PHYSICO-CHEMICAL PROPERTIES, AND WATER AND OIL UPTAKE CHARACTERISTICS OF NOVEL, SOY-BASED SNACKS PROCESSED USING EXTRUSION

by

SWATHI SREE KODAVALI

B.Tech., Acharya N.G. Ranga Agricultural University, India, 2009

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Grain Science and Industry
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2012

Approved by:

Major Professor
Dr. Sajid Alavi

Abstract

Extrusion processing and frying are the two most commonly used methods to produce savory snacks. These snacks are mostly starch based and also contain high amounts of fat. Snacking percentage has increased drastically over the past few decades causing many health problems like obesity, hypertension and cardiovascular diseases. The overall objective of this study was to develop novel soy based savory snack that are high in protein and has less fat using both extrusion processing and frying. In the first part of this study both defatted soy (25-75%), wheat flour, monoglycerides (0.375 & 0.75%) and sodium bicarbonate (0 and 0.5%) were used to produce dense extrudates, which mimic the shape of lentils using pilot scale twin screw extruder. The extrudates were soaked in water and fried in corn oil to produced savory snacks. Soy influenced the water absorption during soaking and oil uptake during frying. The water uptake and % fat decreased with increase in soy and the amount of water uptake influenced the % fat absorption in the product. No significant differences were observed in overall acceptability and to summarize the increased protein and dense structure of the products challenge the texture of the products. In the second part of this research, dynamics of water and oil uptake were studied to see the role of texture modifiers like soy protein isolate (4, 8, & 12%), calcium bicarbonate (0.2, 0.4 & 0.6%) and pregelatinized wheat starch (4, 8, & 12%) on texture, water and oil uptake. Descriptive sensory analysis was conducted to study the sensory attributes of the products. Water holding capacity is influenced by the level of % starch addition and the degree of starch degradation during processing. Oil uptakes correlates to that of WHC and is also affected by the degree of gelatinization and crust formation. Degree of starch gelatinization, oil uptake and oil and starch matrix interactions had an impact on hardness. Among SPI, $CaCO_3$ and PGWS,

PGWS lowered the product hardness followed by SPI and $CaCO_3$. Descriptive sensory results are similar to experimental results with PGWS samples having lower initial or substantial hardness and more oxidized or heated oil aroma and flavor.

Table of Contents

List of Figures

List of Tables

Acknowledgements

I would like to express my sincere gratitude and acknowledge the flowing people and organizations for their contributions:

My major advisor Dr. Sajid Alavi for his constant encouragement and guidance throughout my masters program. His support and friendly advice has been invaluable on both an academic and a personal level, for which I am extremely grateful.

My committee members Dr. Hulya Dogan, Dr. Koushik Adhikari and Dr. Girish Ganjyal for their support and inputs that set directions of focus throughout my project.

Mr. Eric Maichel, Operations Manager of Extrusion Lab and his team for technical assistance with extrusion processing.

Kansas Soy bean Commission for their support in funding this project

Cargil Foods, Cereal Food Processor, Danisco, Solae, MGP Ingredients for kindly donating the required amounts of material to conduct my experiments.

The faculty and staff of Department of Grain Science and Industry for sharing their knowledge and resource and for all their help

My friends Hyma Gajula, Moses Khamis, Paul Matchel, Sravya Boggavarapu, Sindhu Thotakura, Soumya Bala and Srikanth Rallband and all my lab mates Natraj Padhmanabhan, Akinbode Adedeji, Anubha Garg, Michael Gibson, Ryan Roberts, Michael Joseph, Juhyun Yoo, Elisa Karkle, Jhoe Stonestreet, and Dr. XiaoZhi Tang.

My friend Jyothir kumar Nimmagadda for his constant support and love.

My family for their unconditional love, and encouragement without which nothing could have been possible.

Dedication

I would like to dedicate this thesis to my parents

Chapter 1 - Introduction

1.1 Increased snack consumption and its impact

Snacks are small portions of food consumed in between meal times. The consumption of snacks has considerable increased because of change in life styles and based on demand for convenience foods. Over the past few years there was a shift in the food consumption patterns from traditional meal habits to processed foods. The change in eating habits includes consumption of snacks, high energy foods and constant eating. The snacking has increased significantly in all age groups from 71 to 97% in 2003-06 (Piernas and Popkin, 2010). Most snacks are energy dense and high in fat and sugars averaged about 8.7g of fat and 23g sugars (Wildey, et. al., 2000). But, the food consumed has a direct impact on health. The increased consumption of such high energy foods is the major cause for increased health problems such as obesity. It is the major epidemic now-a-days and almost 32% (one-third) of American population aged 2-19years are overweighed or obese (Ogden, et. al., 2010). Obesity causes several health consequences such as hypertension, diabetes, cardiovascular diseases, low self-esteem and eating disorder (French, et. al., 1995).

The increase in obesity and related health diseases necessitated the need for public health official to take immense care to reduce the epidemic. Also, these days there is a growing consumer demand for wholesome and healthier foods in general. This has led food processors to concentrate their research and development efforts towards products low in refined carbohydrates, fat and high in protein.

1.2 Scope of this study

Defatted soy flour in combination of wheat was chosen as base formulation for this work. Wheat is relatively low in protein content (7-14%) and also deficient in certain amino acids such as lysine. However, wheat flour can provide supporting network structure for the product and act as a binding agent. Defatted soy flour on the other hand is much higher in protein (~ 40-50%) and can be used to supplement certain amino acids such as lysine (Liu, 1999 and Rababah et al., 2006). Apart from the high protein content in soy flour, the quality of these proteins, in terms of their functionality and health benefits, make soy an attractive ingredient for food applications (Liu, 1999 and Riaz, 2006). Several studies have proven that soy helped to lower cholesterol and prevent cardio vascular diseases and obesity. Soy isoflavones, the major class of phytoestrogens are associated with the health benefits of soy consumption. They improve plasma lipid profile and help to prevent obesity and other associated diseases (Orgaard and Jensen, 2008). In addition, soy proteins also induce lowering of cholesterol, anti-carcinogenic effects, diabetes, digestive tract irritation, bone, and kidney diseases (Friedman and Brandon, 2001). Effective October 1999, the US Food and Drug Administration has approved the use of soy protein health claims on food labels based on human intervention studies and clinical trials that show a high association between consumption of soy protein and the reduced risk of coronary heart disease (CFR, 1999).

The main hypotheses upon which this study was based are

- The addition of soy would help to develop a snack that is high in protein and low in refined carbohydrate and fat
- The level of soy addition would influence the water absorption during soaking, and ultimately oil uptake during frying
- The addition of texture modifiers like soy protein isolate, pregelatinized wheat starch and calcium carbonate would reduce the hardness of the product.

Objectives

The overall objective of the current study was to develop a novel, high protein, soy-based savory snack product for the U.S. market using extrusion processing. Based on the shape of the product it also mimics lentil based snacks, where lentils are a primary protein source and part of the daily diet in many countries.

In the first chapter this study focused on developing a fried savory snack that is high in protein, low in refined carbohydrates and fat. Both defatted soy flour and soft wheat flours were used as based formulation to produce dense extrudates. The extrudates were fried in oil to produce savory snacks. The effect of soy and monoglycerides levels on water and oil uptake, and sensory acceptability were studied. The sensory properties showed that there is scope to improve the texture of the products

In the second chapter the effect of texture modifiers like soy protein isolate, calcium carbonate and pregelatinized wheat starch on texture was analyzed. Their effect on water and oil uptake was also studied to study their effect on oil uptake and to develop a highly acceptable snack product. The time bound study on water absorption, % fat and texture were analyzed to understand the effect of processing conditions on water absorption during soaking and oil uptake during frying and their impact on texture. Descriptive sensory analysis was conducted to study the effect of these ingredients on sensory characteristics of the product.

1.3 References

CFR 1999. Health claims: Soy protein and risk of coronary heart disease (CHD). 64 FR 57732, Oct. 26, 1999. Electronic-Code of Federal Regulations, Title 21: Food and Drugs, 101.82. Available at: http://ecfr.gpoaccess.gov. Accessed 11/19/2007.

French, S. A., Story, M., & Perry, C. L. (1995). Self-esteem and obesity in children and adolescents: a literature review. *Obesity Research, 3*, 479-490.

Friedman, M., & and Brandon, D. L. (2001). Nutritional and health benefits of soy proteins. *Journal of Agricultural and Food Chemistry, 49*(3), 1069-1086.

Liu, K. S. (1999). Chemistry and nutritional value of soybean components In Anonymous *Soybeans: Chemistry, Technology and Utilization*(pp. 25-113). Gaithersburg,Maryland, USA: Aspen Publ. Inc.

Ogden, C. L., Carroll, M. D., Curtin, L. R., Lamb, M. M., & Flegal, K. M. (2010). Prevalence of high body mass index in U.S. children and adolescents, 2007–2008. *Journal of American Medical Association, 303*(3), 242-249.

Orgaard, A., & and Jensen, L. (2008). The Effects of Soy Isoflavones on Obesity. *Experimental Biology and Medicine, 233*, 1066-1080.

Piernas, C., & Popkin, B. M. (2010). Snacking Increased among U.S. adults between 1977 and 2006. *Journal of Nutrition, 140*(2), 325-332.

Rababah, T., Al-Mahasneh, M., & and Ereifej, K. (2006). Effect of chickpea, broad bean or isolated soy protein addition on the physicochemical and sensory properties of biscuits. *Journal of Food Science, S: Sensory and Nutritive Qualities of Food, 71*(6), 438-442.

Riaz, M.N. 2006. Soy applications in food. Taylor and Francis Group, LLC., Boca Raton, FL. pp. 70.

Wildey, M. B., Pampalone, S. Z., Pelletier, R. L., Zive, M. M., Elder, J. P., & Sallis, J. F. (2000). Fat and sugar levels are high in snacks purchased from student stores in middle schools. *Journal of the American Dietetic Association, 100*(3), 319-322.

Chapter 2 - Moisture and oil uptake characteristics of soy-based extruded snacks

Abstract

Oil or lipids comprise 20-40% of the weight of most savory snack products. These products also usually have high amounts of refined carbohydrates and low protein content. This study focused on a novel high protein soy-wheat based composite snack produced using extrusion followed by a combination of soaking and frying. The primary hypothesis was that water and oil transfer during processing was impacted by the presence of soy proteins and additives in the extruded matrix. Extruded soy-wheat pellets were produced using twin screw extrusion with different ratios of soy to wheat flours (25:75, 50:50, 75:25). Monoglycerides, added at levels of 0.375 and 0.75% and sodium bicarbonate at 0.5% was also tested. Fat % decreased by 24.5-28.3% with the increase in soy from 25 to 75% for both samples with and without sodium bicarbonate respectively. No significant differences ($P \geq 0.05$) were found among the samples for overall acceptability and texture except for sample at 50% soy without sodium bicarbonate. Mechanism of oil uptake was explained based on water absorption capacity and starch protein composition. Incorporation of high levels of soy (up to 50%) in extruded pellets up to certain levels helped to produce savory snack that are rich in protein and low in fat with no significant difference in consumer acceptability.

2.1 Introduction

Savory snacks are widely consumed in the United States, as evidenced by their $28 billion annual market (IBISWorld, 2011). These snacks are produced mostly from refined flours, which are high in carbohydrates and low in protein, and a majority of those are prepared by frying in oil. The most popular snacks in the market contain about 20 to 30% fat (USDA, 2005). Snacks are high in oil and carbohydrates and are perceived as high-calorie foods. Higher consumption of snacks causes health problems such as hypertension and obesity. In the past few decades, obesity has increased dramatically in the United States and caused public health officials to take an interest in reducing the epidemic (Hedley et al., 2004). Statistics indicate that 32% of U.S. adults aged 20 and over are obese and 66% are overweight or obese (CDC, 2006). From 1993 to 2008, obesity in U.S. adults increased 89%, from 14.1% to 26.7% (Jia and Lubetkin, 2010). Obesity has been linked to many chronic diseases, including heart disease, hypertension, diabetes and cancer (Stein and Colditz, 2004), all of which require continual health care and further expenditures.

Research shows that consumers around the globe are moving away from traditional meal-time schedules and snacking more than ever before (Hodgen, 2004). At the same time, consumers are looking for healthy options to add to their diets. The increase in consumer awareness of healthier foods is driving the development of products with less oil and high protein content. Consumers are becoming aware of the health benefits of soy, so it follows that a healthy snack containing soy would be a popular product. The U.S. Food and Drug Administration (FDA) have approved the use of health claims on product labels about the role of soy protein in reducing the risk of coronary heart disease (FDA, 1999). The presence of soy in diets helps to lower cholesterol, has anti-carcinogenic effects, and prevents obesity, diabetes, digestive tract irritation and bone and kidney diseases (Friedman and Brandon, 2001; Messina and Barnes, 1991). This study is a step in the same direction, of developing a healthy snack low in refined carbohydrates and high in protein and focuses on the development of a soy-based, high protein savory snack product.

In pursuit of healthier snacks, we hope to reduce oil absorption. Most snacks are prepared by deep-fat frying which involves immersion and cooking of foods in hot oil. The amount of oil absorbed during frying depends on the composition, initial moisture content, frying time, frying temperature and porosity of the product (Makinson et al., 1987; Nair et al., 1996; Gamble et al., 1987; Gamble and Rice 1988; Song et. al, 2007; Pinthus et al., 1993; Ziaiifar et al., 2010; Adedeji and Ngadi, 2011). The mechanism of oil absorption can be explained by water replacement. Several studies have shown that higher initial moisture results in higher oil uptake (Gamble and Rice 1988; Moreira et al., 1997; Song et. al, 2007). At high frying temperatures, the water present in the foods vaporizes, leaving many void spaces into which oil is absorbed; this explains the linear relationship between moisture loss and oil uptake (Gamble et al., 1987). Frying time and temperature also affect the amount of oil absorbed during frying. Oil absorption decreases at higher frying temperature because shorter frying time is required and outer crust formation acts as a barrier to oil penetration (Pinthus et al., 1995; Gamble et al., 1987). Porosity determines the amount of oil uptake during frying, as indicated by the linear relationship established between oil absorption and porosity (Pinthus et al., 1995; Ziaiifar et. al., 2010). Porosity also has shown good correlation with moisture loss (Adedeji and Ngadi, 2011). All of these factors need to be considered as we attempt to reduce oil uptake in fried foods.

The main objective of this study was to develop a high-protein, soy-based snack food that will be a novel addition to the snack food market in the U.S and to determine how soy and other additives affect the water holding capacity and oil uptake. Both defatted soy flour and wheat flour were used in combination as a base formulation to produce high-protein extruded soy-wheat pellets. Although wheat flour provides good structure for the product and acts as a binding agent, it is relatively low in protein content (7–14%) and is also deficient in certain amino acids such as lysine. Defatted soy flour, on the other hand, is much higher in protein (~50%) and can be used to supplement certain amino acids such as lysine (Rababah et al., 2006). It was hypothesized that the presence of soy would reduce oil uptake during frying and help develop a high-protein, low-fat savory snack. The effects of sodium bicarbonate were also tested which acts as nucleating agent and affects the porosity, texture, oil uptake and acceptability of the product (Berrios et al., 2004; Lajioie et al., 1996). We selected a lentil shape to mimic the commercial lentil-based snacks available in the Indian market. Legumes, such as lentils and chickpeas, are common features in the Indian diet, and are major ingredients in a class of popular deep-fried salty snacks (Mudambi and Rajagopal, 2001). The preparation of commercial snack from lentils such as moong dhal (Vigna radiate) requires longer soaking times (6–12 h) than extruded soy-wheat snacks, which makes our processes fast and cost-effective. The high cost and limited availability of lentils, the nutritional value of soybeans and the ease of processing of soy-wheat savory snacks seems promising for the snack food market. The extrudates were soaked in excess water, fried them in oil to produce savory snacks and determined the effects of soy, monoglycerides, sodium bicarbonate and initial moisture content on oil uptake.

2.2 Materials and Methods

2.2.1 Materials

The ingredients used in this extrusion study were soft wheat flour (protein 9%), (Cereal Food Processors, Mission Woods, KS); defatted soy flour (protein 50%, fat 1.2%, crude fat 3.5%), Prolia®FLR-200/70 (Cargill, Cedar Rapids, IA), monoglycerides, Dimondan HS K-A (Danisco, Copenhagen, Denmark), salt and sodium bicarbonate. Pure 100% corn oil (ACH Food Companies, Inc., Memphis, TN) was used for frying. Salt and pepper obtained from local grocery store (Walmart, Manhattan, KS) were used for seasoning the product prior to the consumer acceptance study.

2.2.2 Extrusion Processing

The experiment comprised eight treatments, four of them with and the others without sodium bicarbonate (Table 2.1). In each set 25, 50 and 75% levels of soy at 0.75 monoglycerides, and 0.375 and 0.75% monoglycerides at 50% level of soy (flour basis) were tested. The raw materials were blended thoroughly using a ribbon blender (Wenger Manufacturing, Sabetha, KS). All samples were extruded with a pilot scale twin screw extruder (TX-52, Wenger Manufacturing, Sabetha, KS) with a six head configuration, screw diameter of 52 mm and L/D ratio of 16:1. The raw material feed rate was maintained at 80 kg/h. The in-barrel moisture was maintained at 40.3% based on adjustment of steam flow in the preconditioner and water flow in the extruder barrel. A medium shear screw profile (Figure 2.1) was used at a screw speed of 200 rpm. A typical drilled die (model 74010-745, Wenger Manufacturing, Sabetha, KS) was used. The die had a total of 24 4.5 mm size holes, 12 of which were blocked with glue (Figure 2.2). Extrusion conditions were kept constant across all treatments. Extruder conditions were allowed to stabilize for ~10 min. The product was cut immediately after exiting the extruder die with a face-mounted flex knife (3 blades) rotating at 819 rpm and was dried at 190 ^{o}F with a double-pass dryer/cooler (4800 Series, Wenger Manufacturing, Inc.) for 60 min (40 min for the top and 20 min for the bottom belt) followed by a 12 min cooling step. Samples were immediately transferred to thick polyethylene bags and stored at room temperature until analysis.

2.2.3 Specific Mechanical Energy

Specific mechanical energy (SME) was calculated using

$$SME\,(kJ/kg) = \frac{\left(\frac{\tau - \tau_0}{100}\right) \times \frac{N}{N_r} \times P_r}{\dot{m}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.1)$$

where, τ is the % torque; τ_0 is the no load % torque; N is the extruder screw speed (rpm); N_r is the rated screw speed (336 rpm); P_r is the rated motor power (22.38 kW); and $\dot{m}$ is the mass flow rate or throughput (kg/s).

2.2.4 Development of savory snacks

The extruded soy-wheat pellets were soaked in water for 60-75 min for uniform hydration. The soaked samples were air dried for 30-45 min for the surface moisture to distribute uniformly over the pellets. These pellets were then fried (T-Fal Superclean 1250 Gold Deep Fryer 3675) in oil at 160 –180 ^{o}C for 2.5 to 3.5 min. The soaking and frying times were selected based on qualitative or visual observations. The soaking time was determined, at which opaque core disappears by manual pressing of soaked samples between the glass slides. Water holding capacities during soaking and oil uptake during frying were determined.

2.2.5 Water holding capacity (WHC)

Water holding capacity of soaked samples were measured using standard AACC International Method (56-35.01):

$$WHC = \frac{m_s - m_e}{m_e} \times 100 \qquad \ldots\ldots\ldots\ldots\ldots\ldots.. \quad (2.2)$$

where, m_s = weight of sample after soaking and m_e = weight of sample before soaking.

2.2.6 Oil uptake

Oil uptake of fried samples was calculated using mass balance concepts:

$$m_{oil} = \frac{m_f\left(1 - X_{wf}\right) - m_s(1 - X_{ws})}{m_e}$$

$$\%\ oil = \frac{m_{oil}}{(100 + m_{oil})} * 100 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.3)$$

where,

m_{oil} = oil uptake, (g/g)

m_f = weight of sample after frying, g

m_s = weight of sample after soaking, g

X_{wf} = moisture content of sample after frying

X_{ws} = moisture content of sample after soaking

m_e = initial weight of extruded sample, g

2.2.7 Crude fat

All the samples were tested for crude fat using standard AOAC petroleum ether extraction method (920.39).

2.2.8 Consumer acceptance study

Soy-wheat-based savory snacks (25% and 50% level of soy addition both with and without sodium bicarbonate) were tested for consumer acceptance. A large-capacity fryer (Belshaw 614A) was used to prepare a bulk sample for sensory study (approximately 2 kg of each sample). The fried snacks were seasoned with salt (0.5%) and pepper (0.2%). A consumer panel of 107 subjects (77 females and 30 males) were recruited to rate the savory snacks based on overall acceptability and other attributes. Americans and those who have lived in the U.S. for past six years were chosen. All the panelists were screened based on their age and interest in consuming corn nuts, grape-nuts cereal (without milk), kettle chips, or other hard and crunchy products. Panelists were also screened for any food allergies or intolerances. Information on gender, family background and frequency of participating in taste tests were recorded. Each consumer was paid $10 for participating. A 9-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely) was used to evaluate the products (Lawless and Heymann, 1998). Paper ballot was provided to rate the product characteristics such as overall acceptability, appearance, flavor and crunchiness based on 9 point hedonic scale and perceived oiliness and aftertaste based on intensity (not at all, moderate and strong) of perception. Approximately 15g of each sample were prepared for testing and stored at room temperature ($22 \pm 2\ ^{o}C$) in sealed plastic cups (Solo, Illinois). All the samples were randomly coded with three-digit numbers, and the serving order for panelists was randomized. Water and unsalted crackers (Saltines, Kroger), were provided to clean the palate between samples. The consumer acceptability data were analyzed with SAS software (SAS 9.2, SAS Institute Inc., Cary, NC). Fisher's least square difference test was used to determine differences among treatments.

2.3 Results and Discussions

2.3.1 Extrusion processing

Extrusion processing conditions were designed to produce soy-wheat-based, dense, lentil-shaped extrudates. The high in-barrel moisture (38.2–40.3%) reduced the viscosity of the melt generating less mechanical energy. The medium-shear screw profile also generated less shear and friction lowering specific mechanical energy (SME), which was in the range of 37.6–55.6 KJ/kg (Figure 2.3). This low energy input prevented expansion and generated a dense lentil-shaped snack.

There were no significant differences observed in SME ($P > 0.05$) at different levels of soy, but, monoglyceride levels affected SME. Monoglycerides acted as a lubricant by reducing friction and, correspondingly, SME. SME decreased with increasing monoglyceride levels.

2.3.2 Development of savory snacks

Similar soaking and frying conditions could not be maintained for the samples with and without sodium bicarbonate. Because the pellets with sodium bicarbonate were porous, they could not withstand longer soaking times. At 75 min of soaking, they disintegrated and lost their shape, so they were soaked for 60 min. During frying, samples with sodium bicarbonate lost moisture rapidly and disintegrated, so lower frying temperatures (160 ^{o}C instead of 180 ^{o}C) and longer frying times (3.5 min instead of 2.5 min) were selected.

2.3.3 Water holding capacity

Water holding capacity decreased significantly ($p < 0.05$) with increase in soy percentage up to 50% for the samples without sodium bicarbonate, and there was no significant difference ($p > 0.05$) observed between 50 and 75% soy (Figure 2.4). Soy is rich in protein; in general, proteins contain both hydrophilic and hydrophobic amino acids. The replacement of wheat flour with soy flour replaced hydrophilic starch with less hydrophilic protein. Heat treatment of protein modifies protein structure such that it increases the surface hydrophobicity (Xiang et al., 2011). The decrease in hydrophilic starch and increase of surface hydrophobicity of protein by extrusion heat treatment could have led to lower water holding capacity; however, in the samples with sodium bicarbonate, the effect of porosity was also considered in addition to the effect of soy. Sodium bicarbonate acts as a nucleating agent by generating small pores in the extruded matrix and affecting the product's porosity and texture (Berrios et. al., 2004). There was no significant difference ($p > 0.05$) observed in water holding capacity among the treatments with sodium bicarbonate at different levels of soy, which might be because of the porosity effect of sodium bicarbonate. For the samples with and without sodium bicarbonate no significant differences ($p > 0.05$) were observed in water holding capacities at different levels of monoglycerides (Figure 2.5).

2.3.4 Oil uptake

Oil uptake during frying mostly depends on the initial moisture content (Gamble and Rice, 1988; Moreira et. al., 1997; Esturk et. al., 2000; Song et. al., 2007). During frying, oil fills the voids created in the product by rapid loss of water vapor. More rapid loss means more oil uptake. Notably, oil uptake results followed the same trend as water holding capacity (Figure 2.6). There were no significant differences ($p > 0.05$) observed in oil uptake with the increase in levels of soy for samples with and without sodium bicarbonate.

Oil uptake decreased with increased monoglycerides (Figure 2.7). A higher level of monoglycerides reduced shear or SME, causing less starch degradation and thereby less oil uptake; however, oil uptake data did not differ significantly ($P > 0.05$) for the samples with sodium bicarbonate.

2.3.5 Crude fat

Fat content (19.11–13.7%) decreased significantly ($p < 0.05$), by 28.3%, with an increase in soy from 25 to 75% for the samples without sodium bicarbonate. The decrease in water holding capacity with the increase in soy resulted in low oil uptake. In samples with sodium bicarbonate, fat content (16.07–11.73) decreased significantly ($p < 0.05$) by 24.5%, with a 25 to 50% increase in soy, and there were no significant differences ($p > 0.05$) observed between samples at 50 and 75% levels of soy (Figure 2.8). A similar trend of decreased fat content with increased levels of soy flour was observed in fried savory snacks with blends of soy and wheat flour in another study (Senthil et al., 2002). At 50% soy addition the crude fat (15.3%) decreased by 34.3% when compared with the commercial snacks prepared from lentil (23.3%).

With the increase in monoglycerides, crude fat decreased (Figure 2.9) for the samples both with and without sodium bicarbonate. Lower SME was observed at higher levels of monoglycerides, causing less starch degradation, which led to less oil uptake and thereby less fat in the product.

2.3.6 Consumer acceptance study

The consumer acceptability and intensity ratings of different sensory attributes are shown in Figure 2.10. The soy-wheat based savory snacks were neither liked nor disliked by the consumers, receiving hedonic scores between 5 and 6 (“neither likes nor disliked” to “like slightly”). ANOVA results indicate that no significant difference ($P > 0.05$) among the samples for overall acceptability and texture except samples with 50% level of soy without sodium bicarbonate, which received significantly lower overall acceptability because of their hard texture (hedonic scores for texture are between 4 and 5 ("dislike moderately" to "dislike slightly"). Sensory results showed that texture had influenced overall acceptability of the products. Similarly extrudates from maize and partially defatted soy bean that are not puffy and hard to crack received lower acceptability (Veronica et. al., 2006). Samples with and without sodium bicarbonate at the 25% level of soy received higher ratings for flavor compared with the samples at the 50% level of soy.

Panelists rated oiliness and aftertaste based on the intensity of perception. The perceived oiliness was significantly lower for the samples at the 50% level of soy compared with samples at the 25% level of soy. The oiliness perception follows a trend similar to that of the experimental crude fat results. Aftertaste perception was significantly higher for the samples with sodium bicarbonate.

2.4 Conclusion

Overall results indicate that the level of soy addition in extruded savory snacks affects the oil uptake during frying. With an increase in soy from 25 to 50%, fat content decreased in the products. Oil absorption during frying depends on the water holding capacity, composition and porosity of the products. Incorporation of soy affects water absorption during soaking, thereby affecting oil absorption during frying. With the addition of soy, deep fat fried snacks similar to lentils that are low in fat and high in protein can be produced. Consumer acceptability tests emphasized the need for further study to improve the texture of the products. Ingredients or processing conditions that reduces the hardness or increase the crisp to hardness ratio in dense extruded products might improve the texture the products

2.5 References

AACC. (1999). American Association of Cereal Chemist. *International Methods of Analysis.* 11th Ed. Method 56-35.01. AACC International, 653 St. Paul, MN, USA.

Adedeji, A. A. and Ngadi, M. O. (2011). Microstructural characterization of deep-fat fried breaded chicken nuggets using X-ray micro-computed tomography. *Journal of Food Process Engineering*, **34**, 2205–2219.

AOAC. (2010). Association of Analytical Chemists. Method 920.39: Crude fat in feeds - Cereal Grains and Forages. In: *Anonymous Official Methods of Analysis of AOAC International*. 18th ed. Gaithersburg, MD: AOAC International.

Berrios, J. D. J., Wood, D. F., Whitehand, L., and Pan, J. (2004). Sodium bicarbonate and the microstructure, expansion and color of extruded black beans. *Journal of Food Processing and Preservation*, **28**, 321-335.

CDC. (2006). Center for Disease Control and Prevention. Prevalence of overweight and obesity among adults United States, 2003-2004. Available at: http://www.cdc.gov/nchs/products/pubs/pubd/hestats/overweight/overwght_adult_03.htm (Accessed 10/17/2010).

Esturk, O., Kayacier, A., and Singh, R. K. (2000). Reduction of oil uptake in deep fried tortilla chips. *Food Science and Technology International*, **6**, 425-431.

Friedman, M., and Brandon, D. L. (2001). Nutritional and health benefits of soy proteins. *Journal of Agricultural and Food Chemistry*, **49**, 1069-1086.

FDA. (1999). Food labeling health claims: soy protein and coronary heart disease. *Food and Drug Administration*, HHS Final rule. **64**, 57700-57733.

Gamble, M. H., Rice, P., and Selman, J. D. (1987). Relationship between oil uptake and moisture loss during frying of potato slices from c.v. Record U.K. tubers. *International Journal of Food Science and Technology*, **22**, 233-241.

Gamble, M. H., & Rice, P. (1988). Effect of initial tuber solids content on final oil contenct of potato chips. *LWT - Food Science and Technology*, **21**, 62-65.

Hodgen, D.A. 2004. *Global snack food industry trends. Snack Food &Wholesale Bakery* 93. http://www.snackandbakery.com/Archives_ Davinci article=1191 (Accessed 4/30/2009).

IBISWorld. (2011). Snack food production in the US: Market Research Report. Available at: http://www.ibisworld.com/industry/default.aspx?indid=271. (Accessed 2/21/2012).

Jia, H., and Lubetkin, E.L. (2010). Obesity-related quality adjusted life years lost in the U.S. from 1993 to 2008. *American Journal of Preventive Medicine*, **39**, 20 –227.

Lawless, H. T., and Heymann, H. (1998). *Sensory Evaluation of Food: Principles and Practices*. Pp. 827. New York: Kluwer Academic/Plenum Publishers.

Lajoie, M. S., Goldstein, P. K., and Geeding-Schild, D. (1996). Use of bicarbonates in extrusion processing of ready-to-eat cereals. *Cereal Foods World*, **41**, 448-451.

Messina, M., and Barnes, S. (1991). The role of soy products in reducing risk of cancer. *Journal of the National Cancer Institute*, **85**, 541-546.

Moreira R. G., Sun X. and Chen Y. (1997). Factors affecting oil uptake in tortilla chips in deep fat frying. *Journal of Food Engineering*, **31**, 485-498.

Mudambi, S. R. and Rajagopal, M.V. (2001). Snack foods in India. In *Snack Foods Processing* (E. W. Lusas and L. W. Rooney, eds.) Pp. 477– 491, Technomic Publishing Co, Lancaster, PA.

Rababah, T., Al-Mahasneh, M., and Ereifej, K. (2006). Effect of chickpea, broad bean, or isolated soy protein addition on the physicochemical and sensory properties of biscuits. *Journal of Food Science*, **71**, 438-442.

Senthil, A., Ravi, R., Bhat, K. K., and Seethalakshmi, M.K. (2002). Studies on the quality of fried snacks based on blends of wheat flour and soy flour. *Food Quality and Preference*, **13**, 267-273.

Song, X. J., Zhang, M. and Mujumdar, A. S. (2007). Effect of vaccum-microwave predrying on quality of vaccum-fried potato chips. *Drying Technology*, **25**, 2021-2026.

Stein, C. J., and Colditz, G. A. (2004). The epidemic of obesity. *Journal of Clinical Endocrinology & Metabolism*, **89**, 2522-2525.

Makinson, J. H., Greenfield, H., Wong, M. L., and Wills, R. B. H. (1987). Fat uptake during deep fat frying of coated and uncoated foods. *Journal of Food Composition and Analysis*, **1**, 93-101.

Moreira, R. G., Sun, X., and Chen, Y. (1997). Factors affecting oil uptake in tortilla chips in deep-fat frying. *Journal of Food Engineering*, **31**, 485–498.

Nair, C. K. V., Seow, C. C., and Sulbelbe, G. A. (1996). Effects of frying parameters on physical changes of tapioca chips during deep-fat frying. *Journal of Food Engineering*, **31**, 249-256.

Pinthus, E. J., Weinberg, P. and Saguy, I. S. (1993). Criterion for oil uptake during deep fat frying. *Journal of Food Science*, **58**, 204-205.

Pinthus, E. J., Weinberg, P. and Saguy, I. S. 1995. Oil uptake in deep fat frying as affected by porosity. *Journal of Food Science*, **60**, 767–769.

USDA. (2005). United State Department of Agriculture - National nutrient database for standard reference. http://www.ars.usda.gov2005.

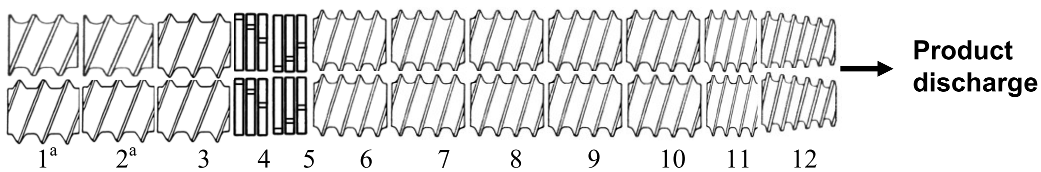
Veronica, A. O., Omuetiolusola, O. and Adebowale, E. A. (2006). Qualities of extruded puffed snacks from maize/soybean mixture. *Journal of Food Process Engineering,* **29**, 149–161.

Xiang, B. Y., Ngadi, M. O., Simpson, B. K., and Simpson, M. V. (2011). Pulsed electric field induced structural modification of soy protein isolate as studied by fluorescence spectroscopy. *Journal of Food Processing and Preservation*, **35**, 563-570.

Ziaiifar, A.M., Courtois, F., and Trystram, G. (2010). Porosity development and its effect on oil uptake during frying process. *Journal of Food Process Engineering*, **33**, 191–212.

Figures and Tables

Head Number	1	2	3	4	5	6
Barrel Temperature (°C)	30	30	60	60	90	85



Element No.

1=SE[b]-1-F-78; 2=SE-1-F-78; 3=SE-2-1-78; 4=KB[c]-3-8.7-30F; 5=KB-3-8.7-30R; 6=SE-2-3/4-78; 7=SE-2-3/4-78; 8=SE-2-3/4-78; 9=SE-2-3/4-78; 10=SE-2-3/4-78; 11= SE-2-1/2-78; and 12=SE (conical)-2-3/4-78.[d]

[a]Left shaft elements are double flighted.
[b]SE = screw element
Numbers:
1st – number of flights
2nd – relative pitch
3rd – element length, mm
[d]All screw elements are forward and intermeshing.

[c]KB = kneading blocks
Letters: F- Forward, R- Reverse
Numbers:
1st – number of elements
2nd – length of element, mm
3rd – angle of elements, degrees

Figure 2-1: Extruder screw configuration and temperature profile.

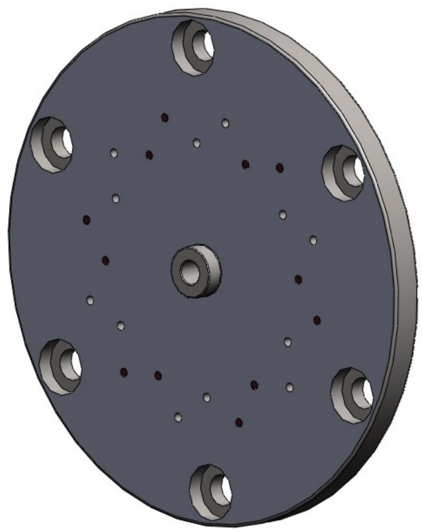


Figure 2-2: Extruder die configuration (3D picture)

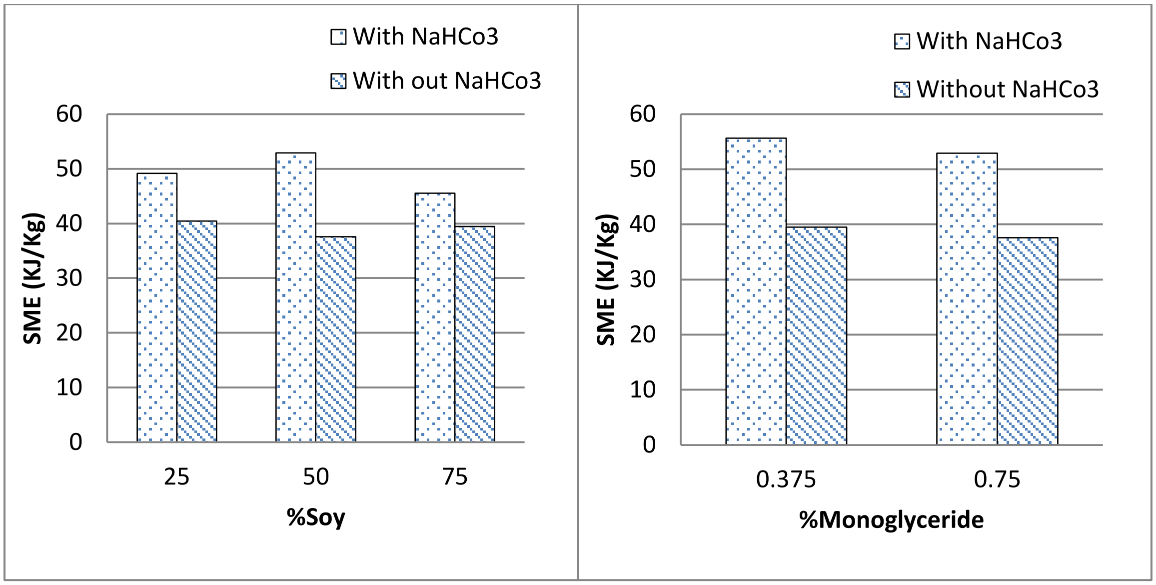


Figure 2-3: Specific mechanical energy (SME) during extrusion processing

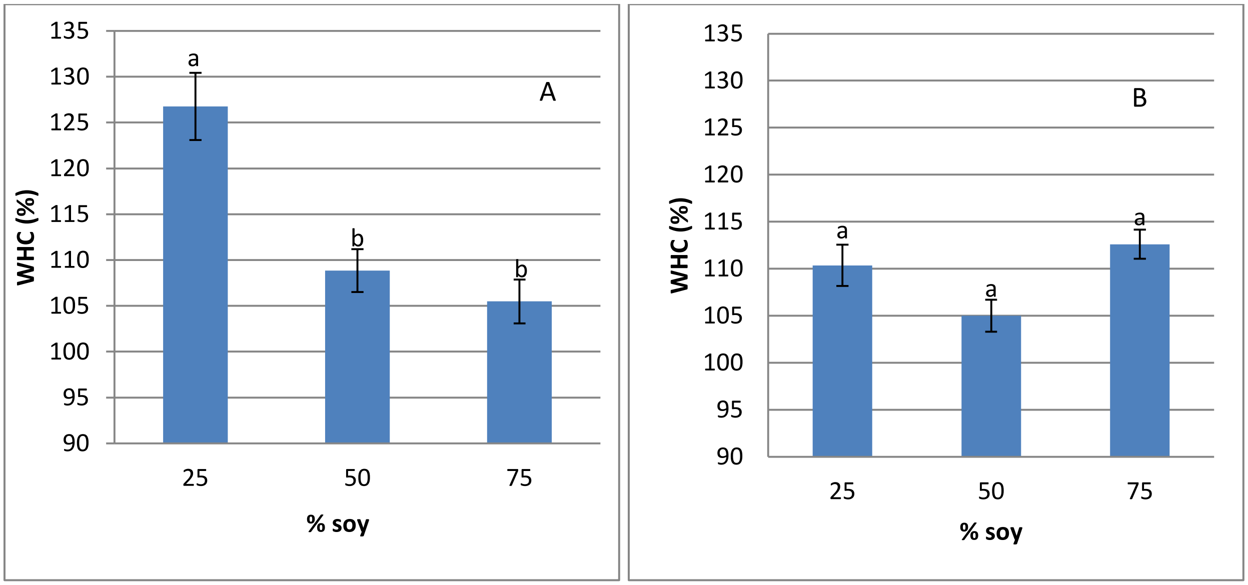


Figure 2-4: Effect of soy on water holding capacity (WHC). (A) without sodium bicarbonate (B) with sodium bicarbonate. *Means bars with different letter notations are significantly different ($p \leq 0.05$)

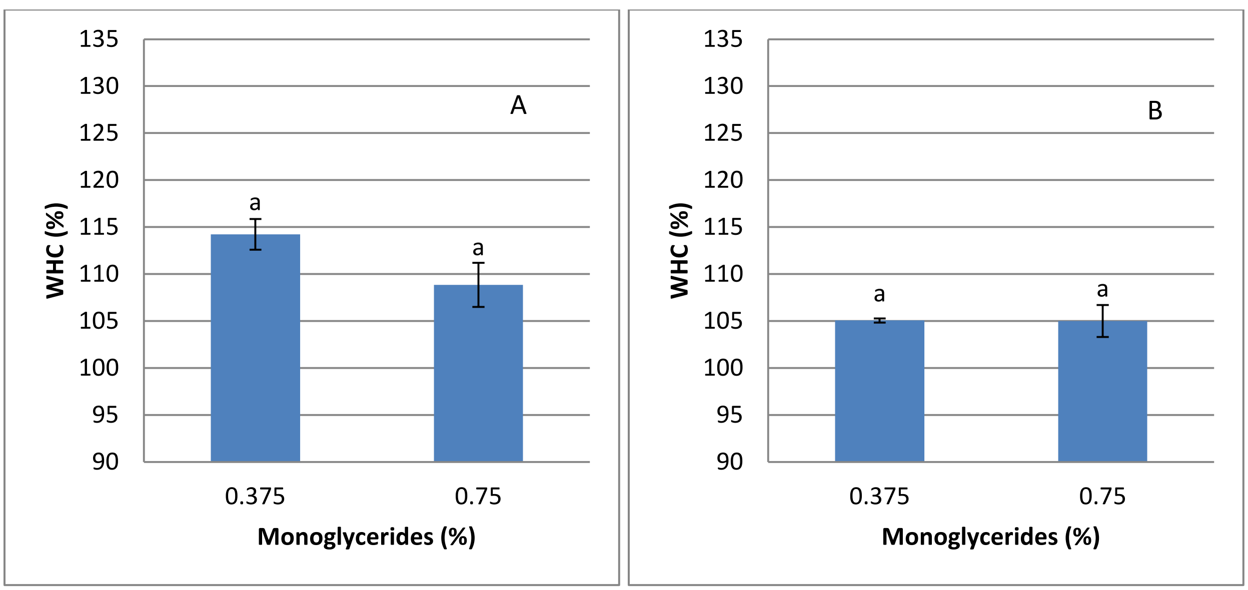


Figure 2-5: Effect of monoglycerides on water holding capacity. (A) without sodium bicarbonate (B) with sodium bicarbonate. *Means bars with different letter notations are significantly different ($p \leq 0.05$)

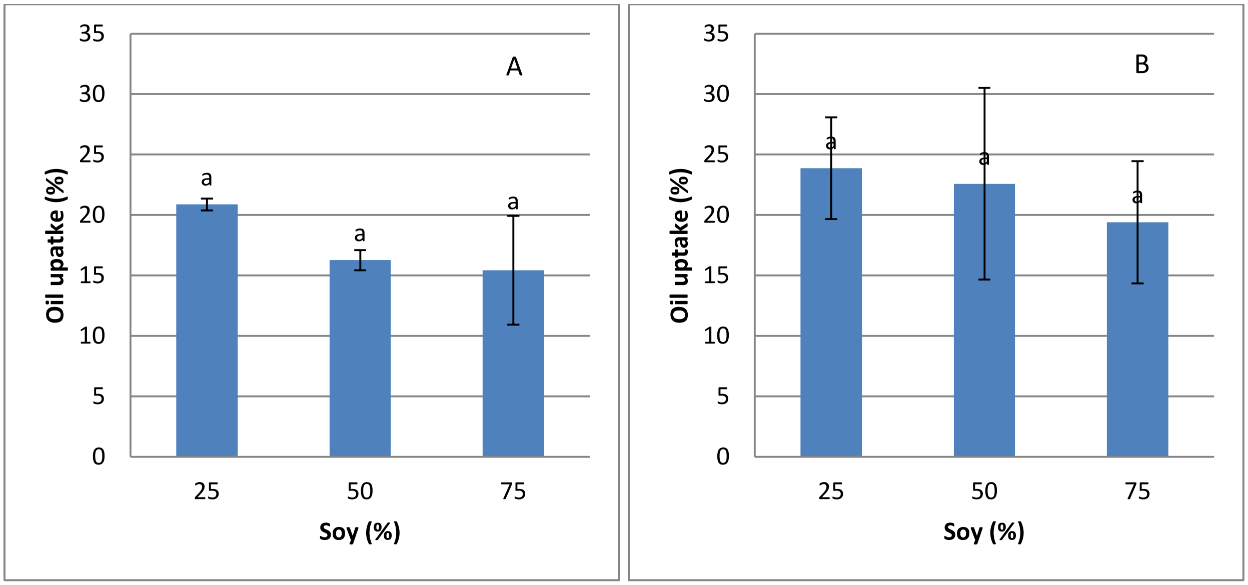


Figure 2-6: Effect of soy on oil uptake. (A) without sodium bicarbonate (B) with sodium bicarbonate. *Means bars with different letter notations are significantly different ($p \leq 0.05$)

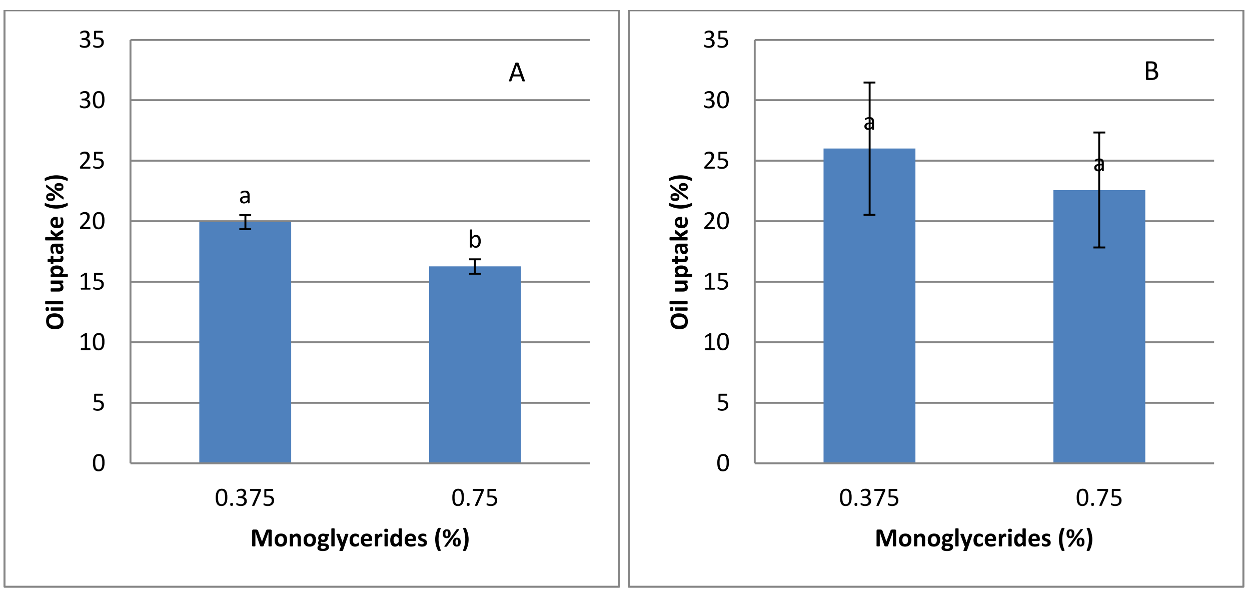


Figure 2-7: Effect of monoglycerieds on oil uptake. (A) without sodium bicarbonate (B) with sodium bicarbonate. *Means bars with different letter notations are significantly different ($p \leq 0.05$)

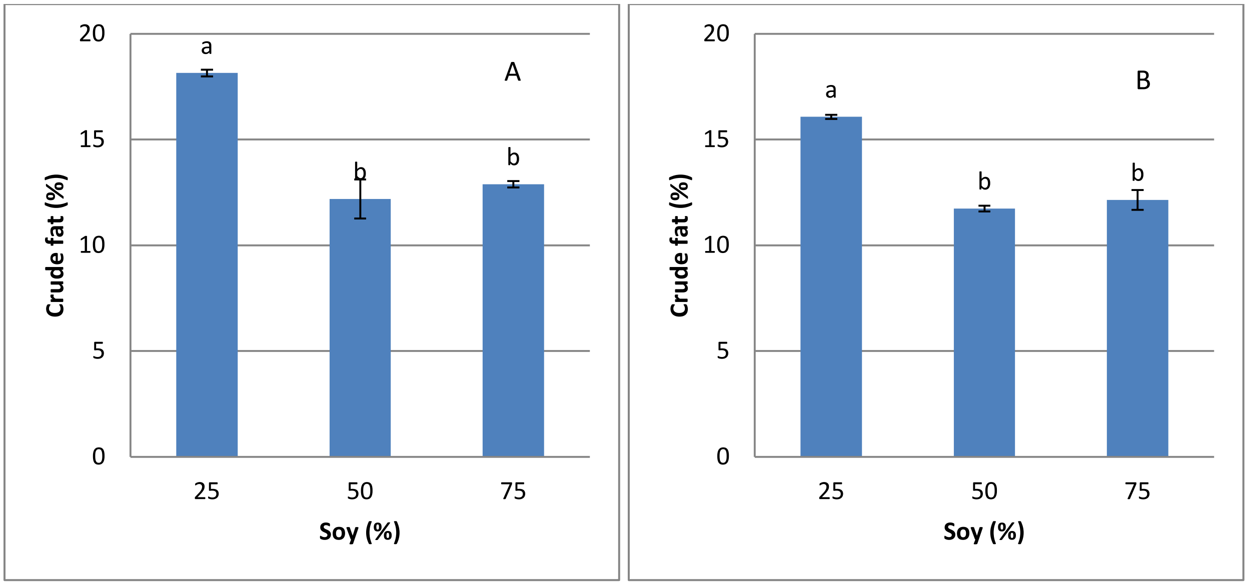


Figure 2-8: Effect of soy on crude fat. (A) without sodium bicarbonate (B) with sodium bicarbonate. *Means bars with different letter notations are significantly different ($p \leq 0.05$)

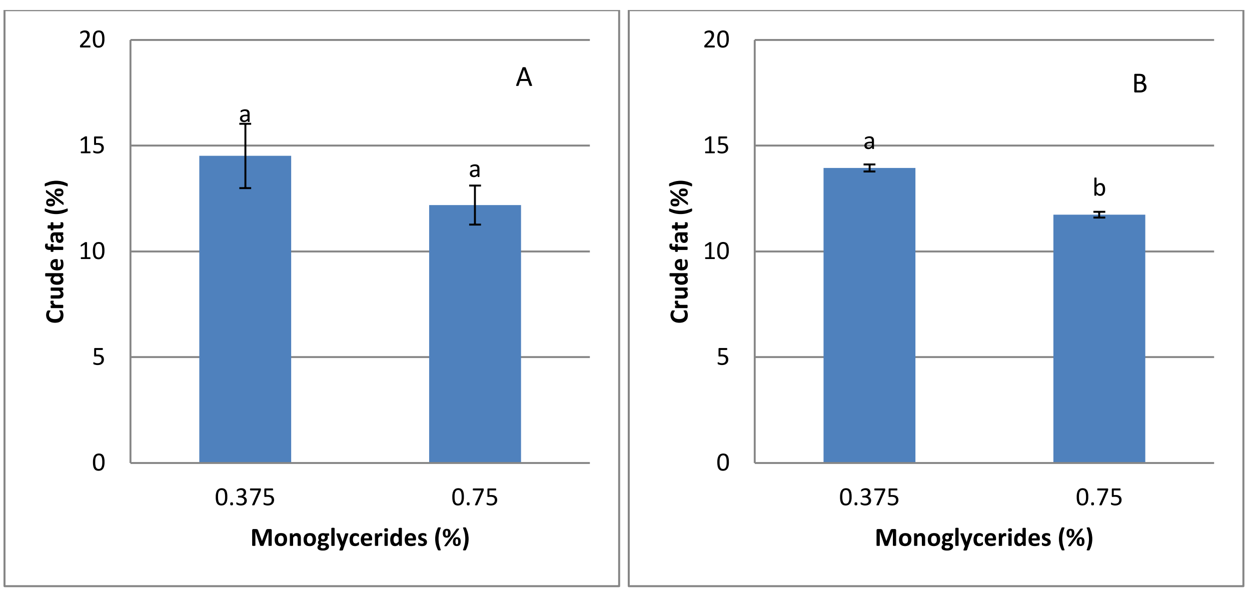


Figure 2-9: Effect of monoglycerides on crude fat. (A) without sodium bicarbonate (B) with sodium bicarbonate. *Means bars with different letter notations are significantly different ($p \leq 0.05$)

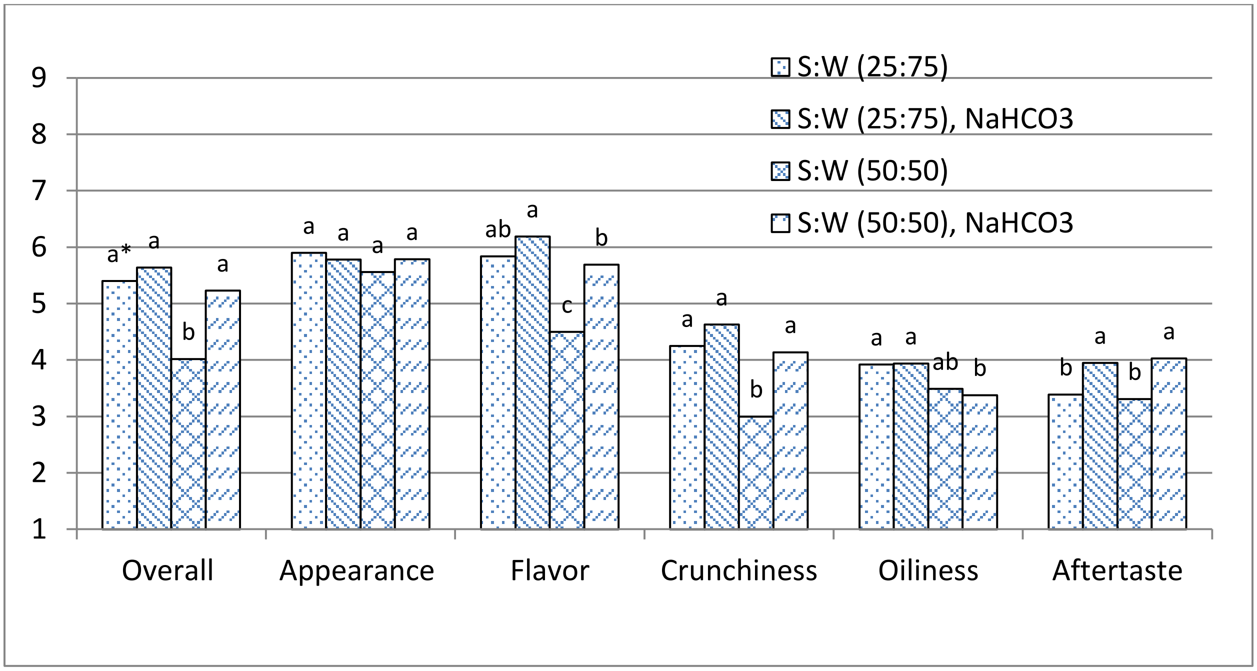


Figure 2-10: Consumer acceptance study. *Means bars with different letter notations are significantly different ($p \leq 0.05$)

Table 2-1: Experimental design

Treatments	1	2	3	4	5	6	7	8
Soft wheat flour	50	50	25	75	50	50	25	75
Defatted soy flour (%)	50	50	75	25	50	50	75	25
Salt (%)	1	1	1	1	1	1	1	1
Monoglycerides (%)	0.375	0.75	0.75	0.75	0.375	0.75	0.75	0.75
Sodium bicarbonate (%)	0	0	0	0	0.5	0.5	0.5	0.5

Chapter 3 - Physico-chemical properties, and water and oil uptake dynamics in soy-based snacks – role of texture modifiers

Abstract

Snacks are widely consumed and the acceptability of these snacks mostly depends on their textural properties, which varies with formulation and processing conditions. The effects of increasing levels of texture modifiers, soy protein isolate (SPI), calcium carbonate ($CaCO_3$) and pregelatinized wheat starch (PGWS) on texture and oil uptake was investigated by studying the dynamics of water and oil uptake during processing. High in-barrel moistures (38.6%) and low barrel temperatures were maintained to produce dense extrudates with defatted soy flour and wheat flour at 50:50 (control) levels. Physico chemical properties like water holding capacity (WHC), oil uptake, crude fat, and texture of all the samples were tested. Addition of texture modifiers decreased WHC. Degree of starch degradation and level of starch additions influenced WHC. Oil uptake correlates with WHC and is also influenced by the degree of starch gelatinization and crust formation. At highest inclusions of SPI and $CaCO_3$, oil uptake decreased by 4% and 9% respectively whereas with PGWS it increased by 19.1%. Texture of the products was impacted by the matrix composition, oil uptake and oil and starch matrix interactions. It increased with SPI (14.4 N) and $CaCO_3$ (17.7 N) whereas with PGWS (13.1 N) it decreased compared to control (13.4 N). Descriptive sensory results agree with the experimental results, with PGWS samples having more oxidized and heated oil aroma and flavor and lower initial and substantial hardness followed by SPI and $CaCO_3$. Surface roughness and after taste were higher in samples with PGWS.

3.1 Introduction

Snacks are most commonly consumed and snack food industry is one of the largest food markets with $77 billion value, globally in 2010 (Business Insights., 2012). The snacking frequency increased over a decade especially in adolescents. On a given day the percentage of snacking among adolescents increased from 61% in 1977-78 to 83% in 2005-06 (Sebastian et. al., 2010). The acceptability of snacks mostly depends on their sensory qualities (Ravi et. al., 2011). Texture in turn is one of the most important sensory attribute and is affected by the ingredient formulation and processing conditions.

Deep fat frying is the one of the most commonly used processing method used to develop snacks that are unique in texture and flavor. It is defined as a process of immersing foods into the oil at a temperature higher than boiling point of water. Both heat and mass transfer are involved affecting the texture of the product. The oil absorption during frying is mostly dependent on formulation, initial moisture, frying time and frying temperature (Nasiri et. al., 2012; Altunakar et.al., 2004; Lim et. al., 2012; Song et. al., 2007; Mohan and Babu., 2007; Moyano and Pedreschi, 2006). Degree of starch gelatinization also influence the amount of oil absorbed during frying (Kawas and Moreira, 2001).

With the advancement of food process technologies over the past few decades, variety of processed products, rich in refined carbohydrates and oil (energy dense foods) were mostly developed. Change in eating patterns, nutritional and dietary habits has led to increase in health problems like obesity. Snacking has considerably increased contributing about 25% of daily calorie intake in U.S. population (IFT., 2011). The snacking % per day increased by 14% from 1977-78 to 1994-96 (Zizza et al., 2001). Over the past two decades obesity has drastically increased and is the result of energy imbalance where intake is more than the energy spent. In U.S. more than 17% of the children and more than one-third of the adults are obese (CDC., 2011). The greater the degree of obesity or overweight more is the inclination towards consuming energy dense foods (Goldfield et. al., 2011). This provides a great challenge to food technologists to design high quality products that contribute to the wellness of the people without compromising texture, taste and flavor. Research is focused in this direction without compromising texture and nutrition.

Addition of soy protein ingredients influence the oil uptake and improve texture of the products. Soy protein isolate reduced the hardness of the products and improved taste and texture acceptability of the products (Siegwein et. al., 2011). Soy flour decreased the oil uptake in fried nuggets during frying (Nasiri et. al., 2012). Replacement of starch with protein also reduce oil uptake during frying. Leavening agents such as calcium carbonate increase the porosity and improve the texture. Increased porosity influences the hardness of the product tending to improve the crispness of the product. Pregelatinized starches increases the water absorption and also affect the texture of the products. The imitation chesses produced with pregeletainized starches were softer compared to the cheese with no starch (Mounsey and Riordan, 2008). Pregelatinized wheat starch caused cold water viscosity with increased water absorption and swelling compared to its native counterpart (Majzoobi et. al., 2011). Starch additions improved the texture (crispness) of the products (Altunakar et. al., 2004).

The objective of this study was to investigate the effect of texture modifiers like soy protein isolate, calcium carbonate and prgelatinized wheat starch on texture and water and oil uptake during processing of dense soy based snacks. Preliminary research showed that the replacement of starch with defatted soy flour reduced the amount of oil uptake during frying but laid challenges to further improve the texture of the products. In this study we hypothesized that soy protein isolate, calcium carbonate and pregelatinized wheat starch would affect the texture of the products. The effect of these ingredients on physciochemical properties (water absorption, oil uptake and texture) were quantified by instrumental and sensory analysis. The effect of initial moisture and frying time were also studied to model the heat and mass transfer during frying process.

3.2 Materials and Methods

3.2.1 Materials

Defatted soy flour (protein 50%, fat 1.2%, crude fat 3.5%), Prolia®FLR-200/70 (Cargil, Cedar Rapids, IA); soft wheat flour (protein 9.25%), (Cereal Food Processors, Mission Woods, KS); soy protein isolate (protein 90%), SUPRO®670 (Solae, St. Louis, MO); pregelatinized wheat starch (protein 1%, viscosity (8% (as is, solids) 350 BU), Prgel™10 (MGP Ingredients, Atchison, KS); calcium carbonate (Lortscher Agri Services Inc, Bern, KS); monoglycerides, Dimondan HS K-A (Danisco, Copenhagen, Denmark) and salt were used in this study. Corn oil (ACH Food Companies, Inc., Memphis, TN) was used to fry the extrudates.

3.2.2 Extrusion Processing

Defatted soy flour and soft wheat flour at 50:50 ratio is extruded as control. Soy protein isolate at 4, 8, 12% flour basis, calcium carbonate at 0.2, 0.4 and 0.6% flour basis and pregelatinized wheat starch at 4, 8, 12% flour basis were extruded to produce dense extrudates. A total of ten different treatments with different ingredients at various levels of inclusions (Table 3.1) were tested to study their impact on texture and oil uptake.

All the materials were mixed in a ribbon mixer (Wenger Manufacturing, Sabetha, KS) for approx. 5min and the blends were extruded in a TX-52 twin screw extruder (Wenger

Manufacturing, Sabetha, KS). The feed rate was maintained at 80kg/hr. High in barrel moistures (40%) and low screw speeds (200rpm) were targeted to generate less specific mechanical energy to prevent expansion. Moisture is added in the form of preconditioner steam (12kg/hr), preconditioner water (20kg/hr) and extruded water (5kg/hr). Medium shear screw profiles with low in barrel temperatures (Figure 3.1) were used. A typical die (Figure 3.2) was used to produce lentil shaped pellets. The extruded samples were cut into small discs with the help of a face mounted flex knife rotating at a speed of 1016 rpm. The extrudates were dried twice in a dual pass drier at 190°F for about 60min (20min on top belt and 40min on the bottom belt) and cooled for about 12min to reduce the product moisture to 7-8%. The dried samples were collected and stored in polyethene bags for post extrusion analysis.

Specific mechanical energy and In-barrel moistures were calculated from the equations

$$SME\,(kJ/kg) = \frac{\left(\frac{\tau - \tau_0}{100}\right) \times \frac{N}{N_r} \times P_r}{\dot{m}} \qquad \text{.................................} \quad (3.1)$$

where, τ is the % torque; τ_0 is the no load % torque; N is the extruder screw speed (rpm); N_r is the rated screw speed (336 rpm); P_r is the rated motor power (22.38 kW); and $\dot{m}$ is the mass flow rate or throughput (kg/s).

In-barrel moisture for all the treatments are calculated using

$$MC = \frac{m_f \times X_f + m_{ps} + m_{pw} + m_{es} + m_{ew}}{m_f + m_{ps} + m_{pw} + m_{es} + m_{ew}} \qquad \text{........................} \quad (3.2)$$

where m_f is the dry feed rate, X_f is the wet basis moisture content of the feed material, m_{ps} is the steam injection rate in the pre-conditioner (kg/hr), m_{pw} is water injection rate in the pre-conditioner (kg/hr), m_{es} is the steam injection rate in the extruder (kg/hr) and m_{ew} is water injection rate in the extruder (kg/hr).

3.2.3 Post extrusion processing

The extrudates were soaked in excess water for 60min and then air dried for about 30min. The air dried samples were fried in oil at 180^{o}C for about 2min. The fried samples were tested for oil uptake, texture and descriptive sensory analysis. Time bound experiments were carried out for water holding capacity for every 10min and texture profile of those samples were tested. Two different soaking conditions were studied to understand the effect of soaking times and moisture absorption on oil uptake, crude fat and texture. The effect of frying time on oil uptake, crude fat and texture were tested.

3.2.4 Starch gelatinization

Degree of starch gelatinization was tested on all the samples to study the effect of starch gelatinization on water holding capacity and oil uptake. Differential scanning calorimeter (DSC) is used to study the change in enthalpy among samples with different degree of gelatinization. The extruded samples were ground using a mottle and pestle to fine powder of size < 300 microns. Approx. 10mg of ground samples was weighed into the DSC pans and distilled water was added using micro pipette to add up the sample moisture to 66%. The pans were equilibrated overnight and tested for change in enthalpy. The samples were heated from 10 to 140^{o}C with a heating rate of 10^{o}C/min and cooling rate of 40^{o}C/min. The degree of gelatinization was calculated based on difference in enthalpy with extruded and raw samples from the equation:

$$DG\ (\%) = \left(\frac{\Delta H_{raw} - \Delta H_{extruded}}{\Delta H_{raw}}\right) \times 100 \qquad \text{..................} \quad (3.3)$$

where,

ΔH raw = gelatinization enthalpy of raw samples (kJ/kg),

ΔH extruded = gelatinization enthalpy of extruded samples (kJ/kg).

3.2.5 RVA Analysis

RVA studies of all the samples were conducted using a Newport Scientific Rapid Visco Analyzer (RVA). The samples were tested at 14% moisture by adding 25 ml of distilled water to 3g of sample. First, the distilled water is measure in container to which the sample were added and tested immediately. A standard 13 min standard RVA profile is used to test the samples, which holds the sample at 50°C for 1min, temperature ramp up from 50 to 95°C in 3min 42sec, holding at 95°C for 2min 30sec, cooling from 95 to 50°C in 3min 48se and holding again at 50°C for 2min. All the samples were tested in duplicates.

3.2.6 Water holding capacity (WHC)

WHC was measured as the difference in weight before and after soaking, by a standard AACC International Method (56-35.01).

$$WHC = \frac{m_s - m_e}{m_e} \times 100 \quad \text{...........................} \quad (3.4)$$

where, m_s = weight of sample after soaking and m_e = weight of sample before soaking.

3.2.7 Oil uptake

Oil uptake was calculated based on mass transfer phenomenon during frying

$$m_{oil} = \frac{m_f\left(1 - X_{wf}\right) - m_s(1 - X_{ws})}{m_e}$$

$$\%\, oil = \frac{m_{oil}}{(100 + m_{oil})} * 100 \quad \text{.........................} \quad (3.5)$$

where,

m_{oil} = oil uptake, (g/g)

m_f = weight of sample after frying, g

m_s = weight of sample after soaking, g

X_{wf} = moisture content of sample after frying

X_{ws} = moisture content of sample after soaking

m_e = initial weight of extruded sample, g

3.2.8 Crude fat

Crude fat is estimated by the standard AOAC petroleum ether extraction method (920.39)

3.2.9 Texture

Texture profile analysis (TPA) was conducted on soaked samples to determine their physical characteristics using 36mm round acrylic probe on texture analyzer (Texture Technologies Corp., Scarsdale, NY). Samples were tested at 75% compression with a test speed of 1mm/s. Two step compressions were performed with 2sec pause between the cycles. Hardness of the samples was expressed as the force applied during the first compression.

Texture of all the fried samples was also evaluated with a texture analyzer (Texture Technologies Corp., Scarsdale, NY) using a 36mm round acrylic probe. The pre-test speed was maintained at 1mm/s, test speed at 5mm/s and post-test speed at 10mm/s. Samples were compressed at 50% strain. Ten samples for each replicate (2 replicates for each treatment) were tested for both soaked and fried samples.

3.2.10 Descriptive sensory analysis

The effect of additions of soy protein isolate (8 and 12%), calcium carbonate (0.6 and 0.8%) and pregelatinized wheat starch (8 and 12%) on sensory attributes of fried samples were tested. A panel consisting of five highly-trained descriptive panelists from the Sensory Analysis Center at Kansas State University evaluated the samples. The panelists had completed 120 h of general training and had a minimum of 1200 h of general sensory testing including grain products. Two 90 min orientation sessions were conducted to familiarize the panelists with the evaluation process and the samples to be tested. During orientation, the descriptive panel developed a list of

39 attributes for flavor, aroma, aftertaste and textures. References for intensity for each attribute also were determined to calibrate the sensory intensity measurements. Three replicates were performed individually by each panelist. Samples were presented in 3.25 oz odorless cups, monadically and in a randomized order with 3-digit random code. The panelists were provided with apples and cucumbers to cleanse the palate after each sample. Each panelist assessed 3 samples per 90 min testing session, without any discussion. Panelists were instructed to taste 5 pieces of the sample for evaluation. The samples were served at room temperature. Attribute intensities were quantified using a 15 point scale with 0.5 increments ((0.0=none to 15=extreme). Panelists also evaluated two appearance attributes by consensus method. Similar procedures have been used previously by Vázquez-Araújo et al., (2011), Vazquez Adhikari et al. (2011) and Koppel and Chambers (2010).

3.2.11 Statistical analysis

The results were analyzed by one- way ANOVA (SAS version 9.2, The SAS Institute Inc., Cary, NC,USA) to determine significant differences between treatment means for each sample. For all significant attributes, the sample effects were assessed using pair-wise comparisons based on SAS least square (LS) means. The criteria for significance was $p<0.05$. The relationship between sensory and instrumental data was explained based on Pearson's correlation and Partial least squares regression analysis.

3.3 Results and Discussion

3.3.1 Extrusion processing conditions

Specific mechanical energy is influenced by the additions of different soy protein isolate, calcium carbonate and pregelatinized wheat starch to the base formulation (Table 3.2). The complex nature of the protein and its hindrance to flow in an extrusion matrix might have lowered the SME. The increased SME was observed with addition of calcium carbonate and pregelatinized wheat starch. The release of gas bubbles from $CaCO_3$ increased the viscosity of the melt thereby increasing the SME during processing. The increase in %starch with PGWS and the ease of processing starch matrix in the extrusion barrel increased the SME.

3.3.2 Starch gelatinization

The degree of starch gelatinization (Table 3.3) increased with addition of soy protein isolate, calcium carbonate and pregelatinized wheat starch, because of the increased SME. Increase in SPI from 4 to 12% lowered the degree of starch gelatinization, because of the decreased starch in the formulation. The degree of calcium carbonate addition has not influenced the degree of starch gelatinization. PGWS has higher degree of gelatinization because of increased level of pregelatinized starch in the formulation and due to the high SME (Table 3.2) during extrusion processing.

3.3.3 RVA Analysis

The peak and final viscosities and pasting temperatures varied among the samples (Table 3.4). The lower peak and final viscosities were observed with texture modifiers (soy protein isolate, calcium carbonate and pregelatinized wheat starch) compared to control. This indicates higher level of starch degradation with texture modifiers because of the higher SME during extrusion processing. The increased mechanical energy during extrusion processing caused more starch damage. There is no particular trend observed with raw formulations (Table 3.5).

3.3.4 Water holding capacity

The difference in formulations influenced water holding capacity (Figure 3.3). Water holding capacity decreased with addition of texture modifiers because of increased level of starch degradation in the samples. There was no significant difference in WHC among different levels of soy protein isolate additions. Calcium carbonate incorporation significantly lowered the water absorption; however no significant difference among 0.2, 0.4 and 0.6% levels of addition. Pregelatinized wheat starch decreased the water absorption. Among SPI, $CaCO_3$ and PGWS calcium carbonate has lower WHC, followed by SPI and PGWS. With PGWS the increased level of % starch might have increased the amount of water absorbed.

3.3.5 Oil uptake

Oil uptake during frying was influenced by the water absorbed during soaking, degree of starch gelatinization, and crust formation. With the addition of SPI and $CaCO_3$ oil uptake decreased (Figure 3.4) because of decreased WHC and increase in degree of starch gelatinization. With the increase in degree of starch gelatinization it forms a barrier, which during frying forms as an outer crust preventing water oil flow into the chips during cooling phase lowering the oil uptake. The addition of texture modifiers lowered the % fat because of decreased water uptake and increased starch gelatinization. Similarly, low oil absorption was observed in fried tortilla chips with the increase in starch gelatinization (Kawas and Moreira, 2001). Among Soy protein isolate, calcium carbonate and pregelatinized wheat starch, $CaCO_3$ has lower oil uptake followed by SPI and PGWS. With PGWS, the increased % starch addition has softened the matrix during frying increasing the surface roughness thereby increasing the oil absorption. Water holding capacity, surface roughness and crust formation during frying influence oil uptake rather than porosity of extrudates as evidenced from bulk density measurements (Table 3.2).

3.3.6 Crude fat

Crude fat results were similar to that of oil uptake data (Figure 3.5). Among SPI, $CaCO_3$ and PGWS, calcium carbonate lowered the oil uptake followed by SPI and PGWS.

3.3.7 Texture

The hardness of fried snacks at 0.4 and 0.6% calcium carbonate was significantly higher ($p < 0.05$) than the control (Figure 3.6). Calcium carbonate increased the hardness of the fried snacks because of the increased starch degradation and low oil uptake. Soy protein isolate also increased the hardness because of the increased protein and low oil uptake. Among soy protein isolate, calcium carbonate and pregelatinized wheat starch, PGWS has lower product hardness, followed by SPI and calcium carbonate. The lower hardness with PGWS might be because of the increased level of starch addition, increased oil uptake and oil and starch matrix interactions. The increased oil uptake and oil and starch matrix interactions might have weekend the matrix lowering the hardness.

3.3.8 Dynamics of water and oil uptake and their impact on texture (time bound study)

Samples with highest incorporations of soy protein isolate (12%), calcium carbonate (0.6%) and pregelatinized wheat starch (12%) were selected for time bound study to understand the relationship between water and oil uptake and their effects on texture. Water holding capacity increased with increase in soaking time for all the treatments, irrespective of the formulation differences (Figure 3.7). Additions of SPI, $CaCO_3$ and PGWS have lower WHC compared to control. Among those, $CaCO_3$ decreased the water absorption and PGWS absorbed more water because of the increase in % starch addition and level of starch degradation. The extruded soy pellets absorb water during soaking and with the increase in water absorption, extrudates becomes soft. The hardness of the soaked extrudates decreased significantly at the initial soaking period and then reduced gradually (Figure 3.8).

Oil uptake and crude fat were estimated at two different soaking times (30 and 60min) to study the effect of water absorption on oil uptake during frying (Figure 3.9 and 3.10). Increased oil absorption was absorbed in samples with 60min of soaking time. At longer soaking period, water holding capacity increased and the increased moisture resulted in increased oil uptake. During frying water evaporates and is replaced by oil (Gamble et al., 1987). Higher the initial moisture, more rapid is the loss of vapor and more is the oil absorbed. Over frying time oil uptake decreased and then it stabilizes. The higher oil uptake at the initial frying period is due to rapid moisture loss. With increase in frying time there was also crust formation which prevents oil to sweep in and adhered to the surface of the product. Surface oil was absorbed by the blotting paper and therefore a decrease in oil uptake was seen, which gets stabilized over increased frying time. Of all the formulations calcium carbonate absorbed lower amounts of oil whereas pregelatinized wheat starch absorbed more oil.

Hardness of the product is influenced by initial moisture content and the extent of frying time (Figure 3.11). With the increase in frying time the hardness of the products increased because of the loss of moisture and also the formation of outer crust. After certain period, once the crust is formed it stabilizes. At 30 min soaking, hardness increased till 40 sec and then stabilized, whereas with 60min soaking hardness increased till 60sec and latter stabilized over 2min frying. This is due to higher initial moisture at 60min soaking which is lost gradually over frying time.

3.3.9 Descriptive sensory analysis

Significant differences were found in texture, aroma, and flavor attributes across the samples (Table 3.6). Significant differences between samples are presented below.

3.3.9.1 Aroma

Samples with PGWS had significantly higher oxidized oil aroma than the other samples, while samples with calcium carbonate and SPI had lower oxidized aroma compared to control. The higher oil aroma with PGWS was attributed to the higher % of fat in the product. Lowest oxidized aroma was found with higher levels of $CaCO_3$ and might be because of less oil absorbed during frying.

3.3.9.2 Flavor

Overall grain flavor was used as a measure of all grain attributes found within the sample, including but not limited to wheat, corn, soy and beany. Samples with $CaCO_3$ has higher overall grain flavor followed by SPI and PGWS. Calcium carbonate at 0.4% has a higher beany flavor and SPI at 8% has lower. $CaCO_3$ at 0.6% has lowest oxidized oil flavor might be due to lower % fat in the samples. The high oil-heated and oxidized oil favor with PGWS was due to high % fat absorbed by the product during frying.

3.3.7.3 Aftertaste

Within aftertaste attributes, samples with PGWS were significantly higher in both oil-heated and oxidized oil aftertaste because of the increased oil uptake during frying. Both $CaCO_3$ and SPI were lower in oil heated and oxidized oil aftertaste compared to PGWS and control. No significant differences were found among $CaCO_3$ and SPI.

3.3.9.4 Texture

Pregelatinized wheat starch samples were different from other samples regarding texture attributes. PGWS at 8% and at 12% were significantly different from each other as well as different from the rest of the samples for surface roughness. PGWS samples had higher surface roughness, due to the clumping of extruded pellets during soaking and frying, which increased with the increase in % PGWS. Calcium carbonate at 0.4% has lower surface roughness. Samples with 12% PGWS has significantly lower Initial hardness and Initial crispness than other samples might be because of the increased level of starch gelatinization. Higher initial crispness was found in $CaCO_3$ samples. Samples with PGWS has lower denseness, sustained hardness and sustained crispness compare to control, SPI and Calcium carbonate. Calcium carbonate has higher denseness and sustained hardness. Similarly, lower hardness for samples with PGWS and highest hardness for samples with $CaCO_3$ were observed when instrumentally tested using texture analyzer.

3.3.9.5 Appearance

Samples with 12% SPI were highest in overall color, while PGWS samples at 12% were lowest in overall color. PGWS samples were highest in surface roughness while samples with calcium carbonate were lowest in surface roughness.

3.3.10 Correlation between descriptive sensory results and instrumental data

To evaluate the effect of instrumental measurements on sensory parameters, the Pearson's statistic correlation was performed between instrumental and sensory data. Results emphasized a positive correlation between oil uptake, and sensory attributes like oil heated flavor, oil heated aftertaste, oxidized oil aroma, oxidized oil flavor, oxidized oil after taste, and surface roughness (Table 3.7). Similarly positive correlation was observed between hardness and sensory attributes like initial hardness, initial crispness, denseness, sustained hardness and sustained crispness. Partial least square regression analysis (PLS) was performed to study the relationship between sensory and instrumental data among soy protein isolate, calcium carbonate and pregelatinized wheat starch (Figure 3.12). The sensory hardness attributes of all the samples had strong correlation to instrumental hardness and that of oiliness attributes to oil uptake data. The hardness of the samples is explained by calcium carbonate and oil uptake by pregelatinized wheat starch. When compared among soy protein isolate, calcium carbonate and pregelatinized wheat starch, samples the initial hardness, initial crispness, sustained harness and sustained crispness, denseness, beany aftertaste and overall grain flavor has strong correlation with calcium carbonate samples and the oiliness attributes like oil uptake, heated oil aftertaste, heated oil flavor, oxidized oil aftertaste, oxidized oil flavor, oxidized oil aroma were strongly correlated to pregalatinized wheat starch samples. PGWS samples have strong correlation to surface roughness because of the increased WHC causing rapid moisture loss and oil uptake during frying. In total, the PLS plot explained 72% of instrumental data and 79% of the descriptive sensory data.

3.4 Conclusion

Soy protein isolate, calcium carbonate and pregelatinized wheat starch influenced the texture and % fat absorbed during frying. The PGWS lowered the hardness of the fried products followed by SPI and $CaCO_3$. Hardness is impacted by matrix composition, oil uptake and oil and starch matrix interactions. Calcium carbonate lowered the fat absorption and increased the hardness of the fried samples. Water holding capacity is affected by the % level of starch addition, and degree of starch degradation. The water holding capacity, degree of starch gelatinization and crust formation influenced the oil absorbed during frying. Descriptive sensory results showed a strong correlation with that of experimental results. Dynamics of water and oil uptake clearly explained the phenomenon of water and oil uptake, crust formation during frying and its impact on oil uptake and texture.

3.5 References

Adhikari, K., Chambers, E. I., Miller, R., Vazquez-Araujo, L., Bhumiratana, N., & and Philip, C. (2011). Development of a lexicon for beef flavor in intact muscle.*Journal of Sensory Studies, 26*, 413-420.

AACC. (1999). American Association of Cereal Chemists. *International Methods of Analysis.* 11th Ed. Method 56-35.01. AACC International, 653 St. Paul, MN, USA.

Altunakar, B., Sahin, S., & Sumnu, G. (2004). Functionality of batters containing different starch types for deep-fat frying of chicken nuggets. *European Food Research and Technology, 218*, 318-322.

AOAC. (2010). Association of Analytical Chemists. Method 920.39: Crude fat in feeds - Cereal Grains and Forages. In: *Anonymous Official Methods of Analysis of AOAC International*. 18th ed. Gaithersburg, MD: AOAC International.

Business Insights (2012). Innovation in savory snack formats. <http://www.reportlinker.com/p0819272-summary/Innovation-in-Savory-Snack-Formats.html>.

Center for Disease Control and Prevention. (2011). Obesity-Halting the epidemic by making health easier at a glance. <http://www.cdc.gov/chronicdisease/resources/publications/AAG/obesity.htm>.

Gamble, M. H., Rice, P., & and Selman, J. D. (1987). Relationship between oil uptake and moisture loss during frying of potato slices from c.v. record U.K.*International Journal of Food Science and Technology, 22*, 233-241.

Golddield, G. S., Lumb, A. B., & Colapinto, C. K. (2011). Relative reinforcing value of energy-dense snack foods in overweight and obese adults. *Canadian Journal of Dietetic Practice and Research, 72*(4), 170-174.

IFT (2011). Snacking constiturtes 25 percent of calories consumed in U.S. <http://www.ift.org/newsroom/news-releases/2011/june/20/snacking-constitutes-25-percent-of-calories-consumed-in-us.aspx>.

Kawas, M. L, and Moreira, R. G. (2001). Effect of degree of starch gelatinization on quality attributes of fried tortilla chips. *Journal of Food Science, 66*(2), 300-306.

Koppel, K., & and Chambers, E. I. (2010). Development and application of a lexicon to describe the flavor of pomegranate juice. *Journal of Sensory Studies, 25*(6), 819-837.

Lim, S. M., Kim, J., Shim, J. Y., Imm, B. Y., Sung, M. H., & Imm, J. Y. (2012). Effect of poly-gamma-glutamic acids (PGA) on oil uptake and sensory quality in doughnuts. *Food Science and Biotechnology, 21*(1), 247-252.

Majzoobi, M., Radi, M., Farahnaky, A., Jamalian, J., Tongdang, T., & Mesbahi, G. (2011). Physicochemical properties of pre-gelatinized wheat starch produced by a twin drum drier. *Journal of Agricultural Science Technology, 13*, 193-202.

Mohan, K. B. L., & Babu, R. (2007). Effect of frying conditions on quality of fried onion slices. *Journal of Food Science and Technology, 44*(5), 483-486.

Mounsey, J. S., & O'Riordan, E. D. (2008). Modification of imitation cheese structure and rheology using pre-gelatinised starches. *European Food Research and Technology, 226*, 1039-1046.

Moyano, P. C., & and Pedreschi, F. (2006). Kinetics of oil uptake during frying of potato slices: Effect of pre-treatments. *LWT - Food Science and Technology, 39*, 285-291.

Nasiri, F. D., Mohebbi, M., Yazdi, F. T., & Khodaparast, M. H. H. (2012). Effects of soy and corn flour addition on batter rheology and quality of deep fat-fried shrimp nuggets. *Food Bioprocess Technology, 5*, 1238-1245.

Ravi, R., Singh, V. K., & Prakash, M. (2011). Projective mapping and product posistioning of deep fat fried snacks. *Food and Nutrition Sciences, 2*, 674-683.

Siegwein, A. M., Vodovotz, Y., & Fisher, E. L. (2011). Concentration of soy protein isolate affects starch based confections' texture, sensory and storage properties. *Journal of Food Science, 76*(6), 422-428.

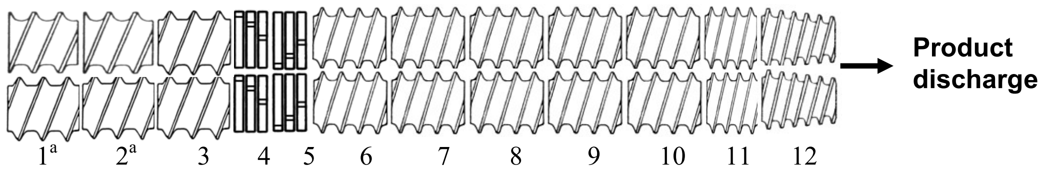
Song, X. J., Zhang, M., & and Mujumdar, A. S. (2007). Effect of vacuum-microwave predrying on quality of vacuum-fried potato chips. *Drying Technology, 25*, 2021-2026.

Vázquez-Araújo, L., Chambers, E. I., & and Funk, D. B. (2011). References for "musty" odor notes in sensory analysis of grain sorghum. *Journal of Cereal Science, 54*(3), 460-466.

Zizza, C. R. D., Siega-Riz, A. M. R. D., & Popkin, B. M. (2001). Significant increase in young adults' snacking between 1977–1978 and 1994–1996 represents a cause for concern! *Preventive Medicine, 32*, 303-310.

Figures and Tables

Head Number	1	2	3	4	5	6
Barrel Temperature (°C)	30	30	60	60	90	85



Element No.

1=SE[b]-1-F-78; 2=SE-1-F-78; 3=SE-2-1-78; 4=KB[c]-3-8.7-30F; 5=KB-3-8.7-30R; 6=SE-2-3/4-78; 7=SE-2-3/4-78; 8=SE-2-3/4-78; 9=SE-2-3/4-78; 10=SE-2-3/4-78; 11= SE-2-1/2-78; and 12=SE (conical)-2-3/4-78.[d]

[a]Left shaft elements are double flighted.
[b]SE = screw element
Numbers:
1st – number of flights
2nd – relative pitch
3rd – element length, mm
[d]All screw elements are forward and intermeshing.

[c]KB = kneading blocks
Letters: F- Forward, R- Reverse
Numbers:
1st – number of elements
2nd – length of element, mm
3rd – angle of elements, degrees

Figure 3-1: Extruder screw configuration and temperature profile.

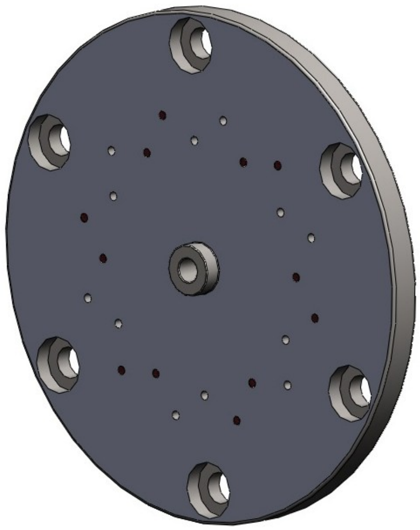


Figure 3-2: Die configuration.

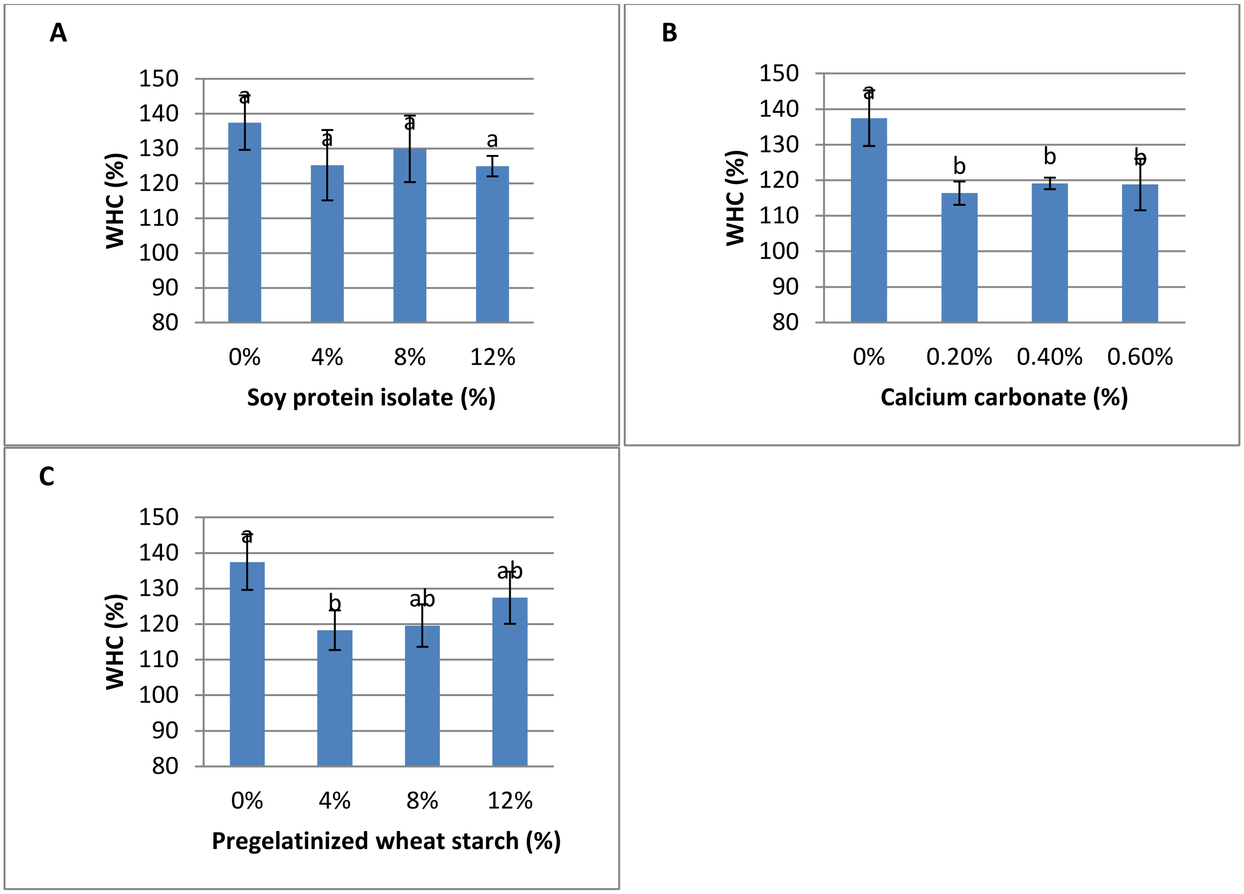


Figure 3-3: Water holding capacity at different levels of (A) Soy protein isolate (B) Calcium carbonate (C) Preglatinized wheat starch. Means with different letters indicate significant difference ($p \leq 0.05$).

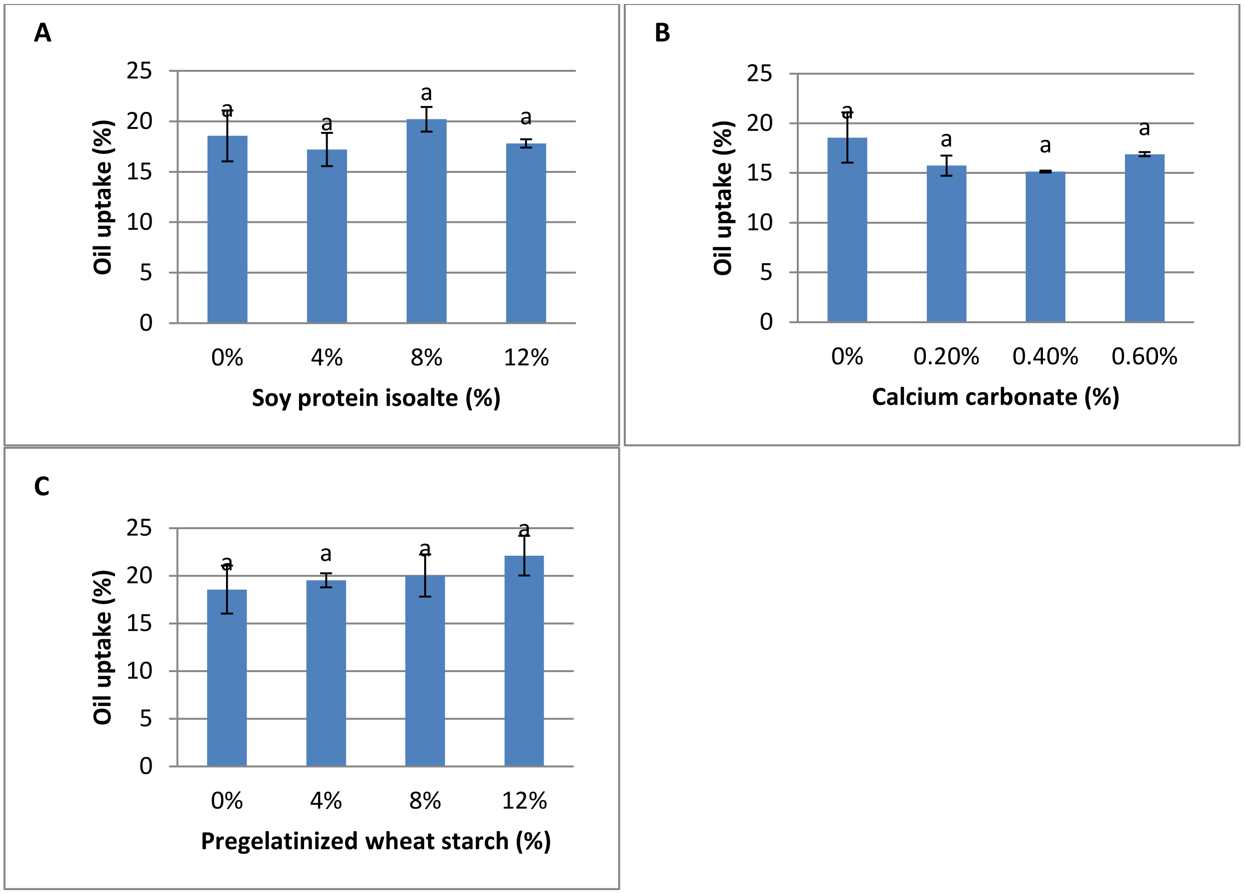


Figure 3-4: Oil uptake at different levels of (A) Soy protein isolate (B) Calcium carbonate (C) Preglatinized wheat starch. Means with different letters indicate a significant difference ($p \leq 0.05$).

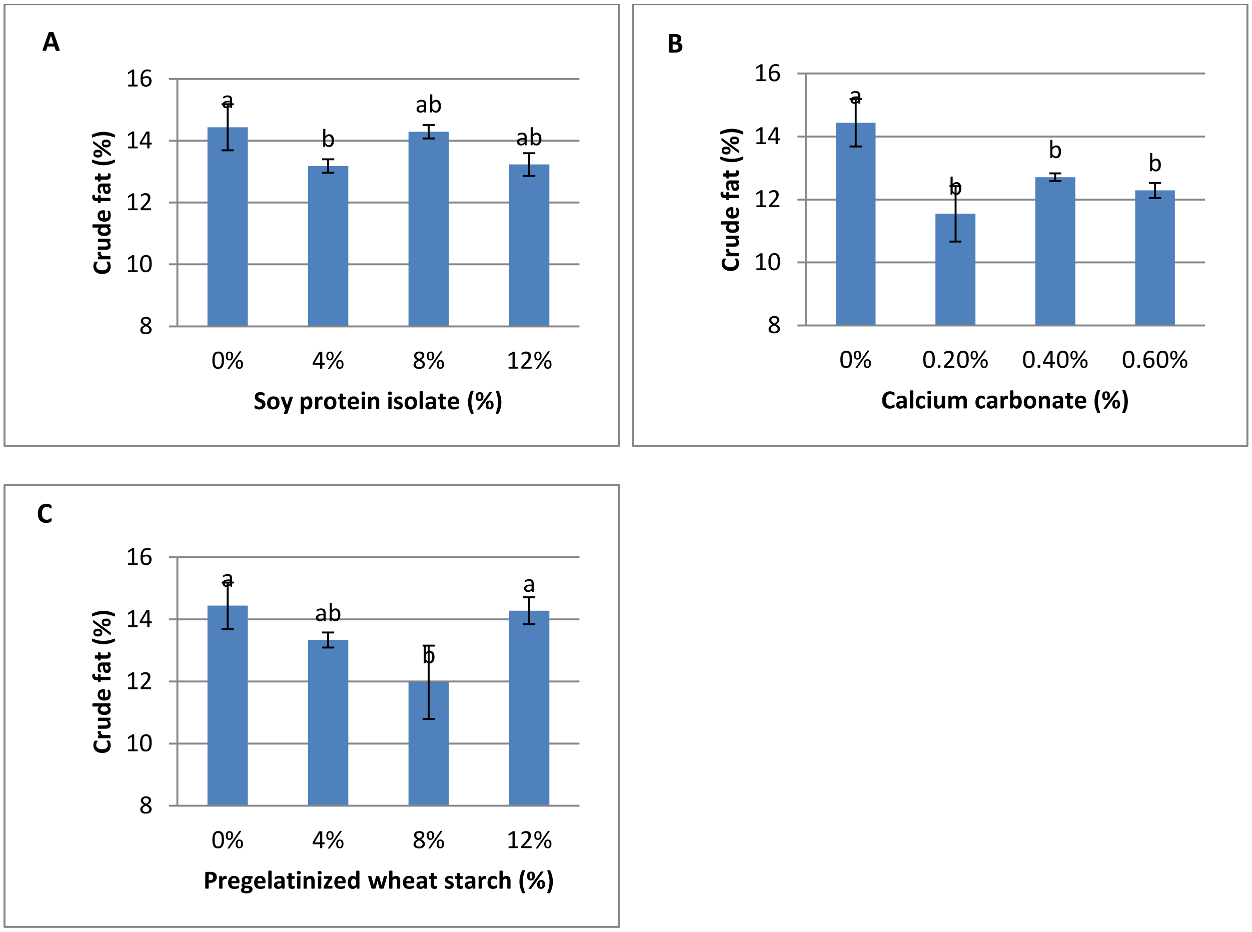


Figure 3-5: Crude fat at different levels of (A) Soy protein isolate (B) Calcium carbonate (C) Preglatinized wheat starch. Means with different letters indicate significant difference ($p \leq 0.05$).

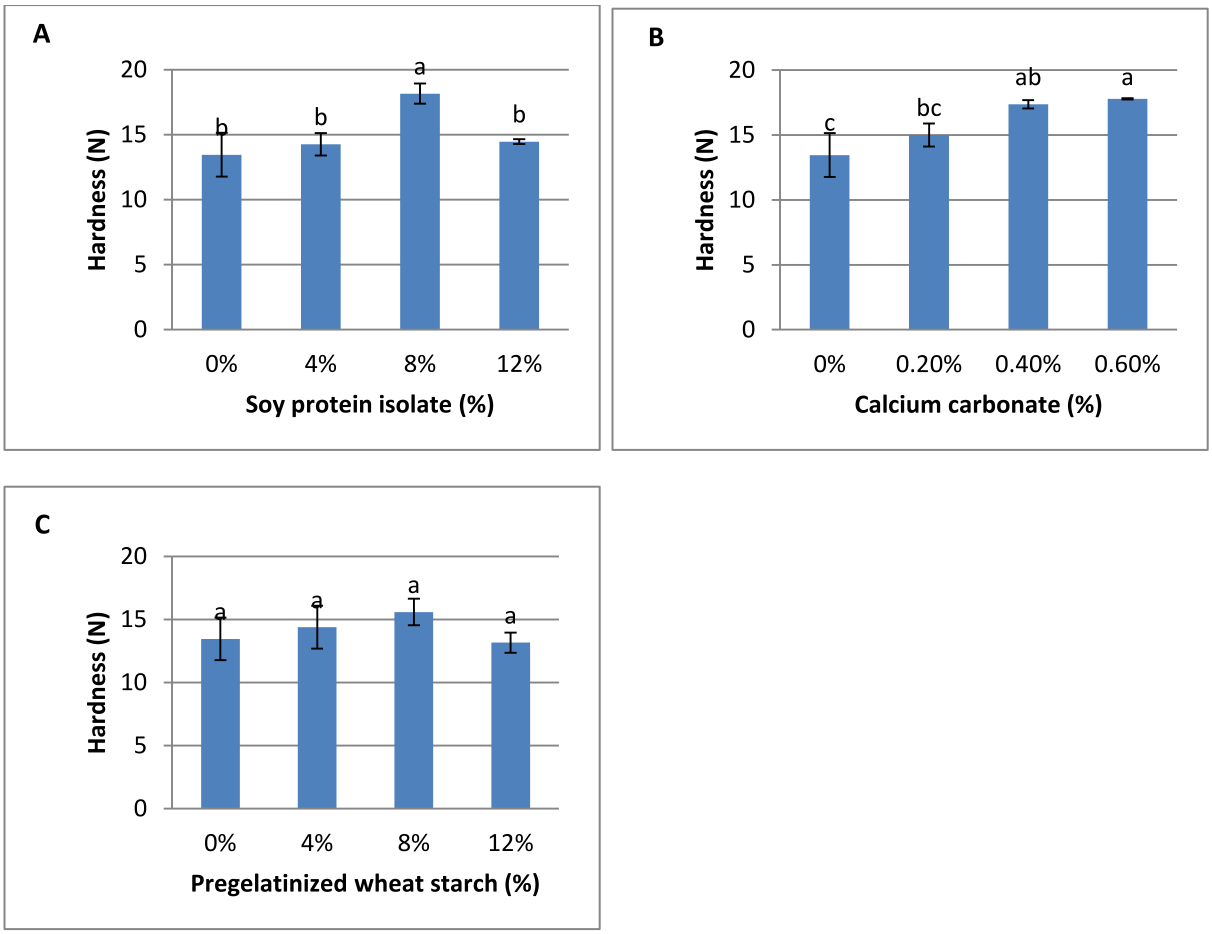


Figure 3-6: Texture of soy-wheat savory snacks at different levels of (A) Soy protein isolate (B) Calcium carbonate (C) Preglatinized wheat starch. Means with different letters indicate significant difference ($p \leq 0.05$).

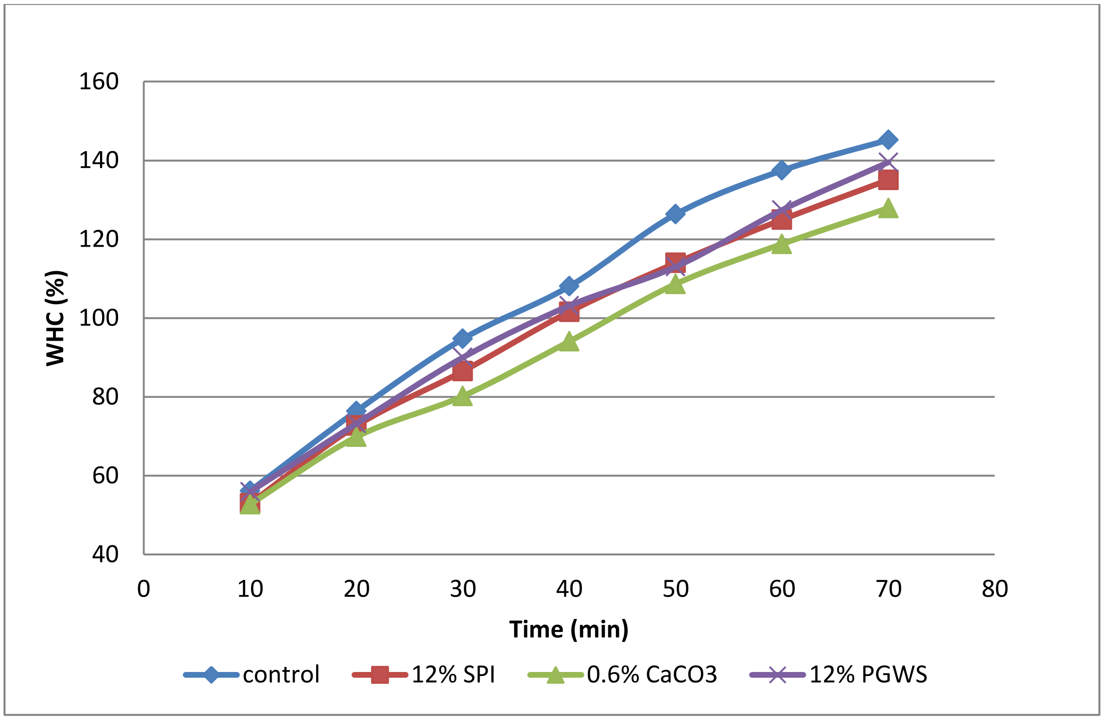


Figure 3-7: Effect of formulation types on water holding capacity of soy-wheat extrudates during soaking

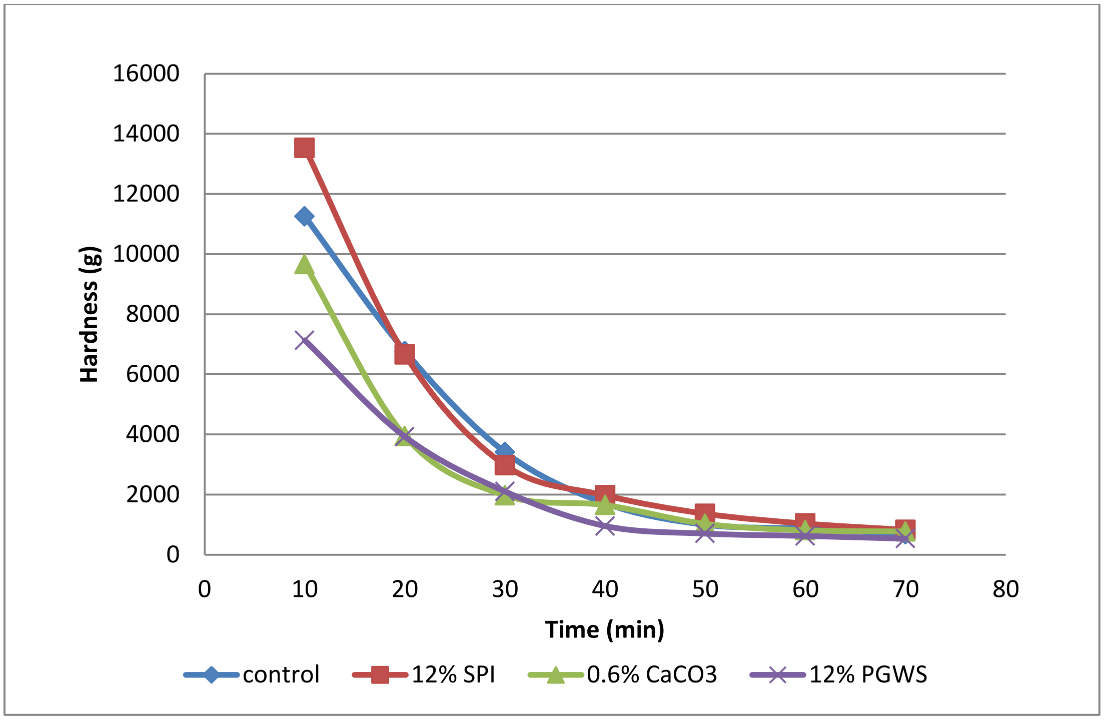


Figure 3-8: Effect of formulation types on texture of soy-wheat extrudates during soaking

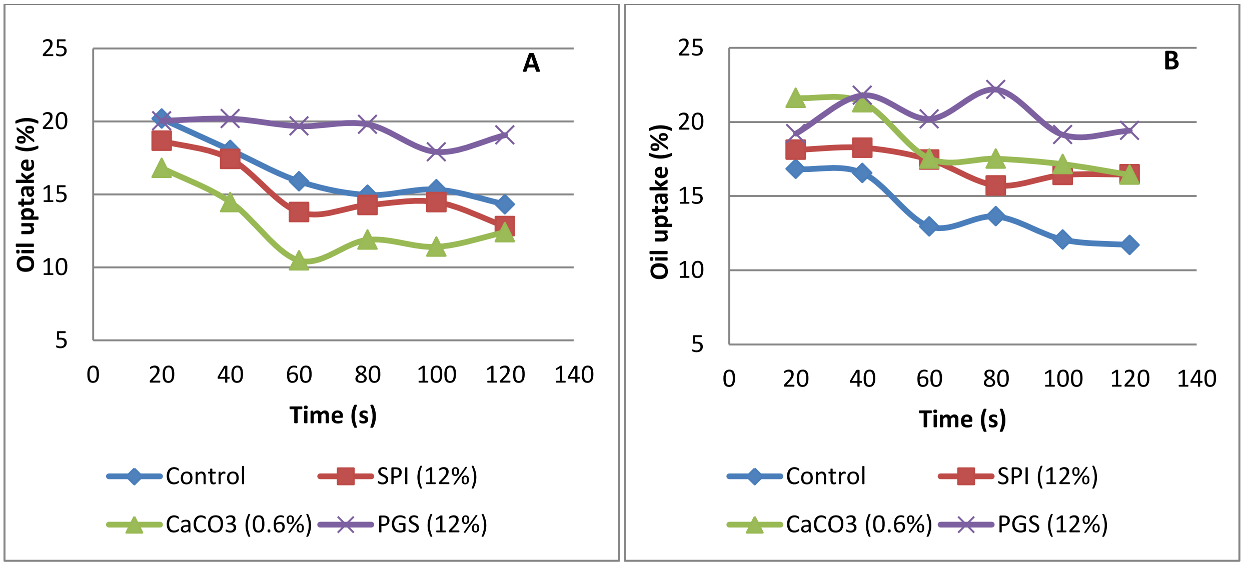


Figure 3-9: Effect of different soaking times and formulation types on oil uptake during frying of soy-wheat based snacks. (A) soaking time of 30min (B) soaking time of 60min

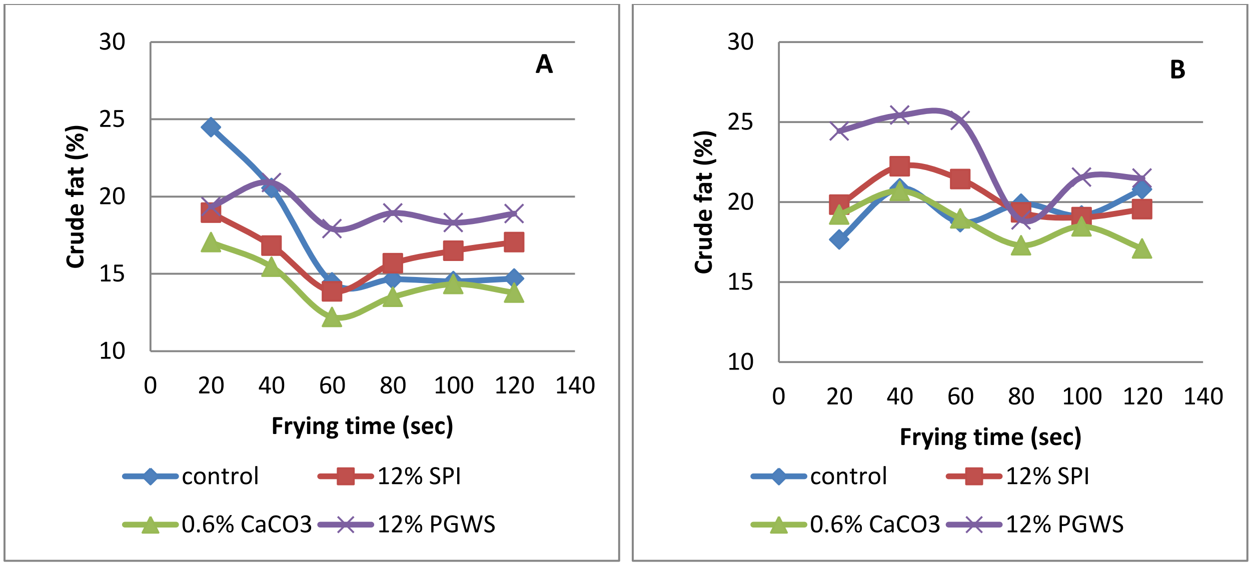


Figure 3-10: Effect of different soaking times and formulation types on crude fat during frying of soy-wheat based snacks. (A) soaking time of 30min (B) soaking time of 60min

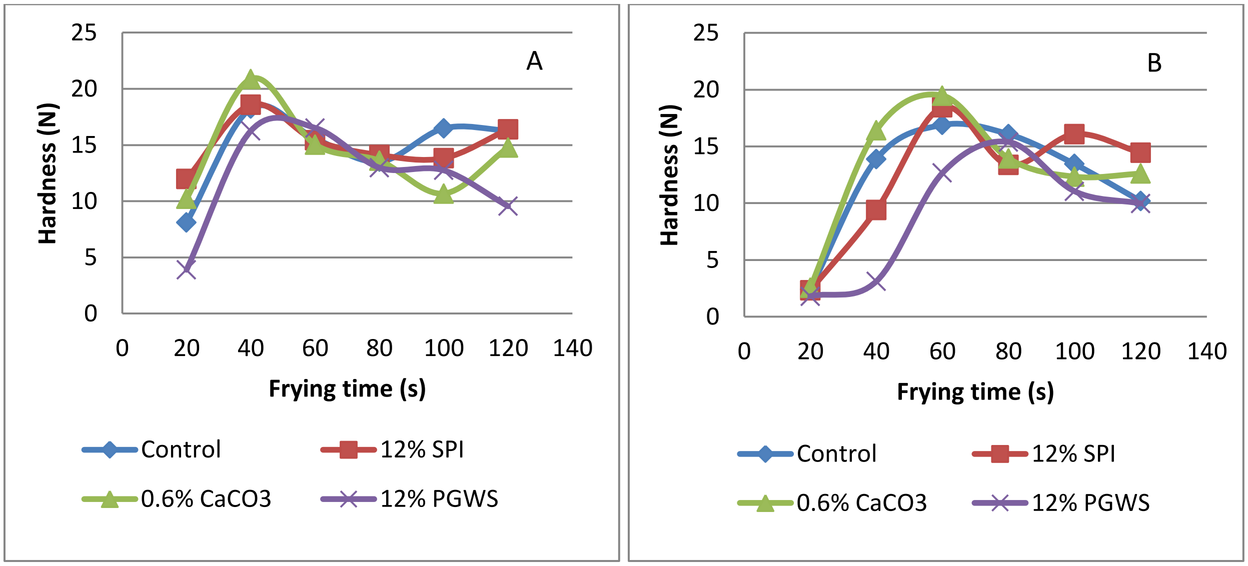


Figure 3-11: Effect of different soaking times and formulation types on texture during frying of soy-wheat based snacks. (A) soaking time of 30min (B) soaking time of 60min

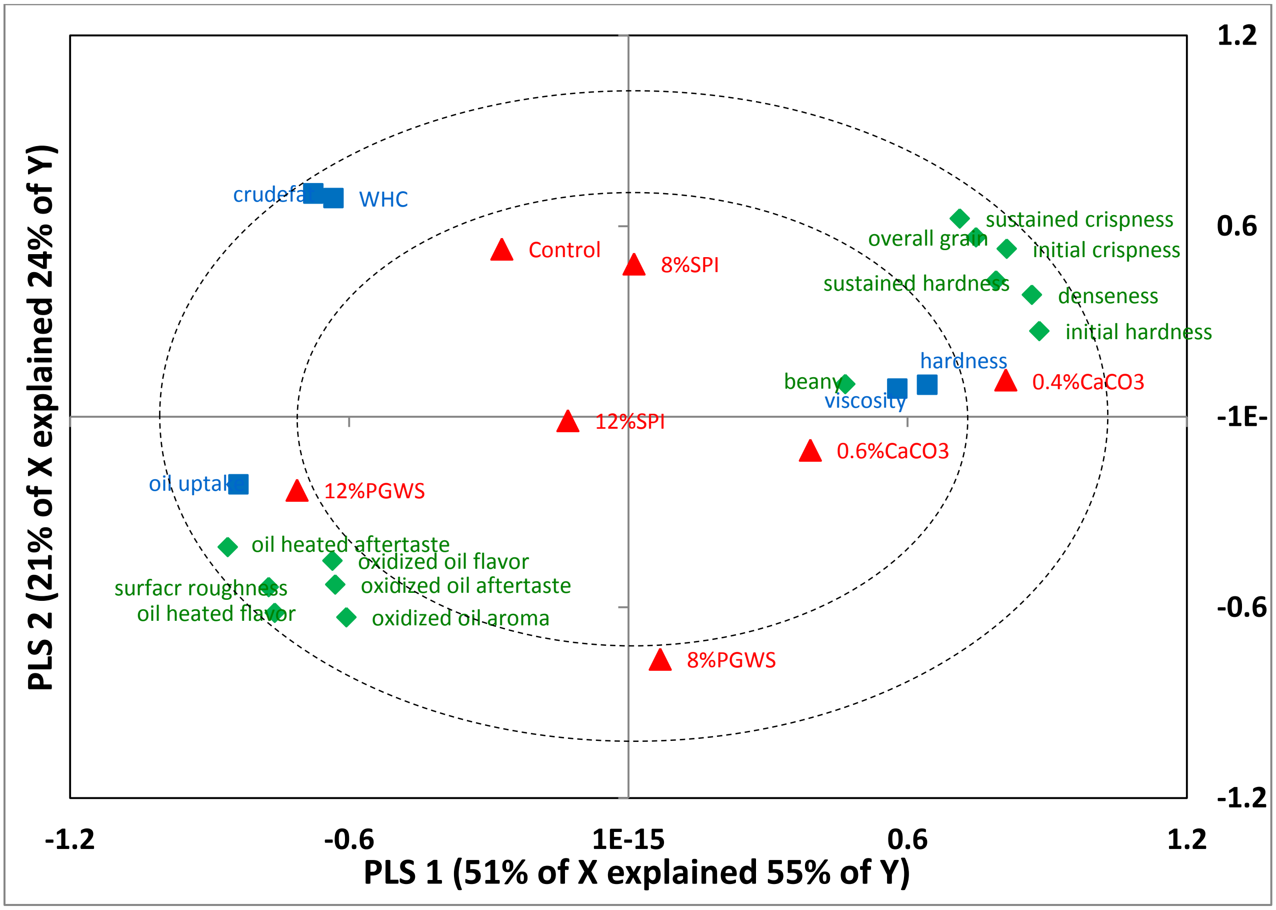


Figure 3-12: PLS2 correlation between sensory and instrumental data among all the samples

Table 3-1: Experimental design – formulation and labeling of all the treatments

Material	Control	4%SPI	8%SPI	12%SPI	.2%$CaCO_3$	.4%$CaCO_3$	.6%$CaCO_3$	4%PGWS	8%PGWS	12%PGWS
Wheat flour	50	50	50	50	50	50	50	50	50	50
Soy flour	50	50	50	50	50	50	50	50	50	50
Salt	1	1	1	1	1	1	1	1	1	1
Monoglycerides	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Soy Protein isolate	-	4	8	12	-	-	-	-	-	-
Calcium Carbonate	-	-	-	-	0.2	0.4	0.6	-	-	-
Pregelatinized wheat starch	-	-	-	-	-	-	-	4	8	12

Table 3-2: Specific mechanical energy, In-barrel moisture and bulk density of extrudes of different formulations

Treatments	SME (kJ/kg)	In-barrel moisture (%)	Bulk density (g/l)
Control	50.48	37.98	698
4% SPI	47.96	38.62	685
8% SPI	48.85	38.3	678
12% SPI	46.27	39.34	682
0.2% $CaCO_3$	64.94	39.8	694
0.4% $CaCO_3$	56.42	38.57	688
0.6% $CaCO_3$	53.29	38.46	699
4% PGWS	67.31	38.62	765
8% PGWS	67.31	37.88	792
12% PGWS	71.05	37.98	771

Table 3-3: Gelatinization temperature, enthalpy and degree of gelatinization of all the treatments

Treatments	Gelatinization temp (^oC)	Enthalpy (kJ/kg)	Gelatinization temp (^oC)	Enthalpy (kJ/kg)	Mean Enthalpy	DG %
Control	59.08	0.7811	59.53	0.747	0.7641	73.74^{e}
4% SPI	60.57	0.3937	60.76	0.4386	0.4162	87.83^{ab}
8% SPI	59.76	0.494	51.4	0.4129	0.4535	83.39^{bcd}
12% SPI	60.57	0.4426	59.16	0.4819	0.4623	79.2^{cde}
0.2% CaCO3	59.65	0.5616	62.25	0.5774	0.5695	78.88^{cde}
0.4% CaCO3	59.78	0.4776	61.13	0.4154	0.4465	82.17^{cd}
0.6% CaCO3	60.26	0.4002	59.4	0.4928	0.4465	83.75^{abc}
4% PGWS	56.72	0.5421	59.59	0.5734	0.5578	84.26^{abc}
8% PGWS	59.71	0.5718	60.92	0.584	0.5779	78.05^{de}
12% PGWS	62.22	0.2461	62.55	0.281	0.2636	89.05^{a}

Table 3-4: RVA Analysis of extruded samples

Treatments	Peak viscosity (cP)	Trough (cP)	Break down (cP)	Final Viscosity (cP)	Set back (cP)	Peak Time (min)	Pasting Temp (^oC)
Control	223.5	86	137.5	279	193	5.05	87.1
4% SPI	234	101.5	132.5	227	125.5	5.015	51.85
8% SPI	216	84.5	131.5	193	108.5	4.92	56.9
12% SPI	184	81	103	168	87	4.85	64.925
0.2% $CaCO_3$	195.5	44	151.5	156	112	4.985	70.4
0.4% $CaCO_3$	236	63.5	172.5	193	129.5	5.015	67.45
0.6% $CaCO_3$	198.5	50	148.5	159	109	4.98	59.45
4% PGWS	195.5	46	149.5	128.5	82.5	4.88	53.75
8% PGWS	230.5	71.5	159	163.5	92	4.82	88.75
12% PGWS	181	53.5	127.5	161	107.5	4.815	-

Table 3-5: RVA Analysis of raw fromulations

Treatments	Peak viscosity (cP)	Trough (cP)	Breakdown (cP)	Final Viscosity (cP)	Setback (cP)	Peak Time (min)	Pasting Temp (^oC)
Control	296.5	258.5	38	478.5	220	4.815	77.9
4% SPI	269	257	12	459	202	5.715	89.975
8% SPI	368.5	354	14.5	640.5	286.5	6.815	88.425
12% SPI	337	321	16	581	260	6.915	79.125
0.2% CaO_3	269.5	246	23.5	456.5	210.5	4.82	88.8
0.4% $CaCO_3$	369	350.5	18.5	651	300.5	6.685	89.6
0.6% CaO_3	304.5	279	25.5	544	265	5.75	89.95
4% PGWS	380	362	18	698	336	6.72	88.85
8% PGWS	294	280	14	538	258	5.78	87.15
12% PGWS	258	241	17	435	194	4.75	-

Table 3-6: Descriptive sensory attributes with significant differences.

Attribute	p-value	Control	8%SPI	12%SPI	.4%$CaCO_3$	.6%$CaCO_3$	8%PGWS	12%PGWS
Aroma								
Oxidized Oil	<0.0001*	0.70^{bc}	0.37^{dc}	0.56^{dc}	$0.43d^{c}$	0.33^{d}	1.07^{a}	0.97^{ab}
Flavor								
Overall Grain	0.027*	6.20^{ab}	6.27^{ab}	6.07^{b}	6.63^{a}	6.20^{ab}	5.90^{b}	5.87^{b}
Beany	0.043*	2.67^{ab}	2.30^{c}	2.63^{abc}	2.87^{a}	2.73^{ab}	2.43^{bc}	2.53^{abc}
Oil- Heated	0.049*	3.40^{b}	3.30^{b}	3.57^{ab}	3.20^{b}	3.27^{b}	3.87^{ab}	4.20^{a}
Oxidized Oil	0.001*	1.10^{abc}	0.57^{cd}	0.77^{bcd}	0.90^{bcd}	0.50^{d}	1.30^{ab}	1.60^{a}
Aftertaste								
Oil- Heated	0.025*	2.07^{abc}	1.90^{bc}	1.87^{bc}	1.47^{c}	1.83^{bc}	2.27^{ab}	2.60^{a}
Oxidized Oil	0.0004*	0.77^{ab}	0.20^{c}	0.43^{bc}	0.37^{c}	0.40^{bc}	0.90^{a}	0.97^{a}
Texture								
Surface Roughness	<0.0001*	4.73^{c}	4.33^{dc}	4.57^{dc}	4.10^{d}	4.27^{dc}	5.60^{b}	6.70^{a}
Initial Hardness	0.012*	12.4^{a}	12.3^{a}	12.2^{a}	12.7^{a}	12.8^{a}	12.2^{a}	11.3^{b}

Initial Crispness	0.019*	12.8[abc]	13.0[ab]	12.5[bc]	13.2[a]	13.0[ab]	12.5[bc]	12.3[c]
Denseness	<0.0001*	11.9[ab]	12.1[ab]	11.9[ab]	12.5[a]	12.5[a]	11.5[b]	10.3[c]
Sustained Hardness	<0.0001*	11.5[ab]	11.7[ab]	11.7[ab]	11.9[a]	12.2[a]	11.0[bc]	10.3[c]
Sustained Crispness	<0.0001*	11.3[a]	11.7[a]	11.4[a]	11.9[a]	11.9[a]	10.4[b]	10.3[b]

Table 3-7: Pearson Correlation between sensory and instrumental data

Pearson Correlation Coefficients, N = 7 Prob > |r| under H0: Rho=0							
	SME	**WHC**	**Oil uptake**	**Crude fat**	**Hardness**	**Viscosity**	**DSC**
Oxidized oil aroma	0.77825 0.0393	0.08629 0.8540	0.64968 0.1142	-0.00407 0.9931	-0.70343 0.0778	-0.03536 0.9400	-0.07326 0.8760
Overall grain	-0.50385 0.2489	-0.11757 0.8018	-0.79249 0.0336	-0.05840 0.9010	0.59848 0.1557	0.53659 0.2143	-0.10352 0.8252
Beany	-0.16016 0.7316	-0.28024 0.5427	-0.80808 0.0279	-0.29738 0.5172	-0.00433 0.9926	0.09543 0.8387	-0.11676 0.8031
Oil heated flavor	0.78739 0.0356	0.03514 0.9404	0.78349 0.0371	0.12102 0.7961	-0.68596 0.0888	-0.45319 0.3071	0.33189 0.4671
Oxidized oil flavor	0.82185 0.0233	0.16562 0.7227	0.58377 0.1688	0.18532 0.6908	-0.75586 0.0493	-0.06355 0.8923	0.10300 0.8261
Oil heated aftertaste	0.68171 0.0917	0.30346 0.5082	0.90826 0.0047	0.31405 0.4928	-0.67478 0.0963	-0.41671 0.3524	0.23059 0.6189
Oxidized oil aftertaste	0.76838 0.0436	0.16635 0.7215	0.56664 0.1847	0.05946 0.8992	-0.78373 0.0370	-0.09946 0.8320	-0.06357 0.8923
Surface roughness	0.84104 0.0177	0.10937 0.8154	0.80663 0.0284	0.20603 0.6576	-0.67692 0.0949	-0.38989 0.3872	0.37341 0.4093
Initial hardness	-0.60847 0.1471	-0.29640 0.5186	-0.85018 0.0154	-0.48142 0.2740	0.67964 0.0930	0.54504 0.2058	-0.44577 0.3161
Initial crispness	-0.51765 0.2341	-0.15109 0.7464	-0.72086 0.0676	-0.14708 0.7530	0.78485 0.0366	0.57620 0.1758	-0.10339 0.8254
Denseness	-0.72809 0.0636	-0.24747 0.5926	-0.84536 0.0166	-0.37974 0.4008	0.72456 0.0655	0.47674 0.2794	-0.39107 0.3857
Sustained hardness	-0.79849 0.0313	-0.22154 0.6331	-0.82763 0.0215	-0.32028 0.4837	0.68993 0.0863	0.27055 0.5573	-0.30143 0.5112
Sustained crispness	-0.79831 0.0314	-0.09828 0.8340	-0.78270 0.0375	-0.08240 0.8606	0.68642 0.0886	0.21302 0.6465	-0.11195 0.8111

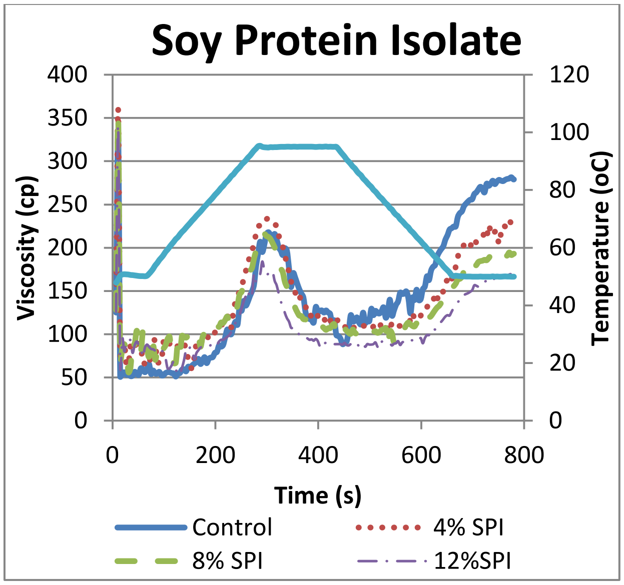
Chapter 4 - Conclusion

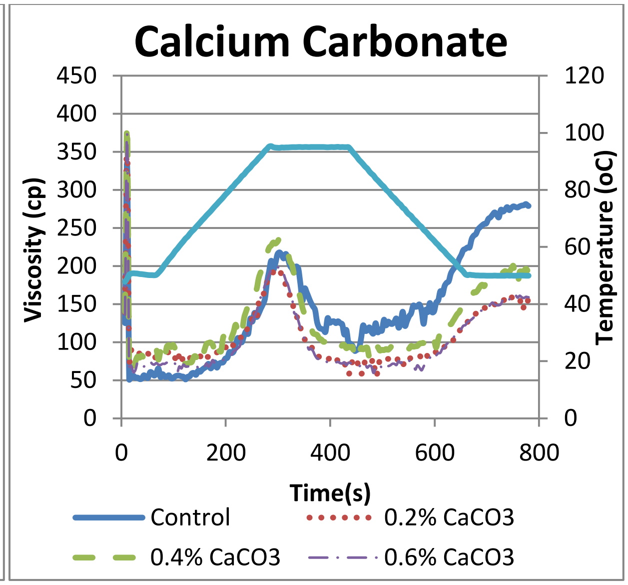
Soy is high in protein content and those proteins affect the water holding capacity. Heat treatment of proteins modifies their structure such that it increases the surface hydrophobicity, and thereby lowering the water absorption during soaking of extruded soy-wheat pellets. Water holding capacity is also affected by the % of starch incorporation and level of starch degradation. Oil uptake correlates with water holding capacity. Water during frying is lost as vapor leaving void spaces, and oil fills in those voids. Higher the water holding capacity higher is the oil uptake. Degree of starch gelatinization and the crust formation during frying also influenced oil uptake. Monoglycerides addition lowers specific mechanical energy during extrusion processing, lowering the degree of cook thereby decreasing water absorption and oil uptake.

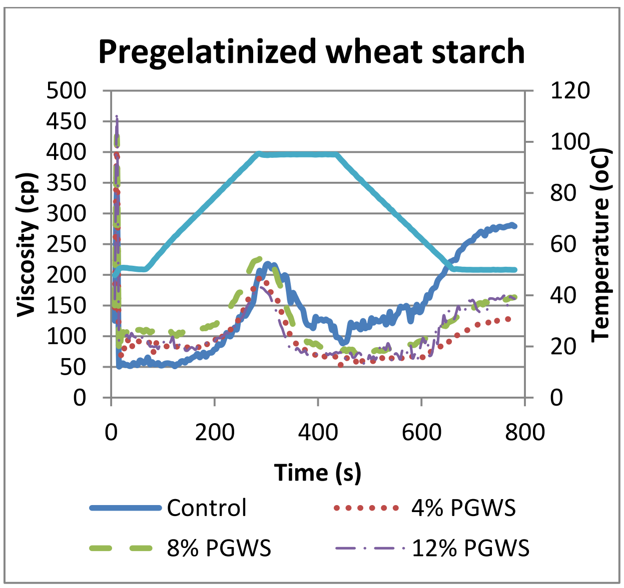
Texture of the product had a direct impact on overall acceptability. Texture of the products is impacted by the percentage of soy, amount of oil absorbed and oil and starch matrix interactions. Sodium bicarbonate increases the porosity of the product hence, lowering the hardness and increasing the oil uptake. Statistical analysis highlighted a strong correlation between sensory results and experimental data.

Appendix

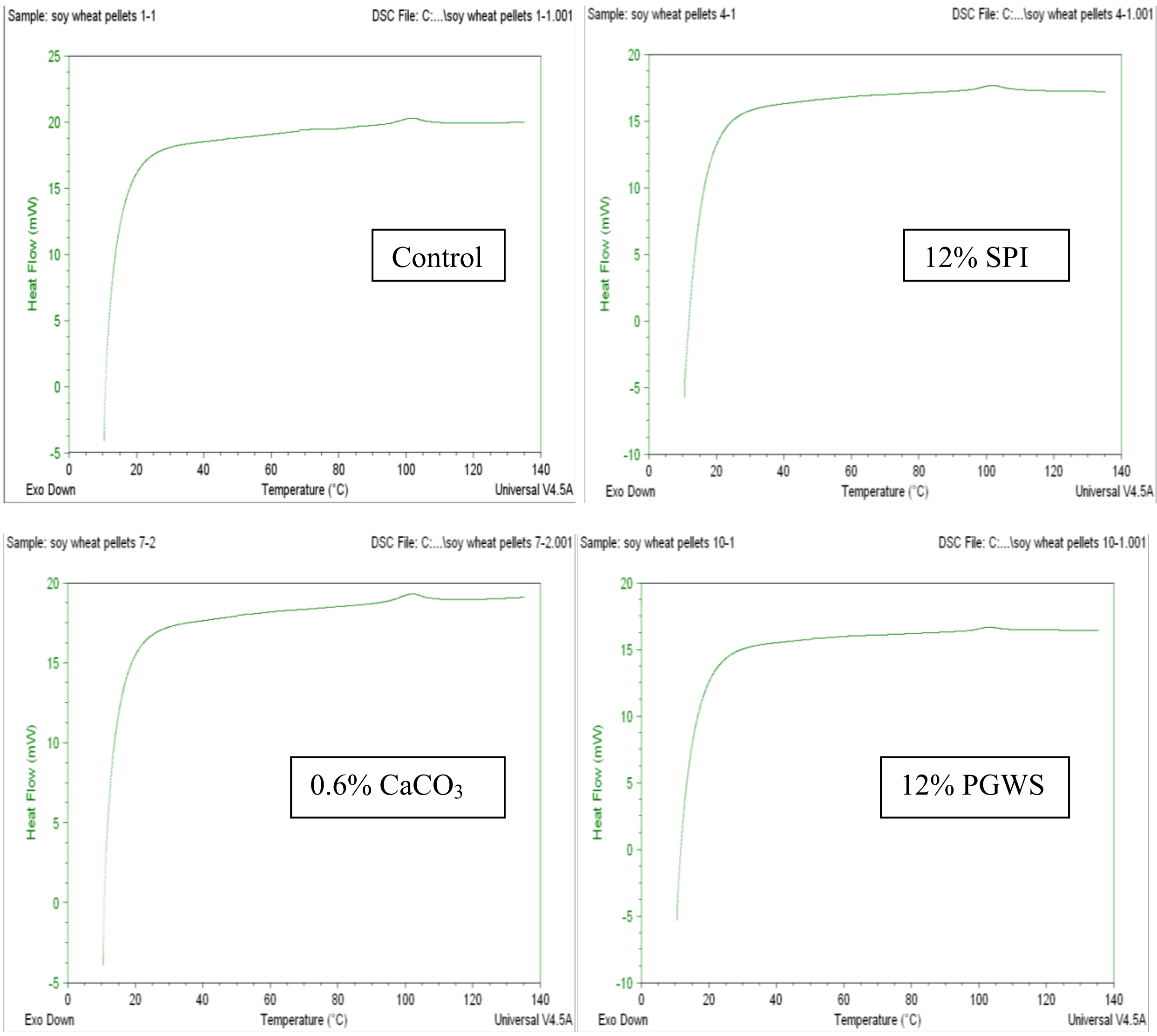
I. RVA pasting curves in reference to data presented in chapter 3







II. Selected DSC thermogram for each sample at higher level of inclusion in reference to data presented in Chapter 3



III. Descriptive sensory study reference sheet in reference to data presented in Chapter3

Definition and Reference Sheet		
Palate Cleansers: Apples and Cucumbers ***Serve references at room temperature.***		
Tasting Instructions: Take 5 pieces of the snack per bite		
Appearance		
Attribute	***Definition***	***Reference***
Overall Color	Light to dark evaluation of color of the product.	Paint Sample 18 B-4 Chocolate Turtle = 6.0 Paint Sample C91 Camel = 9.0
Surface Roughness	Indentations/bumps on surface; smooth to rough	Cheerios= 4.0 Wheaties=8.0
Aroma		
Attribute	***Definition***	***Reference***
Oxidized Oil	The aromatic associated with aged or highly used oil and fat.	Microwave Oven Heated Vegetable Oil = 6.0 (aroma) Preparation: Add 300ml of oil from a newly purchased and opened bottle of Wesson Vegetable Oil to a 1000ml glass beaker. Heat in the microwave oven on high power for 3 minutes. Remove from microwave and let sit at room temperature to cool for approximately 25 minutes. Then heat another three minutes, let cool another 25 minutes, and heat for one additional 3 minute interval. Let beaker sit on counter uncovered overnight. Serve 1 tablespoon of the oil in a medium snifter, covered.
Cardboard	The aromatic associated with cardboard or paper packaging. The intensity rating is only for the 'cardboardy' character within the reference.	Cardboard soaked in water, covered with watch glass= 7.5 (aroma) Preparation: Place 2" square piece of cardboard in a snifter. Cover with water. Cover with a watch glass.

Flavor		
Attribute	***Definition***	***Reference***
Overall Grain	A general term used to describe the light dusty/musty aromatics associated with grains such as corn, wheat, bran, rice and oats	Cheerios= 4.0 Wheaties=8.0
Wheat	A light, cooked, wheat flavor aromatic.	American Beauty Elbo-Roni = 5.0 (aroma) General Mills Wheaties = 11.0 (flavor) Gold Medal Whole Wheat Flour = 8.5 (flavor)
Corn	Grain aromatics characteristic of corn	Quaker Yellow Corn Meal = 5.0 (flavor) Toasted Corn Doritos = 8.0 (flavor)
Soy	Flavor associated with soybeans or soy products.	Soy nuts (Hy-Vee Bulk) = 4.5
Beany	A slightly brown, musty, slightly nutty and starchy flavor associated with cooked dried beans.	Green Giant Pinto Beans = 5.5 (flavor) Soy beans = 4.0
Nutty	The non-specific nut-like aromatic that is typical of several different nuts such as pecans, hazelnuts, and peanuts.	Gold Medal Whole Wheat Flour = 4.5 (flavor) Kretschmer Wheat Germ= 7.5 (flavor)
Toasted	A moderately browned/ baked impression	Post Shredded Wheat (Spoon size) = 3.5 (flavor) General Mills Cheerios = 7.0 (flavor)
Leavening	The aromatics associated with baking soda and/or baking powder in baked flour products.	Jiffy Corn Bread mix = 4.0 Preparation: Prepare according to package direction
Cardboard	The aromatic associated with cardboard or paper packaging. The intensity rating is only for the 'cardboardy' character within the reference.	Cheerios = 4.5
Oil-Heated	The aromatics commonly associated with heated oil.	Wesson Pure Vegetable Oil = 10.0 (flavor) Preparation: Heat 1/3 cup oil for 2 min on high power in microwave oven. Serve in covered 1 oz cups
Oxidized Oil	The aromatic associated with aged or highly used oil and fat.	Microwave Oven Heated Vegetable Oil = 5.0 (flavor) Preparation: Add 300ml of oil

Overall Sweet	The perception of a combination of sweet taste and aromatics.	Post Shredded Wheat Spoon Size = 1.5 (flavor)
Sweet	A fundamental taste factor of which sucrose is typical.	1% Sucrose Solution = 1.0
Salt	A fundamental taste factor of which sodium chloride is typical.	0.15% NaCl Solution = 1.5 0.20% NaCl Solution = 2.5
Bitter	The fundamental taste factor of which caffeine or quinine is typical.	0.010% Caffeine Solution = 2.0 0.020% Caffeine Solution = 3.5 0.035% Caffeine Solution = 5.0
Sour	A fundamental taste factor of which citric acid in water is typical.	0.015% Citric Acid Solution = 1.5
Astringent	The feeling of a puckering or a tingling sensation on the surface and/or edges of the tongue or mouth.	0.03% Alum solution = 1.5 0.05% Alum Solution = 2.5
Aftertaste		
Attribute	***Definition***	***Reference***
Overall Grain	A general term used to describe the light dusty/musty aromatics associated with grains such as corn, wheat, bran, rice and oats	Cheerios= 4.0 Wheaties=8.0
Wheat	A light, cooked, wheat flavor aromatic.	American Beauty Elbo-Roni = 5.0 (aroma) General Mills Wheaties = 11.0 (flavor) Gold Medal Whole Wheat Flour = 8.5 (flavor)
Corn	Grain aromatics characteristic of corn	Quaker Yellow Corn Meal = 5.0 (flavor) Toasted Corn Doritos = 8.0(flavor)
Soy	Flavor associated with soybeans or soy products.	Soy nuts (Hy-Vee Bulk) = 4.5
Beany	A slightly brown, musty, slightly nutty and starchy flavor associated with cooked dried beans.	Green Giant Pinto Beans = 5.5 (flavor) Soy beans = 4.0
Toasted	A moderately browned/ baked impression	Post Shredded Wheat (Spoon size) = 3.5 (flavor) General Mills Cheerios = 7.0 (flavor)
Oil-Heated	The aromatics commonly associated with heated oil.	Wesson Pure Vegetable Oil = 10.0 (flavor) Preparation: Heat 1/3 cup oil for 2 min on high power in microwave oven. Serve in covered 1 oz cups

Oxidized Oil	The aromatic associated with aged or highly used oil and fat.	Microwave Oven Heated Vegetable Oil = 6.0 (aroma) Microwave Oven Heated Vegetable Oil = 5.0 (flavor) Preparation: Add 300ml of oil from a newly purchased and opened bottle of Wesson Vegetable Oil to a 1000ml glass beaker. Heat in the microwave oven on high power for 3 minutes. Remove from microwave and let sit at room temperature to cool for approximately 25 minutes. Then heat another three minutes, let cool another 25 minutes, and heat for one additional 3 minute interval. Let beaker sit on counter uncovered overnight. Serve 1 tablespoon of the oil in a medium snifter, covered.
Bitter	The fundamental taste factor of which caffeine or quinine is typical.	0.010% Caffeine Solution = 2.0 0.020% Caffeine Solution = 3.5 0.035% Caffeine Solution = 5.0
Texture		
Attribute	***Definition***	***Reference***
Surface Roughness	The amount of indentations/bumps and surface abrasions which can be perceived by gently manipulating one piece between the palate and the tongue.	Cheerios (one piece) = 5.0 Wheaties (one piece) = 9.0
Initial Hardness	The force required to bite completely through the sample with molar teeth.	Wheaties (one piece) = 7.5 Planter, shelled Almonds = 11.0 Bob's Winter Wheat = 14.5
Initial Crispness	The intensity of audible noise at first chew with molars.	Cheerios = 8.0 Wheaties = 10.5
Fracturability	The force with which the sample ruptures. Evaluate on first bite down with the molars.	Cheerios (one piece) = 4.0 Wheaties (one piece) = 7.5 Scotch Hard Candy (one piece) = 14.0
Denseness	The compactness of the cross section (strength and ratio of the air cells), judged when bitten with molars until the mouth is closed. (2 pieces)	Cheerios=4.0 (3 pieces) Graham crackers = 6.0 Almonds = 14.0

Sustained Hardness:	The duration of hardness perceived during mastication with the molars that is equal to the first bite.	Wheaties (one piece) = 7.5 Post Grape nuts= 9.0 Bob's Winter Wheat = 13.0
Sustained Crispness	The duration of crispness perceived during mastication with the molars that is equal to the first bite.	Cheerios = 4.0 Wheaties = 7.0
Roughness Of Mass	The degree of abrasiveness of particles perceived when gently manipulating the mass against the palate after 5-7 chews.	Cheerios = 4.0 Wheaties = 8.0
Tooth Packing	The amount of sample packed in and between the molar teeth after swallowing.	Wheaties = 7.0
Particles(Residuals)	The amount of small pieces of sample remaining in mouth just after swallowing. This does not incorporate toothpacking and refers only to particulate matter on mouth surfaces other than in and between the molar teeth.	Wheaties = 7.0 Quaker Quick Oats Oatmeal=9.5 (1/2 teaspoon)

IV. Descriptive sensory study ballot in reference to data presented in Chapter 3

Tasting Instructions: Take 5 pieces of the snack per bite

<u>AROMA</u>

Oxidized Oil	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Cardboard	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15

<u>FLAVOR</u>

Overall Grain	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Wheat	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Corn	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Soy	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Beany	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Nutty	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Toasted	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Leavening	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Cardboard	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Oil- Heated	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Oxidized Oil	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Overall Sweet	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Sweet	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Salt	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Bitter	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15

Sour 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15

Astringent 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15

AFTERTASTE

Overall Grain 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15

Wheat 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15

Corn 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15

Soy 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15

Beany 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15

Toasted 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15

Heated Oil 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15

Oxidized Oil 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15

Bitter 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15

TEXTURE/MOUTHFEEL

Surface Roughness 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15

Initial Hardness 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15

Initial Crispness 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15

Fracturability 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15

Denseness 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15

Sustained Hardness 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15

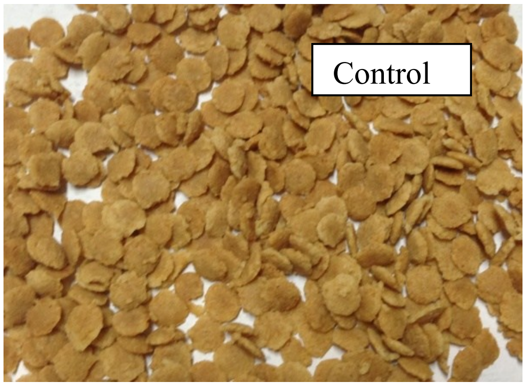
Sustained Crispness 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15

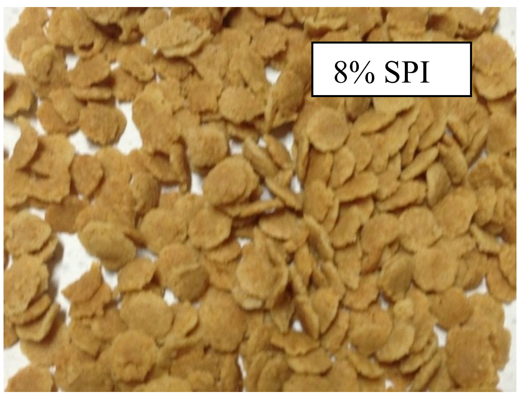
Roughness of Mass 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15

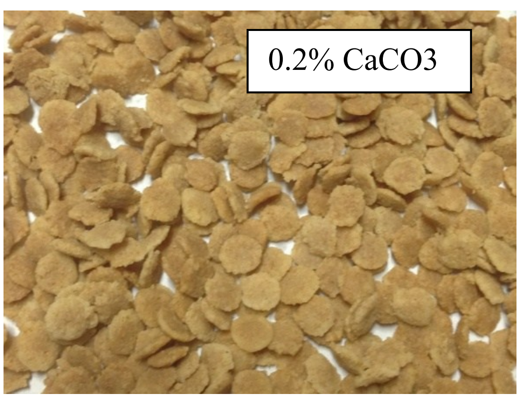
Tooth Packing 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15

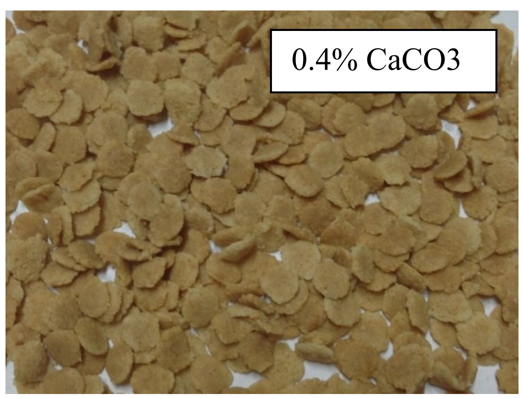
Particles (Residuals): 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15

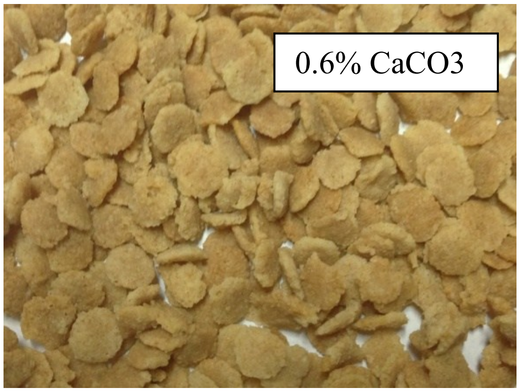
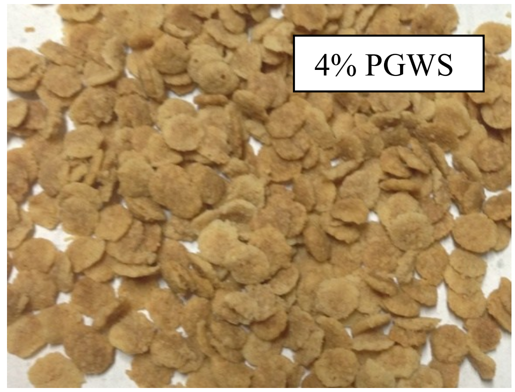
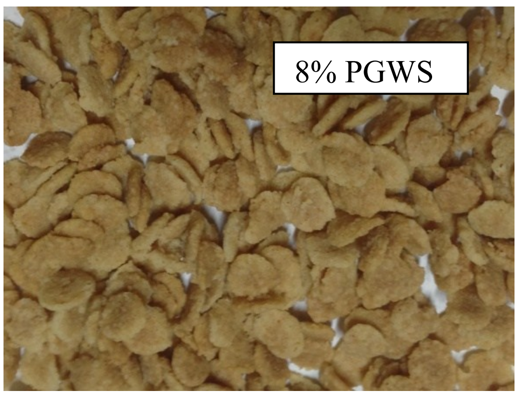
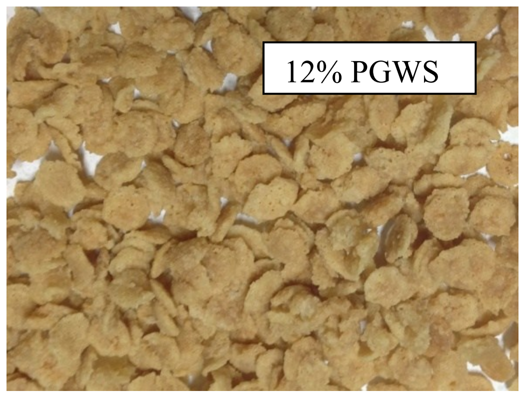
V. Pictures of products after frying from all treatments in reference to the data presented in Chapter 3










0.6% CaCO3

4% PGWS

8% PGWS

12% PGWS