145	13.8	60	0.78±0.00	0.42±0.00
145	13.8	120	0.79±0.01	0.51±0.01
165	0	0	0.81±0.00	0.57±0.01
165	8.1	0	0.77±0.01	0.27±0.01
165	8.1	60	0.79±0.01	0.42±0.01
165	8.1	120	0.80±0.01	0.53±0.03
165	13.8	0	0.75±0.00	0.22±0.02
165	13.8	60	0.76±0.00	0.48±0.01
165	13.8	120	0.82±0.01	0.51±0.05
185	0	0	0.78±0.00	0.63±0.01
185	8.1	0	0.82±0.00	0.31±0.04
185	8.1	60	0.80±0.00	0.59±0.00
185	8.1	120	0.78±0.00	0.57±0.00
185	13.8	0	0.79±0.00	0.25±0.01
185	13.8	60	0.79±0.00	0.41±0.01
185	13.8	120	0.76±0.00	0.47±0.01

Tests were performed in triplicate.

T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time, RMC = rinsed slices' moisture content, and FOC/RMR = final oil content/moisture removed from RMC.

Thickness of raw and rinsed slices and potato chips for non-pretreated potato chips.

T_{oil}	CS	CT	Thickness		
			Raw slices	Rinsed slices	Chips
(°C)	(RCF)	(s)	(mm)	(mm)	(mm)
145	0	0	1.58±0.01	1.66±0.11	1.45±0.13
145	8.1	0	1.59±0.04	1.62±0.08	1.54±0.11
145	8.1	60	1.64±0.06	1.65±0.09	1.65±0.06
145	8.1	120	1.55±0.00	1.59±0.10	1.71±0.31
145	13.8	0	1.52±0.10	1.63±0.12	1.77±0.27
145	13.8	60	1.72±0.07	1.72±0.07	1.65±0.23
145	13.8	120	1.70±0.07	1.65±0.03	1.51±0.12
165	0	0	1.67±0.07	1.67±0.03	1.39±0.11
165	8.1	0	1.69±0.10	1.59±0.04	1.45±0.09
165	8.1	60	1.69±0.07	1.61±0.08	1.44±0.03
165	8.1	120	1.73±0.07	1.57±0.09	1.52±0.12
165	13.8	0	1.63±0.09	1.69±0.11	1.60±0.06
165	13.8	60	1.66±0.05	1.66±0.10	1.59±0.11
165	13.8	120	1.72±0.11	1.63±0.11	1.59±0.15
185	0	0	1.66±0.07	1.55±0.06	1.41±0.07
185	8.1	0	1.67±0.08	1.58±0.07	1.39±0.04
185	8.1	60	1.56±0.05	1.55±0.03	1.34±0.04
185	8.1	120	1.60±0.04	1.62±0.09	1.55±0.21
185	13.8	0	1.55±0.05	1.54±0.08	1.39±0.08
185	13.8	60	1.59±0.02	1.53±0.05	1.31±0.04
185	13.8	120	1.66±0.10	1.66±0.09	1.46± 0.13

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time.

Diameter of rinsed slices and potato chips for non-pretreated potato chips.

T_{oil}	CS	CT	Diameter			
			Rinsed slices		Chips	
			Small	Large	Small	Large
(°C)	(RCF)	(s)	(mm)	(mm)	(mm)	(mm)
145	0	0	50.97±0.23	51.16±0.20	45.98±1.90	46.42±1.89
145	8.1	0	51.11±0.04	51.29±0.05	46.47±1.11	47.07±0.91
145	8.1	60	51.29±0.12	51.53±0.18	46.39±1.04	47.52±0.75
145	8.1	120	51.04±0.29	51.43±0.39	45.04±2.12	45.95±1.68
145	13.8	0	51.05±0.11	51.35±0.20	46.66±1.08	47.28±0.91
145	13.8	60	50.97±0.08	51.27±0.07	46.78±0.16	47.64±0.75
145	13.8	120	50.95±0.37	51.47±0.06	46.88±0.65	47.39±0.18
165	0	0	51.19±0.28	51.52±0.11	47.79±0.54	48.36±0.09
165	8.1	0	51.22±0.12	51.55±0.16	48.16±0.67	48.80±0.48
165	8.1	60	51.28±0.33	51.70±0.07	47.84±0.49	48.33±0.47
165	8.1	120	51.59±0.20	51.75±0.23	47.54±0.65	47.99±0.73
165	13.8	0	50.95±0.32	51.41±0.17	48.49±0.94	48.72±0.70
165	13.8	60	51.18±0.24	51.42±0.28	48.18±0.35	49.14±0.46
165	13.8	120	50.96±0.23	51.32±0.22	46.78±0.87	47.28±0.76
185	0	0	50.72±0.24	51.10±0.25	47.57±0.61	48.13±0.59
185	8.1	0	51.08±0.33	51.49±0.06	47.60±1.03	48.64±0.51
185	8.1	60	50.93±0.25	51.14±0.23	48.00±0.64	48.13±0.66
185	8.1	120	50.97±0.28	51.26±0.24	47.90±0.60	48.52±0.41
185	13.8	0	50.85±0.03	51.17±0.21	47.93±0.74	48.34±0.49
185	13.8	60	50.74±0.18	51.08±0.20	47.60±0.66	48.39±0.68
185	13.8	120	50.89±0.27	51.33±0.25	48.05±0.46	48.71±0.63

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time.

Volume of raw and rinsed slices and potato chips for non-pretreated potato chips.

T_{oil}	**CS**	**CT**	**Volume**		
			Raw slices	**Rinsed slices**	**Chips**
			x10^{-6}	**x10^{-6}**	**x10^{-6}**
(°C)	**(RCF)**	**(s)**	**(mm^3)**	**(mm^3)**	**(mm^3)**
145	0	0	3.21±0.02	3.39±0.23	2.44±0.27
145	8.1	0	3.23±0.09	3.33±0.17	2.65±0.20
145	8.1	60	3.33±0.13	3.42±0.19	2.86±0.13
145	8.1	120	3.14±0.01	3.29±0.21	2.78±0.53
145	13.8	0	3.07±0.22	3.35±0.24	3.06±0.48
145	13.8	60	3.48±0.14	3.52±0.15	2.89±0.40
145	13.8	120	3.45±0.14	3.41±0.06	2.63±0.21
165	0	0	3.38±0.14	3.46±0.06	2.52±0.19
165	8.1	0	3.42±0.20	3.29±0.07	2.68±0.17
165	8.1	60	3.42±0.15	3.36±0.16	2.61±0.06
165	8.1	120	3.51±0.15	3.28±0.18	2.73±0.21
165	13.8	0	3.30±0.19	3.48±0.24	2.98±0.14
165	13.8	60	3.36±0.11	3.43±0.20	2.95±0.20
165	13.8	120	3.49±0.24	3.36±0.22	2.76±0.28
185	0	0	3.36±0.15	3.15±0.13	2.53±0.13
185	8.1	0	3.38±0.17	3.25±0.14	2.53±0.09
185	8.1	60	3.16±0.10	3.17±0.07	2.42±0.09
185	8.1	120	3.23±0.08	3.32±0.18	2.83±0.38
185	13.8	0	3.13±0.11	3.16±0.16	2.54±0.15
185	13.8	60	3.23±0.05	3.11±0.10	2.37±0.09
185	13.8	120	3.36±0.20	3.40±0.19	2.68±0.24

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time.

Shrinkage in diameter of rinsed slices for non-pretreated potato chips, compared to chips.

T_{oil}	CS	CT	Shrinkage in diameter Rinsed slices	
			Small	Large
(°C)	(RCF)	(s)	(mm)	(mm)
145	0	0	0.10±0.04	0.09±0.04
145	8.1	0	0.09±0.02	0.08±0.02
145	8.1	60	0.10±0.02	0.08± 0.01
145	8.1	120	0.12± 0.04	0.11±0.03
145	13.8	0	0.09±0.02	0.08±0.02
145	13.8	60	0.08±0.00	0.07±0.01
145	13.8	120	0.08±0.01	0.08±0.00
165	0	0	0.07±0.01	0.06±0.00
165	8.1	0	0.06±0.01	0.05±0.01
165	8.1	60	0.07±0.01	0.07±0.01
165	8.1	120	0.08±0.01	0.07±0.01
165	13.8	0	0.05±0.02	0.05±0.01
165	13.8	60	0.06±0.01	0.04±0.01
165	13.8	120	0.08±0.02	0.08±0.02
185	0	0	0.06±0.01	0.06±0.01
185	8.1	0	0.07±0.02	0.06±0.01
185	8.1	60	0.06±0.01	0.06±0.01
185	8.1	120	0.06±0.01	0.05±0.01
185	13.8	0	0.06±0.01	0.06±0.01
185	13.8	60	0.06±0.01	0.05±0.01
185	13.8	120	0.06±0.01	0.05±0.01

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time.

Shrinkage in volume of rinsed slices for non-pretreated potato chips, compared to chips.

T_{oil}	**CS**	**CT**	**Shrinkage in volume**
			Rinsed slices
			Small
(°C)	**(RCF)**	**(s)**	**(m^3/m^3)**
145	0	0	0.28±0.09
145	8.1	0	0.10±0.04
145	8.1	60	0.09±0.02
145	8.1	120	0.10±0.02
145	13.8	0	0.12±0.04
145	13.8	60	0.09±0.02
145	13.8	120	0.08±0.00
165	0	0	0.08±0.01
165	8.1	0	0.07±0.01
165	8.1	60	0.06±0.01
165	8.1	120	0.07±0.01
165	13.8	0	0.08±0.01
165	13.8	60	0.05±0.02
165	13.8	120	0.06±0.01
185	0	0	0.08±0.02
185	8.1	0	0.06±0.01
185	8.1	60	0.07±0.02
185	8.1	120	0.06±0.01
185	13.8	0	0.06±0.01
185	13.8	60	0.06±0.01
185	13.8	120	0.06±0.01

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time.

Rinsed slices' moisture content and final oil content/moisture removed from rinsed slices' moisture content for control, non-pretreated potato chips fried at 165°C.

CS	**CT**	**RMC**	**FOC/RMR**
(RCF)	**(s)**	**(w.b.)**	**(g/g)**
0	0	0.82±0.01	0.70±0.01
8.1	0	0.83±0.00	0.32±0.00
8.1	15	0.84±0.01	0.50±0.01
8.1	30	0.82±0.01	0.58±0.01
8.1	45	0.82±0.01	0.62±0.01
8.1	60	0.80±0.02	0.66±0.02
13.8	0	0.81±0.00	0.28±0.00
13.8	15	0.80±0.01	0.41±0.01
13.8	30	0.79±0.01	0.54±0.01
13.8	45	0.83±0.01	0.54±0.01
13.8	60	0.82±0.01	0.63±0.01

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time, RMC = rinsed slices' moisture content, and FOC/RMI = final oil content/moisture removed from RMC.

Thickness of raw and rinsed slices and potato chips for non-pretreated potato chips.

CS	CT	Thickness		
		Raw slices	Rinsed slices	Chips
(RCF)	(s)	(mm)	(mm)	(mm)
0	0	1.58±0.02	1.64±0.00	1.43±0.02
8.1	0	1.53±0.02	1.57±0.02	1.42±0.02
8.1	15	1.54±0.01	1.55±0.02	1.41±0.02
8.1	30	1.52±0.02	1.55±0.02	1.45±0.02
8.1	45	1.54±0.02	1.52±0.02	1.41±0.02
8.1	60	1.53±0.01	1.57±0.02	1.37±0.02
13.8	0	1.52±0.02	1.55±0.02	1.38±0.02
13.8	15	1.53±0.02	1.57±0.01	1.43±0.02
13.8	30	1.53±0.02	1.57±0.02	1.48±0.01
13.8	45	1.53±0.02	1.54±0.02	1.43±0.02
13.8	60	1.53±0.01	1.54±0.02	1.39±0.02

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time.

Diameter of rinsed slices and potato chips for non-pretreated potato chips

CS	CT	Diameter			
		Rinsed slices		Chips	
		Small	Large	Small	Large
(RCF)	(s)	(mm)	(mm)	(mm)	(mm)
0	0	51.30±0.29	51.47±0.24	47.50±0.62	48.06±0.60
8.1	0	51.44±0.43	51.69±0.45	47.49±0.50	47.99±0.62
8.1	15	51.34±0.19	51.52±0.23	47.30±0.66	47.89±0.56
8.1	30	51.34±0.04	51.59±0.21	47.74±0.62	47.93±0.66
8.1	45	51.27±0.09	51.52±0.19	47.71± 0.56	47.87±0.46
8.1	60	51.33±0.28	51.64±0.25	47.44±0.68	47.82±0.64
13.8	0	51.11±0.20	51.41±0.17	47.42±0.63	48.03±0.68
13.8	15	51.34±0.23	51.52±0.18	47.58±0.41	47.78±0.58
13.8	30	51.02±0.32	51.50±0.26	47.26±0.65	47.87±0.69
13.8	45	51.10±0.17	51.40±0.22	47.73±0.31	47.87±0.64
13.8	60	51.32±0.35	51.56±0.28	47.63±0.47	47.92±0.58

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time.

Volume of raw and rinsed slices and potato chips for non-pretreated potato chips.

CS	CT	Volume of slices		
		Raw slices	Rinsed slices	Chips
		$x10^{-6}$	$x10^{-6}$	$x10^{-6}$
(RCF)	(s)	(mm^3)	(mm^3)	(mm^3)
0	0	3.21±0.04	3.40±0.03	2.57±0.06
8.1	0	3.10±0.04	3.29±0.06	2.55±0.05
8.1	15	3.11±0.02	3.23±0.05	2.52±0.06
8.1	30	3.07±0.05	3.23±0.04	2.61±0.06
8.1	45	3.12±0.05	3.16±0.05	2.53±0.05
8.1	60	3.10±0.02	3.27±0.05	2.45±0.06
13.8	0	3.09±0.04	3.20±0.05	2.48±0.06
13.8	15	3.09±0.05	3.25±0.03	2.56±0.05
13.8	30	3.10±0.04	3.24±0.05	2.63±0.06
13.8	45	3.11±0.04	3.18±0.05	2.57± 0.05
13.8	60	3.11±0.02	3.20±0.04	2.49±0.05

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time.

Shrinkage in diameter of rinsed slices for non-pretreated potato chips, compared to chips.

CS	CT	Shrinkage in thickness Rinsed slices
(RCF)	(s)	(mm/mm)
0	0	0.13±0.01
8.1	0	0.10±0.02
8.1	15	0.09±0.02
8.1	30	0.07±0.02
8.1	45	0.07±0.02
8.1	60	0.12±0.02
13.8	0	0.11±0.02
13.8	15	0.09±0.01
13.8	30	0.06±0.02
13.8	45	0.07±0.02
13.8	60	0.10±0.02

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time.

Shrinkage in diameter of rinsed slices for non-pretreated potato chips, compared to chips.

CS	CT	Shrinkage in diameter Rinsed slices	
		Small	Large
(RCF)	(s)	(mm/mm)	(mm/mm)
0	0	0.07±0.01	0.07±0.01
8.1	0	0.08±0.01	0.07±0.01
8.1	15	0.08±0.01	0.07±0.01
8.1	30	0.07±0.01	0.07±0.01
8.1	45	0.07±0.01	0.07±0.01
8.1	60	0.08±0.01	0.07±0.01
13.8	0	0.07±0.01	0.07±0.01
13.8	15	0.07±0.01	0.07±0.01
13.8	30	0.07±0.01	0.07±0.01
13.8	45	0.07±0.01	0.07±0.01
13.8	60	0.07± 0.01	0.07± 0.01

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time.

Shrinkage in volume of rinsed slices for non-pretreated potato chips, compared to chips.

CS	CT	Shrinkage in volume Rinsed slices
(RCF)	(s)	(m^3/m^3)
0	0	0.24±0.02
8.1	0	0.22±0.02
8.1	15	0.22±0.02
8.1	30	0.19±0.02
8.1	45	0.20±0.02
8.1	60	0.25±0.02
13.8	0	0.23±0.02
13.8	15	0.21±0.02
13.8	30	0.19±0.02
13.8	45	0.19±0.02
13.8	60	0.22±0.02

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time.

Rinsed and blanched slices' moisture content, and final oil content/moisture removed from rinsed slices' moisture content for control for potato chips blanched in how water (85°C) before frying

CS	CT	RMC	BMC	FOC/RMR	FOC/RMB
(RCF)	(s)	(w.b.)	(w.b.)	(g/g)	(g/g)
0	0	0.83±0.00	0.82±0.00	0.68±0.01	0.69±0.01
8.1	0	0.82±0.01	0.80±0.00	0.30±0.01	0.31±0.00
8.1	15	0.78±0.01	0.79±0.00	0.32±0.01	0.32±0.01
8.1	30	0.81±0.01	0.82±0.00	0.54±0.01	0.54±0.00
8.1	45	0.85±0.01	0.82±0.00	0.57±0.01	0.59±0.01
8.1	60	0.82±0.00	0.82±0.00	0.55±0.01	0.56±0.01
13.8	0	0.79±0.01	0.79±0.01	0.29±0.00	0.29±0.00
13.8	15	0.81±0.01	0.80±0.00	0.44±0.01	0.45±0.01
13.8	30	0.78±0.00	0.79±0.00	0.58±0.00	0.57±0.00
13.8	45	0.81±0.01	0.83±0.00	0.56±0.01	0.55±0.01
13.8	60	0.81±0.00	0.82±0.00	0.53±0.01	0.52±0.01

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time, RMC = rinsed slices' moisture content, BMC = blanched slice' moisture content, ,FOC/RMR = final oil content/moisture removed from RMC and FOC/RMB = final oil content/moisture removed from BMC.

Thickness of raw, rinsed and blanched slices and chips for potato chips blanched in how water (85°C) before frying

CS	CT	Thickness			
		Raw slices	Rinsed slices	Blanched slices	Chips
(RCF)	(s)	(mm)	(mm)	(mm)	(mm)
0	0	1.57±0.02	1.57±0.02	1.56±0.02	1.43±0.02
8.1	0	1.61±0.02	1.54±0.02	1.50±0.02	1.57±0.02
8.1	15	1.64±0.02	1.59±0.02	1.54±0.02	1.46±0.01
8.1	30	1.55±0.02	1.61±0.02	1.55±0.02	1.41±0.01
8.1	45	1.58±0.02	1.65±0.02	1.56±0.02	1.55±0.02
8.1	60	1.61±0.02	1.65±0.02	1.53±0.02	1.42±0.02
13.8	0	1.55±0.02	1.66±0.02	1.48±0.02	1.46±0.02
13.8	15	1.61±0.02	1.63±0.02	1.53±0.02	1.48±0.01
13.8	30	1.60±0.02	1.64±0.02	1.58±0.02	1.53±0.01
13.8	45	1.68±0.02	1.77±0.02	1.64±0.02	1.44±0.02
13.8	60	1.59±0.02	1.56±0.02	1.53±0.02	1.44±0.02

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time.

Diameter of rinsed and blanched slices and chips for potato chips blanched in how water (85°C) before frying

CS	CT	Diameter					
		Rinsed slices		Blanched slices		Chips	
		Small	Large	Small	Large	Small	Large
(RCF)	(s)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
0	0	51.18±0.13	51.31±0.25	50.51±0.61	51.01±0.43	47.07±0.60	47.75±0.63
8.1	0	51.01±0.33	51.31±0.17	50.40±0.51	50.88±0.51	46.80±0.56	47.69±0.68
8.1	15	51.00±0.21	51.22±0.24	50.01±0.65	50.71±0.67	46.71±0.65	47.52±0.67
8.1	30	50.84±0.30	51.22±0.26	50.38±0.52	50.85±0.51	47.50±0.64	47.79±0.69
8.1	45	51.44±0.12	51.75±0.25	49.67±0.60	50.23±0.56	45.18±0.60	46.31±0.67
8.1	60	51.54±0.17	52.15±0.39	50.23±0.68	50.84±0.67	48.05±0.31	48.46±0.57
13.8	0	51.09±0.30	51.50±0.29	49.97±0.55	50.33±0.39	46.22±0.60	47.04±0.57
13.8	15	51.32±0.27	51.73±0.11	50.20±0.11	50.84±0.68	46.97±0.68	47.42±0.64
13.8	30	51.74±0.39	52.47±0.49	50.81±0.54	51.26±0.68	47.43±0.62	47.90±0.69
13.8	45	51.49±0.47	51.97±0.35	50.87±0.65	51.46±0.68	47.38±0.62	48.37±0.13
13.8	60	50.79±0.17	51.23±0.30	51.29±0.58	51.91±0.67	47.64±0.58	48.18±0.58

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time.

Volume of raw, rinsed and blanched slices and chips for potato chips blanched in how water (85°C) before frying

CS	CT	Volume			
		Raw	Rinsed slices	Blanched slices	Chips
		x10^{-6}	x10^{-6}	x10^{-6}	x10^{-6}
(RCF)	(s)	(mm^3)	(mm^3)	(mm^3)	(mm^3)
0	0	3.17 ±0.04	3.23±0.05	3.16±0.06	2.52±0.06
8.1	0	3.26 ±0.04	3.16±0.05	3.01±0.06	2.74±0.06
8.1	15	3.33 ±0.05	3.25±0.05	3.08±0.07	2.55±0.06
8.1	30	3.14 ±0.05	3.29±0.04	3.11±0.06	2.51±0.06
8.1	45	3.20 ±0.04	3.45±0.05	3.05±0.06	2.54±0.06
8.1	60	3.26 ±0.04	3.48±0.05	3.07±0.07	2.60±0.05
13.8	0	3.15 ±0.05	3.42±0.06	2.92±0.06	2.50±0.05
13.8	15	3.26 ±0.03	3.39±0.05	3.06±0.06	2.58±0.06
13.8	30	3.25 ±0.04	3.50±0.06	3.24±0.07	2.73±0.06
13.8	45	3.40 ±0.04	3.73±0.06	3.37±0.08	2.58±0.04
13.8	60	3.21 ±0.04	3.19±0.05	3.20±0.07	2.59±0.05

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time.

Shrinkage in thickness of rinsed and blanched slices for potato chips blanched in how water (85°C) before frying

CS	CT	Shrinkage in thickness	
		Rinsed slices	Blanched slices
(RCF)	(s)	(mm/mm)	(mm/mm)
0	0	0.09±0.02	0.08±0.02
8.1	0	-0.02±0.02	-0.05±0.02
8.1	15	0.08±0.02	0.05±0.02
8.1	30	0.13±0.01	0.09±0.01
8.1	45	0.06±0.02	0.01±0.02
8.1	60	0.14±0.02	0.07±0.02
13.8	0	0.12±0.02	0.01±0.02
13.8	15	0.09±0.02	0.03±0.02
13.8	30	0.07±0.01	0.03±0.02
13.8	45	0.19±0.01	0.12±0.02
13.8	60	0.08±0.02	0.06±0.02

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time.

Shrinkage in diameter of rinsed and blanched slices for potato chips blanched in how water (85°C) before frying

CS	CT	Shrinkage in thickness			
		Rinsed slices		Blanched slices	
		Small	Large	Small	Large
(RCF)	(s)	(mm/mm)	(mm/mm)	(mm/mm)	(mm/mm)
0	0	0.08±0.01	0.07±0.01	0.07±0.02	0.06±0.01
8.1	0	0.08±0.01	0.07±0.01	0.07±0.01	0.06±0.02
8.1	15	0.08±0.01	0.07±0.01	0.07±0.02	0.06±0.02
8.1	30	0.07±0.01	0.07±0.01	0.06±0.02	0.06±0.02
8.1	45	0.12±0.01	0.10±0.01	0.09±0.02	0.08±0.02
8.1	60	0.07±0.01	0.07±0.01	0.04±0.01	0.05±0.02
13.8	0	0.10±0.01	0.09±0.01	0.08±0.02	0.07±0.01
13.8	15	0.08±0.01	0.08±0.01	0.06±0.01	0.07±0.02
13.8	30	0.08±0.01	0.09±0.02	0.07±0.02	0.07±0.02
13.8	45	0.08±0.01	0.07±0.01	0.07±0.02	0.06±0.01
13.8	60	0.06±0.01	0.06±0.01	0.07±0.02	0.07±0.02

Tests were performed in triplicate.
Toil = oil temperature, CS = Centrifuge Speed, CT = cooling time.

Shrinkage in volume of rinsed and blanched slices for potato chips blanched in how water (85°C) before frying

CS	CT	Shrinkage in volume	
		Rinsed slices	Blanched slices
(RCF)	(s)	(m^3/m^3)	(m^3/m^3)
0	0	0.22±0.02	0.20±0.02
8.1	0	0.13±0.02	0.09±0.03
8.1	15	0.21±0.02	0.17±0.03
8.1	30	0.24±0.02	0.20±0.02
8.1	45	0.26±0.02	0.17±0.03
8.1	60	0.25±0.02	0.15±0.03
13.8	0	0.27±0.02	0.15±0.03
13.8	15	0.24±0.02	0.16±0.02
13.8	30	0.22±0.02	0.16±0.03
13.8	45	0.31±0.02	0.23±0.02
13.8	60	0.19±0.02	0.19±0.02

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time.

Rinsed and soaked slices' moisture content and final oil content/moisture removed from rinsed slices' moisture content for potato chips soaked in 3% NaCl solution (25°C)

CS (RCF)	CT (s)	RMC (w.b.)	SMC (w.b.)	FOC/RMR (g/g)	FOC/SMR (g/g)
0	0	0.82±0.01	0.76±0.01	0.59±0.01	0.63±0.01
8.1	0	0.81±0.01	0.77±0.00	0.24±0.00	0.25±0.00
8.1	15	0.83±0.00	0.81±0.01	0.32±0.00	0.33±0.00
8.1	30	0.80±0.00	0.73±0.01	0.37±0.01	0.40±0.01
8.1	45	0.72±0.00	0.80±0.00	0.40±0.01	0.35±0.01
8.1	60	0.79±0.00	0.74±0.00	0.36±0.00	0.39±0.00
13.8	0	0.80±0.00	0.77±0.01	0.26±0.00	0.27±0.00
13.8	15	0.79±0.00	0.79±0.01	0.29±0.01	0.30±0.01
13.8	30	0.83±0.00	0.75±0.00	0.43±0.01	0.47±0.01
13.8	45	0.82±0.01	0.80±0.01	0.47±0.01	0.48±0.01
13.8	60	0.82±0.00	0.74±0.01	0.42±0.01	0.46±0.01

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time, RMC = rinsed slices' moisture content, SMC = soaked slices' moisture content, FOC/RMR = final oil content/moisture removed from RMC and FOC/SMR = final oil content/moisture removed from SMC.

Thickness of raw, rinsed and soaked slices and potato chips for potato chips soaked in 3% NaCl solution (25°C)

CS	CT	Thickness			
		Raw slices	Rinsed slices	Soaked slices in NaCl	Chips
(RCF)	(s)	(mm)	(mm)	(mm)	(mm)
0	0	1.57±0.02	1.59±0.02	1.49±0.02	1.65±0.02
8.1	0	1.64±0.02	1.66±0.02	1.51±0.02	1.71±0.02
8.1	15	1.53±0.02	1.59±0.02	1.47±0.02	1.63±0.02
8.1	30	1.58±0.02	1.59±0.02	1.47±0.02	1.76±0.02
8.1	45	1.62±0.02	1.67±0.02	1.44±0.02	1.72±0.02
8.1	60	1.62±0.02	1.65±0.02	1.50±0.02	1.71±0.02
13.8	0	1.62±0.02	1.61±0.02	1.50±0.02	1.77±0.02
13.8	15	1.59±0.02	1.63±0.02	1.48±0.02	1.77±0.03
13.8	30	1.57±0.02	1.64±0.02	1.48±0.02	1.75±0.02
13.8	45	1.59±0.02	1.63±0.02	1.47±0.01	1.69±0.02
13.8	60	1.61±0.01	1.69±0.02	1.51±0.02	1.80±0.02

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time.

Diameter of rinsed and soaked slices and potato chips for potato chips soaked in 3% NaCl solution (25°C)

CS	CT	Diameter					
		Rinsed slices		Soaked slices in NaCl		Chips	
		Small	Large	Small	Large	Small	Large
(RCF)	(s)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
0	0	50.96 ±0.34	51.34 ±0.19	49.51±0.19	49.90±0.19	44.74±0.61	45.31±0.63
8.1	0	51.06 ±0.43	51.26±0.25	49.70±0.34	50.05±0.39	45.12±0.36	45.50±0.35
8.1	15	51.31 ±0.31	51.70±0.35	48.44±0.58	48.90±0.62	43.53±0.60	44.05±0.26
8.1	30	51.22 ±0.15	51.54±0.09	49.78±0.24	50.02±0.60	43.55±0.61	44.18±0.56
8.1	45	51.57 ±0.45	51.58±0.29	48.55±0.35	49.10±0.40	43.00±0.59	43.49±0.53
8.1	60	50.96 ±0.34	51.31±0.22	49.51±0.19	49.90±0.19	44.74±0.61	45.31±0.63
13.8	0	51.12 ±0.24	51.67±0.23	49.71±0.09	50.38±0.47	44.52±0.61	45.09±0.61
13.8	15	51.48 ±0.48	52.14±0.52	48.83±0.08	49.60±0.01	44.08±0.06	44.79±0.11
13.8	30	51.17 ±0.28	51.77±0.36	48.47±0.66	48.82±0.59	42.54±0.56	42.83±0.54
13.8	45	51.51 ±0.37	51.92±0.40	49.47±0.62	50.01±0.37	43.57±0.61	44.01±0.60
13.8	60	51.58 ±0.47	51.95±0.35	50.04±0.51	50.40±0.41	43.36±0.56	43.76±0.55

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time.

Volume o raw, rinsed and soaked slices and potato chips for potato chips soaked in 3% NaCl solution (25°C)

CS	CT	Volume			
		Raw	Rinsed	Soaked in NaCl	Chips
		$x10^{-6}$	$x10^{-6}$	$x10^{-6}$	$x10^{-6}$
(RCF)	(s)	(mm^3)	(mm^3)	(mm^3)	(mm^3)
0	0	3.18±0.04	3.27±0.04	2.90±0.04	2.62 ±0.06
8.1	0	3.33±0.04	3.41±0.06	2.94±0.05	2.77 ±0.05
8.1	15	3.10±0.04	3.31±0.05	2.73±0.06	2.45 ±0.05
8.1	30	3.21±0.04	3.30±0.04	2.87±0.05	2.66 ±0.06
8.1	45	3.27±0.05	3.49±0.06	2.70±0.05	2.52 ±0.05
8.1	60	3.29±0.04	3.38±0.05	2.91±0.04	2.73 ±0.06
13.8	0	3.28±0.05	3.34±0.05	2.95±0.05	2.80 ±0.06
13.8	15	3.22±0.04	3.44±0.06	2.81±0.04	2.74 ±0.05
13.8	30	3.18±0.05	3.41±0.05	2.75±0.06	2.51 ±0.06
13.8	45	3.21±0.05	3.42±0.06	2.86 ±0.05	2.54 ±0.06
13.8	60	3.27±0.03	3.55±0.06	2.99 ±0.05	2.68 ±0.06

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time.

Shrinkage in thickness of rinsed and soaked slices for potato chips soaked in 3% NaCl solution (25°C)

CS	CT	Shrinkage in thickness	
		Rinsed	Soaked in NaCl
(RCF)	(s)	(mm/mm)	(mm/mm)
0	0	-0.03±0.02	-0.10±0.02
8.1	0	-0.03±0.02	-0.14±0.02
8.1	15	-0.02±0.02	-0.11±0.02
8.1	30	-0.10±0.02	-0.20±0.02
8.1	45	-0.03±0.02	-0.19±0.02
8.1	60	-0.04±0.02	-0.14±0.02
13.8	0	-0.10±0.02	-0.18±0.02
13.8	15	-0.08±0.02	-0.19±0.03
13.8	30	-0.07±0.02	-0.19±0.02
13.8	45	-0.03±0.02	-0.14±0.02
13.8	60	-0.07±0.02	-0.19±0.02

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time.

Shrinkage in diameter of rinsed and soaked slices for potato chips soaked in 3% NaCl solution (25°C)

CS	CT	Shrinkage in thickness			
		Rinsed		Soaked in NaCl	
		Small	Large	Small	Large
(RCF)	(s)	(mm/mm)	(mm/mm)	(mm/mm)	(mm/mm)
0	0	0.12±0.01	0.12±0.01	0.10±0.01	0.09±0.01
8.1	0	0.12±0.01	0.11±0.01	0.09±0.01	0.09±0.01
8.1	15	0.15±0.01	0.15±0.01	0.10±0.02	0.10±0.01
8.1	30	0.15±0.01	0.14±0.01	0.13±0.01	0.12±0.02
8.1	45	0.17±0.01	0.16±0.01	0.11±0.01	0.11±0.01
8.1	60	0.12±0.01	0.12±0.01	0.10±0.01	0.09±0.01
13.8	0	0.13±0.01	0.13±0.01	0.10±0.01	0.10±0.01
13.8	15	0.14±0.01	0.14±0.01	0.10±0.00	0.10±0.00
13.8	30	0.17±0.01	0.17±0.01	0.12±0.02	0.12±0.02
13.8	45	0.15±0.01	0.15±0.01	0.12±0.02	0.12±0.01
13.8	60	0.16±0.01	0.16±0.01	0.13±0.01	0.13±0.01

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time.

Shrinkage in volume of rinsed and soaked slices for potato chips soaked in 3% NaCl solution (25°C)

CS	CT	Shrinkage in volume	
		Rinsed slices	Soaked slices in NaCl
(RCF)	(s)	(m^3/m^3)	(m^3/m^3)
0	0	0.20±0.02	0.10±0.03
8.1	0	0.19±0.02	0.06±0.02
8.1	15	0.26±0.02	0.10±0.03
8.1	30	0.20±0.02	0.08±0.03
8.1	45	0.28±0.02	0.06±0.03
8.1	60	0.19±0.02	0.06±0.03
13.8	0	0.16±0.02	0.05±0.03
13.8	15	0.20±0.02	0.03±0.02
13.8	30	0.26±0.02	0.09±0.03
13.8	45	0.26±0.02	0.11±0.03
13.8	60	0.24±0.02	0.10±0.02

Tests were performed in triplicate.
T_{oil} = oil temperature, CS = Centrifuge Speed, CT = cooling time.

VITA

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