DEVELOPMENT OF NEW CHIP PRODUCTS FROM BREWER'S SPENT GRAIN

By

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DEVELOPMENT OF NEW CHIP PRODUCTS

FROM BREWER'S SPENT GRAIN

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Title of Study: DEVELOPMENT OF NEW CHIP PRODUCTS FROM BREWER'S SPENT GRAIN

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Abstract:

Brewer's Spent Grain (BSG) is a processing waste generated in large quantities by the brewing industry. It is estimated that over 38 million tons of BSG is produced worldwide each year, and is usually used as animal feed, composted, or thrown into landfills. BSG contains valuable nutritional components, including protein, fiber, and antioxidants. Due to its brittle texture, strong nutty flavors, and dark color profiles from the presence of barley, BSG has seen limited use in food products for human consumption. The objective of this study was to develop a palatable snack product containing varying percentages of brewer's spent grain.

BSG samples were provided by Iron Monk in Stillwater, and were evaluated for nutrients and potential antioxidant capacity. The samples were dried at a low temperature, then milled into flour. Two different formulations were developed, with one containing sweet potatoes. Varying percentages of BSG were incorporated into each formulation.

This project involved further evaluation of water activity, color, and texture (fracture force) in BSG chips. An informal sensory evaluation was performed, evaluating flavor, texture, and probability of purchase using a 5-point hedonic rating scale.
It was expected to observe visual changes in color as BSG levels increased. However, there were no significant differences between the many percentages. The texture fracture force levels decreased as BSG inclusion increased in both formulations. This is largely due to the fact that higher levels of BSG created a more brittle texture, allowing the chips to break sooner than the chips made with lower levels of BSG, which resulted in a more 'leathery' texture. The results observed from the informal sensory testing indicated that chips with higher levels of BSG were more appealing to customers despite being dark in color.

Results from this work could be economically beneficial for our local Iron Monk business as well as breweries nationwide. Development of an alternative value-added product represents an opportunity to turn a processing waste into a future asset.

Keywords: Brewer's Spent Grain (BSG), barley, snack, waste utilization, beer

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INTRODUCTION

1.1 Background

Food waste is generated worldwide, as food losses occur throughout the entire food chain. Food processing operations generate a significant amount of waste that ends up in landfills, causing both economic and environmental problems. In many cases, food waste streams contain valuable components that could be converted to valuable products. The beer brewing industry is an example of a food processing operation that generates a significant amount of solid waste. Brewer's spent grain is a byproduct of the brewing industry. The beer brewing process involves the production of wort, where milled barley malt (or other grains) is processed to convert the starch into fermentable sugars. The solids remaining at the end of this process are known as brewer's spent grain (BSG).

The high fiber, protein, and mineral contents of brewer's spent grain make it an attractive ingredient in food products. BSG is rich in polysaccharides, protein, and lignin (Robertson et al., 2010). There is a great need for added fiber in human diets, which has been shown to improve gastrointestinal function and reduce ulcerative colitis (Broekaert, 2011).

For many years, the spent grain byproducts were primarily sent to landfills; but the potential health benefits of BSG have resulted in its primary current use as an animal feed.

However, the nutrient content of BSG makes it a potentially good candidate to incorporate into human food products, in order to increase its value. Another big advantage of using BSG is that the brewing industry uses materials approved for human consumption, so that there is a real potential for developing new products that can meet regulatory approval (Stojceska & Ainsworth, 2008).

There have been several studies conducted to incorporate spent grain into bakery products such as bread, cookies, and breadsticks; but in those cases, the high fiber content and dark color of the BSG did not allow satisfactory inclusion levels above about 10% BSG. It is hypothesized that the physical properties of BSG would work well in a chip-type product, which would allow much higher inclusion levels of BSG into the product with positive consumer response. Creating a high value-added product for human consumption could give brewers an alternative way to better profit from an unavoidable waste.

1.2 Research Objectives

The objectives of this study were:

- Evaluate the properties of spent grain.
- Produce a snack containing large quantities of spent grain that accentuates its previously unwanted attributes.
- Evaluate differences amongst the water activity, color, and texture of chip products as BSG inclusion levels increased.

CHAPTER II

LITERATURE REVIEW

2.1 Waste Utilization

As the world's population increases, so does our carbon footprint. Food waste is generated worldwide, as food losses occur throughout the entire food chain. Activities such as recycling and composting have become more popular amongst consumers and manufacturers alike in order to become more environmentally conscious, but the food industry still generates large amounts of waste. Food processing operations generate a significant amount of waste, which often ends up in landfills, causing environmental sustainability issues. According to the United States Environmental Protection Agency, 38.1 million tons of food waste was disposed of in landfills in 2017 in the United States (EPA, 2019). In many cases, food waste streams contain valuable components. If some of that value could be extracted, separated, or transformed into new products, then a waste liability can be turned into an asset.

One processing industry that generates waste products of potential value is the beer brewing industry. Brewer's spent grain is a well- known processing waste that is generated during beer production. Roughly 85% of beer production waste is due to spent grain (Alihu & Bala, 2011). In the past, spent grain was thrown into landfills (Mussatto, 2014). Although rendered as spent, brewer's spent grain still contains valuable nutritional components, including protein, fiber, and antioxidants. Nowadays, spent grain is supplied to farmers as a low cost effective- high protein alternative animal feed (Mussatto, 2014).

BSG is available in large quantities throughout the year, although spent grain can only stay fresh for 7 - 10 days before experiencing microbial growth in its wet state (Alihu & Bala, 2011). The high moisture content of ~80% - 85% and composition of BSG makes it highly susceptible to microbial degradation, but microbial contamination is low and considered within acceptable limits for food use at the point of production (Robertson et al., 2010). Nevertheless, dependent on location, it can be tiresome for farmers to drive to breweries as soon as batches of spent grain are available. Therefore, it can be assumed that large quantities of spent grain may still be contributing to waste.

2.2 Beer

The earliest alcoholic concoction was produced in China 9,000 years ago containing rice, honey, and fruit. However, the oldest barley beer recipes recorded on a stone tablet was found in Mesopotamia, dating back 5,000 years (Andrews, 2018). It is thought that the Sumerians that once ruled Mesopotamia were the first to start producing beer with barley until 5,000 year old manufacturing tools were discovered in China that contained barley (Andrews, 2018; Wang et al., 2016).

Currently, beer is one of the most popular alcoholic beverages in the world (Pascari, Ramos, Marín, & Sanchís, 2018). Beer is produced by the brewing and fermentation of the starches and enzymes found in cereal grains, predominately malted barley, along with possible added adjuncts, and is flavored with hops.

In 2019, 1.91 billion hectoliters of beer was produced worldwide. The U.S. alone produced 180 million barrels of beer in 2019 making the U.S. the 2nd largest producer of beer, following China (Statista, 2020). During the production of beer, 15 – 20kg of BSG is produced for every hectoliter of beer (Niemi, Martins, Buchert, & Faulds, 2013).

2.3 Spent Grain Production

Spent grain is a byproduct of the beer making process. Figure 2.1 depicts the steps of the beer making process where spent grain is produced. Mashed malt along with adjuncts are soaked like tea leaves to access the starchy endosperm (Mussatto, Dragone, & Roberto, 2006), and this allows for the enzymatic conversion of starches to access the sugars needed for the fermentation process. Once optimal sugar and enzymatic property extraction is reached, the sugary liquid known as wort and mashed malt mix are separated by draining the liquid from the solids. During the separation process known as the lautering and sparging, the husks from the malted barley are used as filter beds. When all the wort is removed, the grain is rendered as spent (Mussatto, 2006).

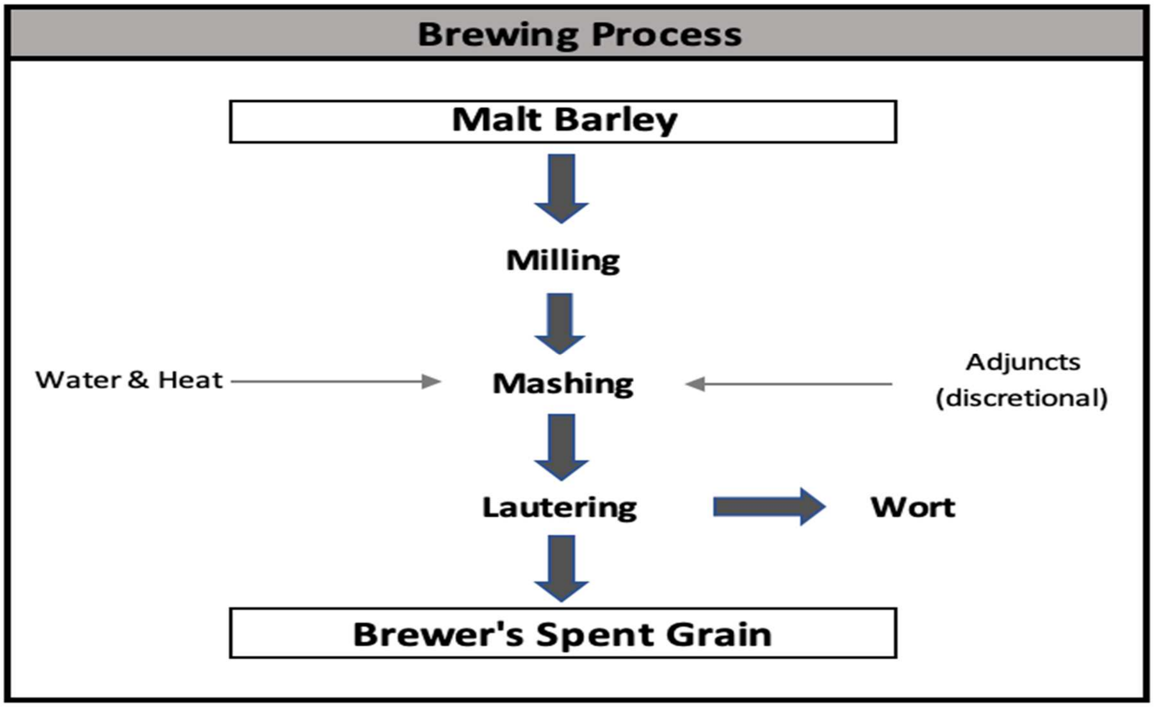

Figure 2.1 - Brewer's spent grain production schematic based on a figure from (Mussatto et al., 2006).

2.3.1 Brewer's Spent Grain Nutrient Content

The chemical composition of BSG varies according to barley variety, harvest time, malting and mashing conditions, and the quality of added grains in the process (Santos et al, 2003).

There are significant amounts of protein in BSG. For example, the oven dried spent grain used during trials conducted by Santos et al. (2003) contained 24.2% protein, 3.9% fat, and 3.4% ash. Generally, the spent waste typically contains about 15%-26% protein, 3%-10% lipids, 15%-25% cellulose, 28%-35% hemicellulose, and 10%-20% lignin on a dry basis (Nigam, 2017).

2.3.2 Protein Content

Essential amino acids make up about 30% of protein, and lysine is the most abundant amino acid in BSG. Most spent grain also contains a large number of minerals, with silicon, phosphorus, and calcium reported at the highest levels (Mussatto, 2014).

Gluten is the main protein that is found in cereal grains such as barley, rye, oats, and wheat. The major proteins of the BSG are hordeins (a ,b, and c), constituting over 50% of the total amount of proteins, followed by gluten (Kerpes, Fischer, & Becker, 2017). The prolamins found in wheat, rye, and barley can be toxic to patients with celiac disease. Celiac disease is a chronic inflammatory reaction in the small intestine triggered by the ingestion of immunogenic prolamin and glutelin peptides found in barley wheat and rye (Kerpes et al., 2017). Those with a gluten allergy or celiac disease should avoid ingesting BSG and enriched foods containing BSG.

2.3.3 Antioxidants

The major components of BSG are the walls of the husk, pericarp, and seed coat that originally covered the barley grain, which are rich in cellulose and non-cellulosic polysaccharides and lignin (Mussatto et al., 2006). The cellulose and hemicellulose fractions are composed of sugars, mainly glucose, xylose, and arabinose. These sugars represent approximately half of the composition of the BSG (on a dry basis).

Antioxidants are mainly found in the husk of barley grain (Gupta, Abu-Ghannam, & Gallaghar, 2010). Phenolic acids have been found to be present in the aleurone layer and endosperm of barley, and are known to contain a valuable antioxidant activity. The extraction of these valuable phenolics has been studied using various extraction techniques, including solid-liquid extraction and microwave-assisted extraction, with some success (Meneses, Martins, Teixeira, & Mussatto, 2013). Flavonoids have also been suggested to be strongly correlated with the antioxidant capacity of BSG as well (Meneses et al., 2013).

The aleurone layer of barley seed consist of tissue surrounding the endosperm (Jacobsen, Knox, & Pyliotis, 1971), and is rich in arabinoxylans (AX). AX are the main non-starch polysaccharide cell wall components found in many cereal grains and are part of dietary fiber (Broekaert et al., 2011), and are known to slow down starch hydrolysis. Arabinoxylooligosaccarides (AXOS) are the products from enzymatic hydrolysis of AX. AX and AXOS contain ferulic acid, and ferulic acid has in vitro antioxidant properties in animal and human studies, and the findings of said studies suggest that ferulic acid may contain antitumor activity against breast {Kampa, 2003 #135} and liver cancer {Lee, 2005 #136} {Broekaert, 2011 #30}.

2.4 Past Uses of Brewer's Spent Grain

Food applications for BSG have been evaluated for foods such as breads, pastas, cookies, ready-to-eat foods (yogurt), and frankfurters (Lynch, 2016; Ainsworth, 2007; Özvural, 2009; Stojceska, 2008). The BSG is milled into flour before being used in bakery products, in order to decrease the particle size and improve the texture of the final products.

Common goals of these applications were to increase dietary fiber and protein of their particular foods product. One study incorporated BSG in frankfurters in order to create a high fiber and low fat processed meat product (Özvural, Vural, Gökbulut, & Özboy-Özbaş, 2009).

Unfortunately, they all experienced issues of unwanted flavors and textural changes. Ultimately, recommendations for the new products included spent grain to be incorporated in relatively small amounts for human foods. Incorporating smaller amounts of BSG such as 5% -10% decreases the probability of unwanted alterations of color, flavor, and texture.

There are a few products that have been produced using BSG. Products such as granola and puffs with brewer's spent grain addition can now be purchased from a small business start-up called, ReGrained. "ReGrained" is a California based company that works with local breweries to upcycle spent grain. The spent grain goes through a patent pending process to rescue nutrients. The final product is then referred to as SuperGrain+ (Kurzrock, 2017).

BSG has also been used for bioethanol production. The cellulose and hemicellulose from the barley husk provide a cheap substrate for ethanol production (Alihu, 2011). Pretreatment methods have been investigated for hydrolysis of the cellulose to glucose, including enzymatic hydrolysis, acid treatment, and microwave digestion (Niemi, 2013; Pirkko Forssell1, 2008). Reported ethanol yields vary significantly, ranging from 30-40% of theoretical yield (Mussatto, 2014). Thermochemical conversion processes have been also successfully used to convert BSG into combustion gases as an alternative form of energy generation (Keller-Reinspach, 1989; Meyer, Jepsen, & Sorensen, 1988; Zanker & Kepplinger, 2002).

2.5 Methods to Improve Binding Capabilities

Due to its high fiber content, one of the issues with utilization of BSG in food products is the lack of binding capability within the matrix of the food product. Binders are seen as the glue that holds baked products together. They also aid in tenderization and texture. Starch granules loosen crystallinity and absorb a large amount of water and swell upon heating in water dispersion resulting in enhancement of viscosity.

2.5.1 Starch

Brewer's Spent Grain has a low starch content after the lautering and sparging process is complete. Starch is converted to sugar during grist and malt preparation. Therefore, most of the barley starch is removed during the mashing process (Kissell & Prentice, 1979).The starch content of the spent grain may further decrease during the moisture removal process depending on drying temperature.

Sweet potatoes are cheaper than other crops as a starch source, yet this abundant resource is still not effectively utilized (Ahmed, Akter, & Eun, 2010). The major component of sweet potato root is starch, which can account for up to 80% of the dry matter (Zhu & Wang, 2014).

Larger native potato starch granules and their high swelling capacity and exceptionally large volume swollen granules result in a high viscosity but generate a rough texture (Colussi et al., 2020). The tuber starch found in sweet potato may aid in texture improvement of the goods produced with BSG by allowing for more aeration, tenderness, and binding power.

2.5.2 Humectants

The incorporation of BSG results in increased water adsorption capacity and higher fiber and protein contents in enriched products. Unfortunately, brewer's spent grain tends to expel all water when dried. Using humectants may slow down the amount of water lost when products enriched with BSG are cooked. Humectants are hygroscopic substances that form hydrogen bonds with water molecules attracting moisture, and are used in the food industry as a means to control water activity (Sloan, 1976).

Honey is a natural sweetener and humectant that is also a high sugar product made by honeybees from the nectar of flowers (Babaan, 2002). The incorporation of honey will aid in the browning process via the Maillard reaction. Still, the light amber color of the honey will have less of an effect on final bake color in comparison to molasses.

Additionally, it was recently reported that honey may cause loss of viscosity in starch-containing food products. Honey's negative effect on the viscosity quality of starch-based foods is due to the naturally occurring amylase found in the honey (Babaan, Pivarnik, & Rand, 2002). What was seen as negative in the past may be beneficial as a softening agent after the starch breakdown.

2.6 Color Expectations and Food

BSG affects the color of final products due to its brown color. The Maillard reaction is responsible for the non-enzymatic browning between amino acids and reducing sugars. Guo (2014) reported that the BSG caused an increase in the amount of amino acid in their starch mixtures.

Flavor perceptions may be influenced by physical, thermal, painful, optical, and olfactory receptors. Humans perceive color differently. Therefore, color differences may actually impact different perceptions of flavor.

The L*a*b* model was created by the Commission Internationale d'Eclairage (CIE), and is referred to as the CIELAB color space. The CIE uses the color-opponent theory, which states that two colors cannot be red and green at the same time or yellow and blue at the same time, and L*a*b* space is used to describe or characterize color.

The L* value is the luminance component of the CIE, which corresponds with lightness (+) or darkness (-), ranging from 0-100 (Yam & Papadakis, 2004). a* and b* are the chromatic components of the CIE, and range from -120 to 120 (Yam & Papadakis, 2004). The a* value corresponds with the colors red (+) and green (-). The b* value corresponds with the colors yellow (+) and blue (-). The cylindrical version of the L*a*b* system corresponds with perceptual attributes, in which are L* (luminance), C* (chroma), and hue angle (h°) (Briones, 2005).

2.7 Snack Chips

In 1853, potato chips were invented by a cook named George Crum. Crum made a batch of fried potatoes that were sliced paper thin to inhibit the use of a fork in a petty effort to further instigate an argument with a picky customer. Surprisingly, the customer thought the fried thin slices of potato were delicious (McCarthy, 2001), and the Saratoga Chip was born.

Pairing salted snacks with beer is an old concept. When Prohibition ended in 1933 the demand for snack chips increased (McCarthy, 2001). Bar owners thought that salted snacks paired well with their beverages. The chips produced from the spent grain could be a new addition to the snack chip market.

For example, in 1964, Frito Lay introduced the Doritos tortilla chips to the snack market. Little did they know the Dorito tortilla chip would become the largest-selling snack food in the world three decades later (McCarthy, 2001). The innovative chips created by companies such as Frito Lay helped spark the ideation of the chip formulations.

For BSG chips, crepes, tortillas, and flatbreads were amongst the first set of trials conducted before deciding final recipes. A basic crepe recipe utilizes milk and eggs, and BSG flour was used to replace some of the wheat flour. Basic tortilla chips can be made via water and baking soda. Again, BSG flour can be used to replace some of the corn or wheat flour.

Utilizing the leftover spent grain for snacks is an overall way to ensure that brewery owners will be able to have an alternative for their waste that will generate profits.

CHAPTER III

METHODOLOGY

3.1 Materials

Brewer's Spent Grain was provided by the local Iron Monk Brewery in Stillwater, OK. Reagents for the ORAC assay, including sodium phosphate, monobasic monohydrate, 98+%, ACS reagent (ACROS Organics), P380-500. Potassium Phosphate Monobasic NF/FCC (Fisher Scientific), Trolox, 97% (ACROS Organics), V-50 2,2' – Azobis(2-amidinpropane) Dihydrochloride AAPH(FujiFilm), Ethyl Alcohol 200 Proof (Pharmco-AAPER), Methanol, Glass purified (Pharmco-AAPER), and Sodium Hydroxide Solution N/100 (Fisher Scientific) were purchased from Fisher Scientific located at Fair Lawn, New Jersey 07410, USA.

All other ingredients such as vegetable oil (Crisco), vegetable oil spray (Great Value), clover honey (Great Value), canned sweet potato (Princella), all-purpose flour (Great Value), and salt (Morton Salt) were purchased from the local grocery store.

3.2 Sample Analysis of Brewer's Spent Grain

Proximate analysis was conducted via the Food and Agricultural Products Center's Analytical Services Lab. A wet sample of brewer's spent grain was analyzed for percent moisture, percent ash, percent fat and percent protein. The percent carbohydrates was calculated by subtraction. Triplicate testing was performed for each analysis. The moisture content of wet spent grain samples was determined using Method 950.6 – Moisture in Meat (International, Latimer, & Horwitz, 2010). Percent Ash of samples was determined using Method 920.153 – Ash of Meat (AOAC, 2010). Determination of Crude Protein was by the Leco Combustion Method (AOCS, 2004).Percent fat was measured using the Percent Fat of Meat Products method by Soxtec (AOAC, 2010).

3.3 Brewer's Spent Grain Flour Preparation

Samples obtained from Iron Monk Brewery were placed into Ziploc freezer bags, and kept frozen in an ultra-low freezer. Frozen spent grain samples were thawed at refrigeration temperature for 48 hours as needed. Samples were dried at 65°C for 72 hours prior to use due to BSG being highly susceptible to microbial degradation, because of its high moisture content (Robertson et al., 2010).

Figure 3.1 shows the wet BSG and BSG flour samples made from Stilly Wheat Ale. Preparation of the Brewer's Spent Grain flour involved drying thawed samples at 65°C for 72 hours. Once dry, the spent grain was homogenized into flour, 1 cup at a time via coffee grinder for 40 seconds. Each cup of dried spent grain produced about 1/3 cup of spent grain flour. BSG flour was stored at refrigeration temperature until needed.

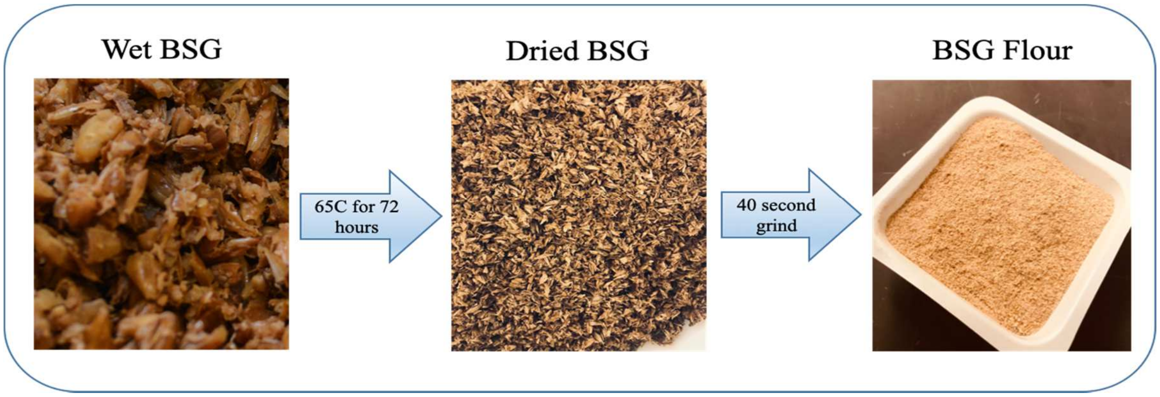

Figure 3.1 Brewer's spent grain flour production.

3.4 Sample Preparation for ORAC

3.4.1 Sample Extraction

Brewer's spent grain supplied by Iron Monk in Stillwater, OK underwent the methods previously stated for lab sample drying. A 75% ethanol concentration with water mixture was used for the extraction of antioxidant phenolic compounds from BSG.

One gram of dried BSG was mixed with 20ml of solvent in a 100-ml Erlenmeyer flask, covered with aluminum foil, and maintained during a 30 minute water-bath at 60°C due to low boiling points of organic solvent (Meneses et al., 2013). Samples introduced to the water bath were swirled by hand periodically in 2-minute intervals for the duration of the water bath.

BSG sample extracts were then filtered through a coffee filter followed by 0.22µm nylon membranes fitted onto 3ml syringes. Completed samples were stored at 2°C until analysis. BSG samples included: Velvet Antler (U.S. Amber Ale), Stilly Wheat Ale, Exit 174 Rye Pale Ale, & The 9 IPA.

3.4.2 Oxygen Radical Absorbance Capacity Protocol

The oxygen radical absorbance capacity was determined using a Perkin-Elmer HTS 7000 Microplate Reader adapted with a Falcon 96 well flat bottom microplate. 1ml of 75% ethanol BSG extract was diluted with 100ml of phosphate buffer. 160µl Fluorescein (Perkin Elmer to measure the rate of degradation and report values) was administered to well columns 2-11, using a 200µl Rainin multi-channel pipette adapted with RC-L250 tips. Using a 20µl Rainin multi-channel pipette adapted with RC-L10 tips, 20µl of phosphate buffer was added to column 2 as a blank, and dilutions of Trolox prepared in phosphate buffer (12.5µM, 25µM, &50µM) was administered as antioxidant standards in wells 3,4,&5. 20µl of diluted sample extract was added to columns 6-11. The microplate with solutions was then introduced to the microplate reader to undergo the plate warming step. Once warm (37°C), 20µl of Azobis (2-amidinpropane) Dihydrochloride known as AAPH was added to wells 2-11 as a peroxyl generator to generate free radicals for the breakdown of fluorescein. Gen5 software was used to relay the values of the fluorescein degradation every 60 seconds for 35 minutes.

The Gen5 relayed values were copied into a Microsoft Excel spreadsheet for further calculation. The calculation used for Trolox equivalent for antioxidants known over the concentration range is shown in Figure 3.2, and was used within the template. Trolox equivalents were expressed as µM of Trolox equivalents per 100 grams (µMTE/100g) ± SD.

$$\text{TE/Concentration Range} = \frac{\text{Slope Regression Curve (Sample)}}{\text{Slope Regression Curve (Trolox)}}$$

Figure 3.2 Trolox equivalent equation based on equation figure from Franka (2014).

3.5 Snack Chip Preparation

3.5.1 Preliminary Snack Chips

Three formulations were displayed at the 2019 Food and Agricultural Products Center's spring symposium in order to gage consumer appeal. One was a batter formulation that had to be cooked before being baked into spent grain crepe chips. The second, was a dough formulation that must be sectioned, pressed with a tortilla press, grilled and then baked into crackers. The third was a spent grain dough formulation that was rolled, sectioned, and baked until crisp. All formulations were reviewed favorably by local consumers at the symposium. However, we soon realized that controlling the thickness of the batter formulation during the cooking process would be difficult. The batter viscosity became harder to control as BSG inclusion increased. The once thin crepe-like bread would form into thick pancakes past 25% BSG inclusion.

Therefore, we decided to use the spent grain formulation that required a grilling step prior to baking. The formulation was easily replicable due to the use of a tortilla press, and could handle maximal amounts of BSG inclusion. There was also an artisan type sweet potato alternative created to possibly woo flavor enthusiasts.

3.5.2 Formulation Trials

Two spent grain chip formulations were further evaluated for color and texture as BSG inclusion increased. The water activity of the chips was measured using a water activity meter. Fracture force was evaluated using a texture analyzer, and reflected color was evaluated using a spectrophotometer. Table 3.1 shows the brewer's spent grain chip and BSG + sweet potato chip formulation ingredients for 18% BSGC & 16% BSG+SPC. The brewer's spent grain and all-purpose flour inclusions varied as the brewer's spent grain inclusion changed.

Table 3.1 Brewer's spent grain chip (18% inclusion) & brewer's spent grain + sweet potato chip (16% inclusion) formulations by weight of ingredients.

Ingredients	***BSGC (g)***	***BSG+SPC (g)***
Brewer's Spent Grain	*45*	*45*
All Purpose Flour	*80*	*75*
Sweet Potato	-	*120*
Water	*79.7*	-
Honey	*28*	*28*
Oil	*14*	*14*
Salt	*2.6*	-

3.5.3 Brewer's Spent Grain Chips (BSGC)

The brewer's spent grain chip formulation was used for analysis. Inclusion of brewer's spent grain was achieved by substituting brewer's spent grain flour for all-purpose flour used within formulation. All ingredients specified for the brewer's spent grain chip formulation were weighed on a tarred Denver Instrument XE-4100 digital laboratory scale, and follow the two-step cooking process featured in Figure 3.3. All dry ingredients were combined in a large mixing bowl. A well was formed in the center of the mixed dry ingredient for the addition of wet ingredients. Once the wet ingredients were added, the ingredients were kneaded by hand until a dough was formed. The dough was then separated and weighed into 25g balls. Weighed dough was pressed into 5” discs utilizing a plastic lined 6” aluminum tortilla press (Harold Import Co.). The pressed dough was griddled at 149°C for 4 minutes per side. Cooked spent grain breads were wrapped in paper towels that were labeled with their appropriate BSG percentage until cool.

Once cooled, cooked spent grain breads were sectioned into 8 triangular pieces. Triangular pieces were then spread in a single layer on foil lined cookie sheets. Chips were lightly sprayed with vegetable oil (3g per sheet). Chips were baked at 176°C for 8 minutes, then transferred to cooling racks to cool at room temperature for 20 minutes. Once cooled, chips were put into Ziploc bags with appropriate labels according to BSG inclusion levels.

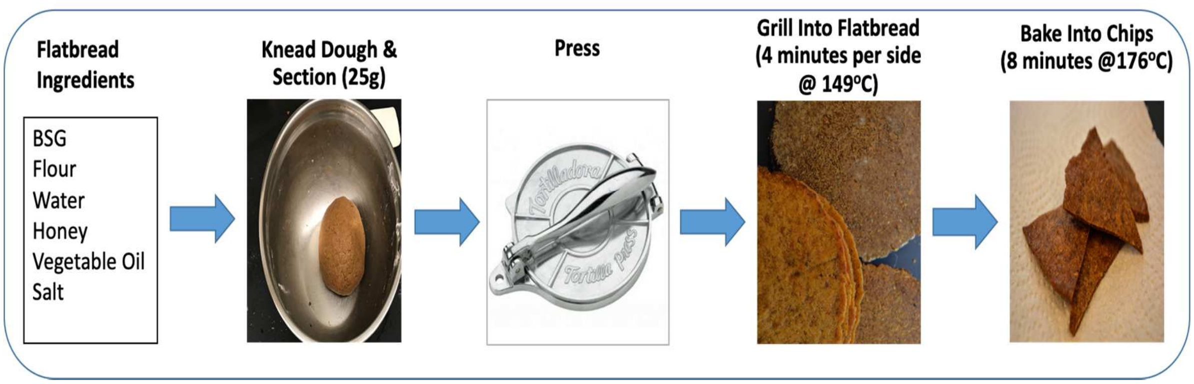

Figure 3.3 Two-step cooking process for chip formulations.

3.5.4 Brewer’s Spent Grain+ Sweet Potato Chip Preparation (BSG+SPC)

In the brewer’s spent grain+ sweet potato chip preparation, canned sweet potato was added to the formulation, and replaced the water in the o brewer’s spent grain chip recipe. Inclusion of brewer’s spent grain was achieved by substituting brewer’s spent grain flour for all-purpose flour used within formulation. All ingredients specified for the BSG+SP chip formulation in Table 3.1 were weighed on a tarred Denver Instrument XE-4100 digital laboratory scale, and follow the two-step cooking process featured in Figure 3.3 with exception of wet ingredients and salt. All dry ingredients were combined in a large mixing bowl. Canned sweet potato was homogenized via mashing until smooth. The wet ingredients were combined, then placed into the flour well. All ingredients were kneaded by hand until a dough was formed. The dough was then separated and weighed into 25g balls. Weighed dough was pressed into 5” discs utilizing a plastic lined 6” aluminum tortilla press. The pressed dough was griddled at 149°C for 4 minutes per side. Spent grain breads were wrapped in paper towels that were labeled with their appropriate formulation and treatment.

The cooled spent grain bread was sectioned into 8 triangular pieces. Triangular pieces were then spread in a single layer on foil lined cookie sheets. Triangular pieces were lightly sprayed with vegetable oil (3g per sheet). Chips were baked at 176°C for 8 minutes, then transferred to cooling racks to cool at room temperature for 20 minutes. Once cooled, chips were put into Ziploc bags with the appropriate labels according to BSG inclusion. Figure 3.4 shows weighed dough from the BSG+SP chip formulation containing the following treatment: 6%BSG, 27%BSG, & 42%BSG. Differences in dough color could be perceived before reaching the final product. Figures 3.5 shows an example of wet spent grain and 42% brewer’s spent grain + sweet potato chip samples.

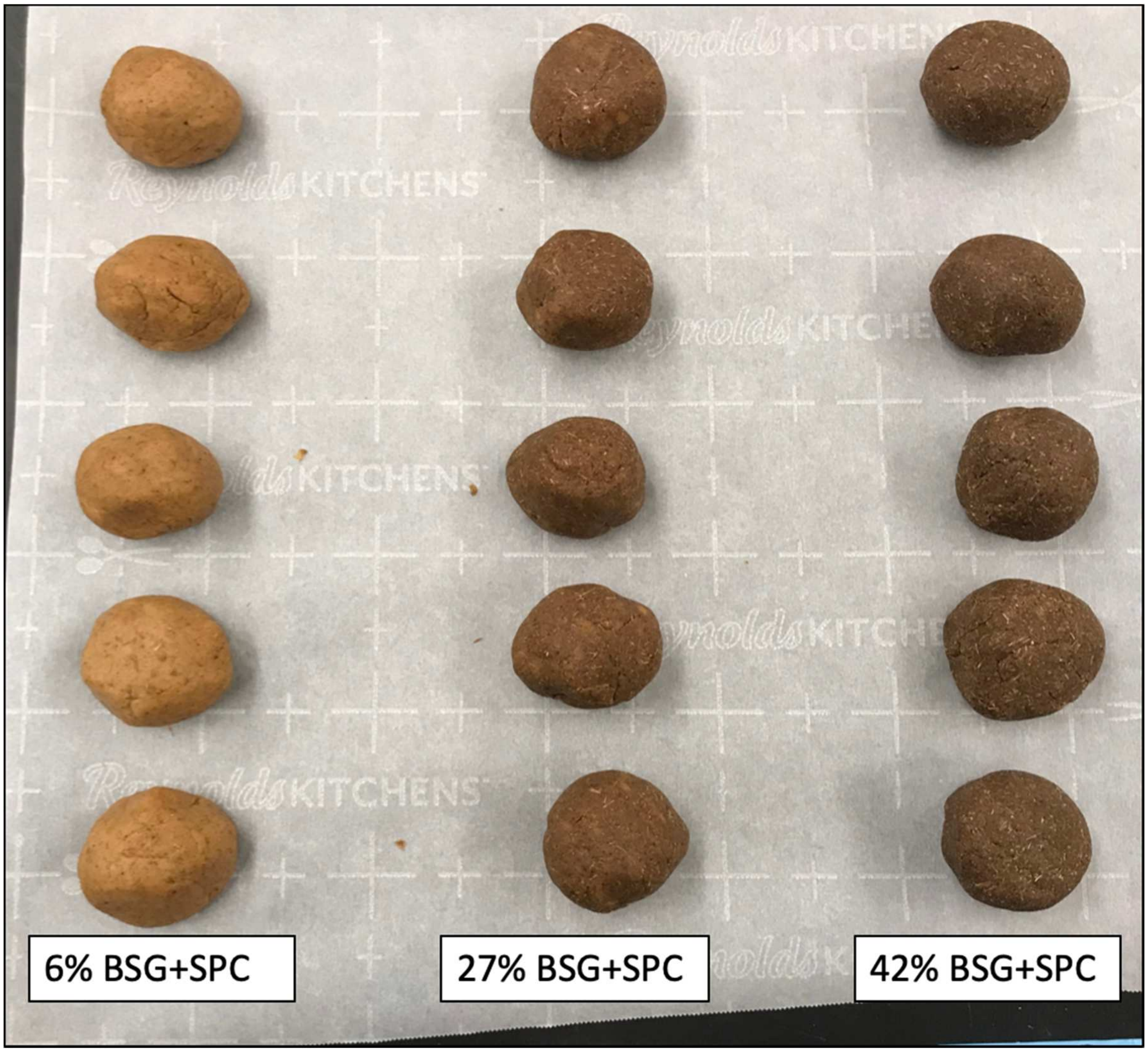

Figure 3.4 Dough containing 6%BSG, 27%BSG, & 42% BSG levels for brewer's spent grain+ sweet potato formulation.


Figure 3.5 Wet spent grain and 42% BSG+ sweet potato chips

3.5.5 BSG Inclusion

Inclusion of spent grain was achieved by substituting brewer's spent grain flour for the all-purpose flour used within each formulation. 80% of the all-purpose flour within the brewer's spent grain chip recipe was substituted with BSG in order to obtain a 40% BSG level chip product, and the 42% BSG level is a 98% all-purpose flour substitution within the brewer's spent grain+ sweet potato chip formulation. Table 3.2 lists the formulations and their corresponding treatments. BSG substitutions were then incrementally reduced in order to further observe changes in color, texture, and flavor.

Table 3.2 BSG chip formulations and corresponding brewer's spent grain inclusion levels.

Formulation	***%BSG Inclusion Level***
Brewer's Spent Grain Chip	*8%*
	18%
	24%
	32%
	40%
Brewer's Spent Grain + Sweet Potato Chip	*6%*
	16%
	27%
	42%

3.6 Characteristics of Brewer's Spent Grain Chips

3.6.1 Water Analysis

Water activity analysis was conducted using a benchtop water activity meter from Aqualab (Decagon Inc). BSG chips were broken into shards suitable for filling 2 centimeters of the 4-centimeter sample cups. The water activity was recorded for chip samples from the lowest and highest BSG levels, and analyzed for variations. The results are the average of 3 samples per treatment. Triplicate testing was performed per treatment.

3.6.2 Color Analysis

A Minolta Spectrophotometer was used to measure the reflected color of the BSG chip samples. BSG chips were placed on top of a petri dish to prevent chip dust from entering the lens of the spectrophotometer. Changes in L*a*b* were observed as various percentages of BSG were included into formulations. The results are the average of ten samples per treatment. Triplicate testing was performed per treatment.

3.6.3 Texture Properties

A texture analyzer (TA-XT 2i) equipped with a 3-point bend rig and a cylindrical probe were used to evaluate the textural properties of the chip samples. The speed of the probe was set to 0.5mm/s. Peak force was recorded using the Exponent Stable Microsystems Plus software. Ten samples were measured from each different treatment. Triplicate testing was performed per treatment.

3.7 Informal Sensory Evaluation

BSG chip samples were prepared according to the methods described. An informal sensory evaluation was conducted using the 2 formulations with 3 varying amounts of BSG inclusion rates from each formulation (6 samples total). Samples were prepared 24-48 hours prior to evaluating. The samples were stored at room temperature (~37°C), and sealed in Ziploc sandwich bags.

A total of 10 panelists were asked to evaluate the 6 samples, by marking the number that best described their feelings about the samples. Texture, flavor, and possibility of purchase were recorded in a 5-point hedonic rating scale on their ballots (Appendix 1: Figure 4.9). Responses were converted to numerical values for computing purposes.

3.8 Statistical Methods

Table 3.3 shows the sample size for each variable. Triplicate testing was performed for each treatment, with the exception of the sensory panel. The mean values and standard deviations were calculated for all treatments. An ANOVA one-way statistical analysis was used to find differences between data within the results of the color analysis, texture analysis, and sensory analysis observations, in which the statistical significance was considered at P ≤ 0.05. A Tukey Kramer procedure was performed to further analyze significant differences.

Table 3.3 Number of observations.

	Number of Observations
Water Activity (a_w)	*45 observations* *(3 replications x 5 treatments x 3 subsamples*
Color Analysis	*270 observations* *(3 replications x 9 treatments x 10 subsamples)*
Texture Analysis	*270 observations* *(3 replications x 9 treatments x 10 replications)*

CHAPTER IV

RESULTS & DISCUSSION

4.1 Proximate Analysis of Spent Grain

Table 4.1 shows the composition from the proximate analysis of spent grain of Stilly Wheat Ale. Stilly Wheat spent grain contains 16.85% protein, 4.87% fat, and 2.9% ash (dry basis). These results are within the ranges of 15%-26% protein, 3%-10% lipids, and 75.2% carbohydrates nutrient content of previously analyzed brewer's spent grain results on a dry basis (Nigam, 2017).

Table 4.1 – Proximate composition of Stilly Wheat brewer's spent grain.

Brewer's Spent Grain Proximate Composition		
	Wet Basis (%)	*Dry Basis (%)*
Moisture	*74.96*	-
Ash	*0.73*	*2.9*
Fat	*1.22*	*4.87*
Protein	*4.22*	*16.85*
Carbohydrates	*18.88*	*75.37*

4.2 ORAC Assay (Total ORAC)

The oxygen radical absorbance capacity (ORAC) values were evaluated for four different brewer's spent grain samples. ORAC values were determined using a Perkin-Elmer HTS 7000 Microplate Reader adapted with a Falcon 96 well flat bottom microplate. Gen5 relayed values were copied into a Microsoft Excel spreadsheet for further calculation. Figure 4.1 shows the fluorescein degradation curve for The 9 IPA spent grain sample. The calculation used for Trolox equivalent over the concentration range was used within the template. Trolox equivalents were expressed as µM of Trolox equivalents per 100 grams (µMTE/100g) ± SD.

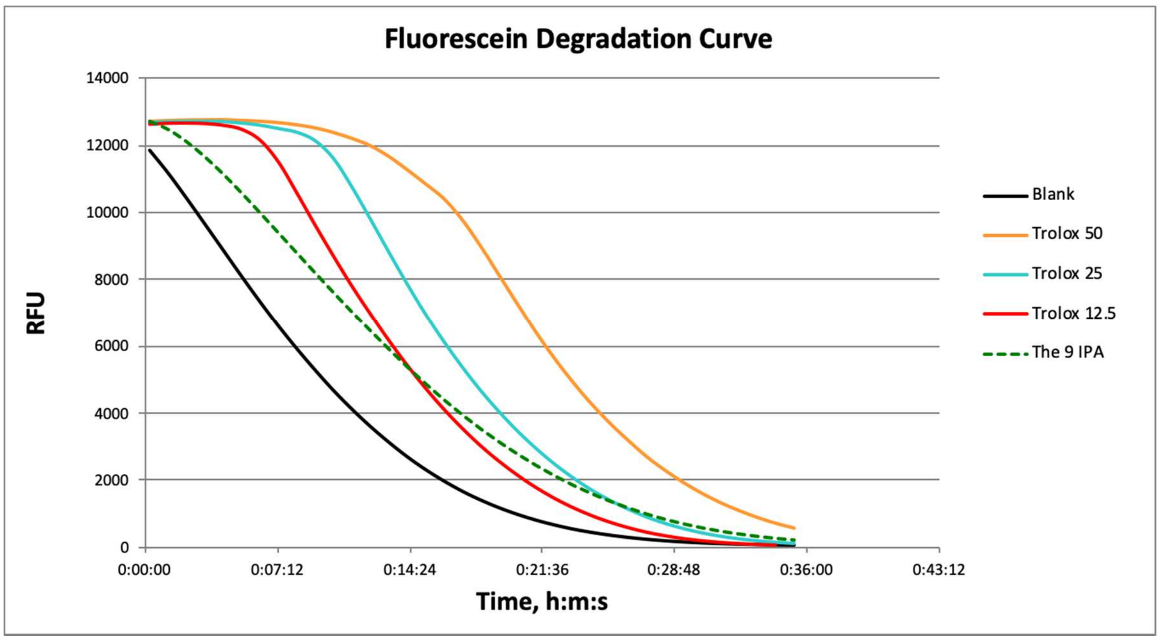

Figure 4.1 Fluorescein degradation curve for trolox & The 9 IPA sample.

Figure 4.2 is the Trolox Standard Curve for the dilutions of Trolox prepared in phosphate buffer (12.5µM, 25µM, &50µM) used for The 9 IPA spent grain sample comparison. The Trolox curves are normally distributed and maximum values are shown post AAPH injection. The Trolox Standard Curve R^2 =.9983. The nearly 100% Trolox linear regression establishes that it is ideally suited for the sample comparison.

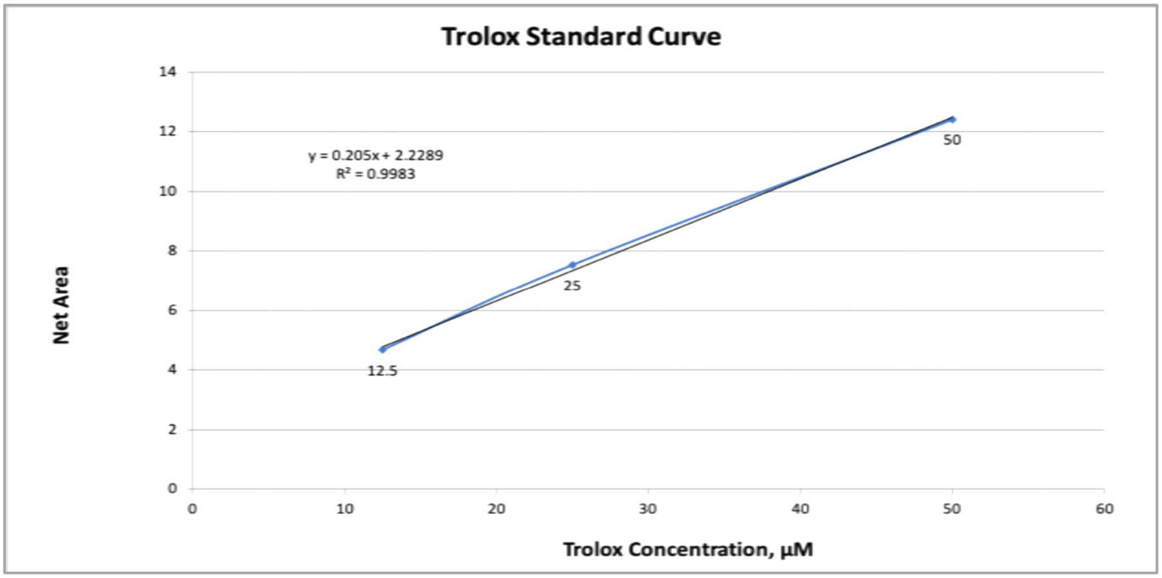

Figure 4.2 Trolox standard curve used for The 9 IPA Total ORAC comparison.

Brewer's spent grain from four different types of beer samples were tested for ORAC value. Those four samples included Stilly Wheat, Velvet Antler Amber Ale, Exit 174 Rye Pale Ale, and The 9 IPA. As shown in Table 4.2, ORAC values for Stilly Wheat were 5164 ± 553 µMTE/100g and Velvet Antler ORAC values were 5052± 436 µMTE/100g. The 9 IPA ORAC values were 1542 µMTE/100g and Exit 174 ORAC value was 2507 µMTE/100g.

There were large differences in ORAC assay results amongst beer varieties within the Iron Monk samples. However, there was no significant difference observed between the Stilly Wheat and the Velvet Antler ORAC assays.

Table 4.2 Total-ORAC values of BSG spent grain samples, which are reported as µM of Trolox equivalents per 100 grams (µMTE/100g). The mean value (mg/100g)± SD values are recorded for each BSG sample. (N = number of tests, n = 6 duplicate samples per test)

Description	***N***	***Mean ORAC value*** (µMTE/100g)
Brewer's spent grain, Velvet Antler (Amber Ale)	3	5052 ± 436
Brewer's Spent Grain, Stilly Wheat Ale	2	5164 ± 553
Brewer's Spent Grain, The 9 IPA	1	1542
Brewer's Spent Grain, Exit 174 Rye Pale Ale	1	2507

Iron Monk describes their Stilly Wheat Ale as a wheat beer that is infused with coriander. Therefore, the wheat along with coriander brew could be responsible for elevating the overall ORAC levels of the Stilly Wheat Ale. Amber ale is usually produced from a different malt variety than wheat beers such as the melano malt. Melano malts are slowly dried as temperatures are raised, allowing melanoidins to form as part of the kilning process (Moreira et al., 2013).

Table 4.3 shows the Total ORAC values of food items similar to the BSG samples reported in Table 4.2. Stilly Wheat and the Velvet Antler spent grain ORAC value averages were closer to raw raspberries (5065± 205), coriander (5141.3± 531), and raw mature soybeans (5409± 341) with all values expressed in µMTE/100g.

Both The 9 IPA & Exit 174 beers are produced from lighter malts. Nevertheless, the rye adjunct used for manufacturing Exit 174 could perhaps be responsible for their dissimilarity. The rye pale ale spent grain expressed ORAC values comparable to fortified dried instant oat cereals (1517). The fortified dried instant oats displayed a similar division in comparison to plain Quaker Brand Oat life RTE cereal (2308) and RTE corn flakes (2359).

Table 4.3 Total-ORAC values of food items similar to the BSG samples reported in Table 4.2. The values are reported in µM of Trolox equivalents per 100 grams (µMTE/100g). The mean value (mg/100g)± SD values are recorded for each sample.

Description	***N***	***Mean ORAC Value*** (µMTE/100g)
Cereals Ready-To-Eat, Quaker, Quaker Oat Life, plain *(Wu et al., 2004)*	1	1517
Cereals, Oat, Instant, fortified, plain, dry (Wu et al., 2004)	1	2308
Cereals Ready-To-Eat, Corn Flakes *(Wu et al., 2004)*	1	2359
Coriander (Cilantro) leaves, raw *(Ninfali, Mea, Giorgini, Rocchi, & Bacchiocca, 2005)*	4	5141.3 ± 531
Soybeans Mature seed, raw *(Xu & Chang, 2008)*	40	5409 ± 341
Raspberries, raw *(Wolfe et al., 2008)*	9	5065 ± 205

***Source USDA database (Haytowitz & Bhagwat, 2010).**

Differences in ORAC values of the BSG spent grain samples could be due to sources of malt & adjuncts (Robertson et al., 2010). The introduction of different adjuncts into the same mixture does not significantly change the phenolic content, but can change the ORAC value, which accurately represents the antioxidant capacity of the mixture (Ninfali et al., 2005).

4.3 Water Activity Analysis

Water activity analysis was conducted using a benchtop water activity meter from Aqualab (Decagon). The average temperature of the sample chamber was ~25°F. Table 4.4 shows results from the a_w measurements of both BSGC and BSG+ SPC samples. The brewer's spent grain+ sweet potato chip samples ranged from .41 to .3, and the brewer's spent grain chips ranged from .4 to .25 a_w. Lower BSG levels such as 6% BSG & 8% BSG produced a lower intermediate a_w (range from 26% to 75% a_w), which is similar to snacks like cookies or granola bars. The average a_w of chips with higher BSG levels displayed a low a_w, which is similar to snacks such as chips and crackers.

Chips made using the BSGC & BSG+SPC formulations experienced gradual decreases in a_w with increases of BSG substitutions. Similar results by Guo (2014) reported not having a water activity above 0.4 while substituting BSG for all- purpose flour in biscuit (cookie) formulations. Data from Ktenioudaki (2012) showed more than a 2% loss in the moisture content of breadsticks as BSG levels increased from 0% - 35%. Particle size and water-holding capacity of BSG may be responsible for these observations. Generally, fibrous samples are hard to grind due to their softness and lower density (Kim, Chun, Cho, & Park, 2012); meaning that the flour may not have contained fully uniform particles. Non-uniform particles in conjunction with the higher amounts of protein as BSG levels increased could have affected the water-holding capacity.

Table 4.4 Mean $a_w \pm$ SD, of BSG chip product samples. (n=3 replications, 3 subsamples per treatment)

BSG Chip Water Activity (a_w)					
% BSG & Formulation	**6% BSG+SPC**	**42% BSG+SPC**	**8% BSGC**	**32% BSGC**	**40% BSGC**
Mean $a_w \pm$ STD	0.4109 ± .01	0.3015 ± .06	0.4095 ± .03	0.3456 ± .02	0.2507 ± .04

4.4 Color Analysis

A Minolta Spectrophotometer was used to examine the reflected color of the chip samples. Changes in L*a*b* were observed as various percentages of BSG were included into formulations. **Figures 4.3 & 4.4** are the mean and standard deviation results of the color L*a*b* value results of the BSG chip samples. The ANOVA analysis can be found in Appendix 2.

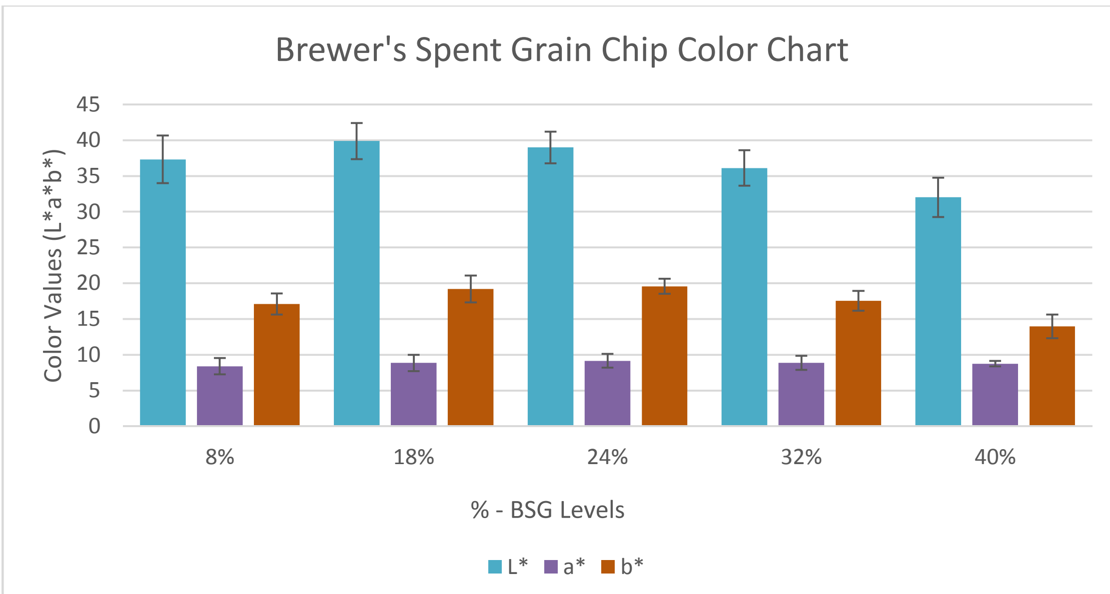

Figure 4.3 L*, a*, and b* color values for BSGC samples. Values shown are mean ± standard deviation. (n = 3 replications, 10 subsamples per treatment)

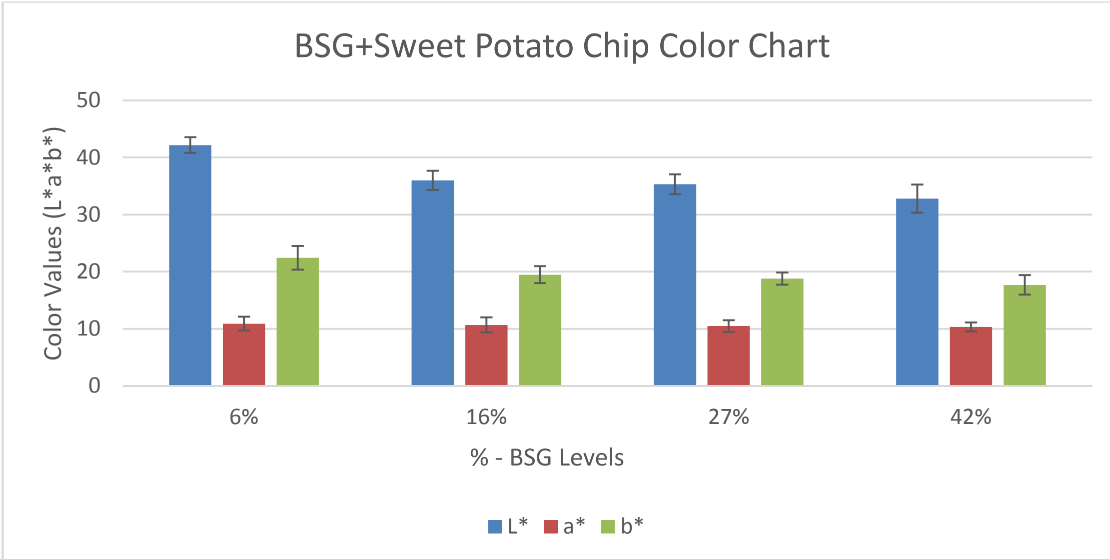

Figure 4.4 L*, a*, and b* color values for brewer's spent grain+ sweet potato chip samples. Values shown are mean ± standard deviation. (n= 3 replications, 10 subsamples per treatment)

The L* value is the luminance component of the CIE, which corresponds with lightness (+) or darkness (-), ranging from 0-100 (Yam & Papadakis, 2004). Samples of BSG chips became darker from the inclusion of BSG shown in Figures 4.3 & 4.4. The averages ranged from 32.01 to 39.89 for BSGC, and 32.80 to 42.18 for BSG+ SPC. As shown in Table 4.5 & 4.6, there were no statistical differences observed among the L* values for the BSGC samples. However, there were differences observed among the L* values for the BSG+ SPC samples with a $p < .05$. Within groups, the only treatment that was significantly different from the others was the 6% BSG+SPC, which displayed the greatest amount of luminance of all samples.

Table 4.5 Statistical differences between the L* values for BSGC samples.

Treatment	*Formulation*	*Average*	*P-Value*
8%	*BSGC*	*37.33 a*	*.1577*
18%	*BSGC*	*39.89 a*	
24%	*BSGC*	*38.99 a*	
32%	*BSGC*	*36.11 a*	
40%	*BSGC*	*32.01 a*	

***Means within the same column accompanied by the same letter are not significantly different (P ≤ 0.05).**

Table 4.6 Statistical differences between the L* values for BSG+ SPC samples.

Treatment	*Formulation*	*Average*	*P-Value*
6%	*BSG+SPC*	*42.18 a*	*.0006*
16%	*BSG+SPC*	*36.00 b*	
27%	*BSG+SPC*	*35.09 b*	
42%	*BSG+SPC*	*32.80 b*	

***Means within the same column accompanied by the same letter are not significantly different (P ≤ 0.05).**

a* and b* are the chromatic components of the CIE, and range from -120 to 120 (Yam & Papadakis, 2004). The a* value corresponds with the colors red (+) and green (-). The b* value corresponds with the colors yellow (+) and blue (-).

There were no significant differences among the different BSG levels within the a* value for both formulations (Table 4.7). All a* values were positive, which indicates that the corresponding colors displayed varied in the color red.

Table 4.7 Statistical analysis of the a* values for both BSGC& BSG+SPC samples. There were no significant differences between different BSG levels for either formulation.

Treatment	***Formulation***	***Average***	***P-Value***
8%	*BSGC*	*8.40 a*	*.8251*
18%	*BSGC*	*8.85 a*	
24%	*BSGC*	*9.16 a*	
32%	*BSGC*	*8.86 a*	
40%	*BSGC*	*8.76 a*	
6%	*BSG + SPC*	*10.89 a*	*.9030*
16%	*BSG+ SPC*	*10.67 a*	
27%	*BSG+ SPC*	*10.50 a*	
42%	*BSG+ SPC*	*10.30 a*	

There were differences observed along the b* value of both formulations having a $p < .05$. (Tables 4.8 & 4.9). The 40% BSGC, and the 6% BSG+ SPC were significantly different from the other treatments within their formulations.

Table 4.8 Statistical differences between the b* values for brewer's spent grain chip samples.

Treatment	*Formulation*	*Average*	*P-Value*
8%	*BSGC*	*17.09 ab*	*.0217*
18%	*BSGC*	*19.19 ab*	
24%	*BSGC*	*19.57 a*	
32%	*BSGC*	*17.55 ab*	
40%	*BSGC*	*13.94 b*	

***Means within the same column accompanied by the same letter are not significantly different (P ≤ 0.05).**

Table 4.9 Statistical differences between the b* values for brewer's spent grain + sweet potato chip samples.

Treatment	*Formulation*	*Average*	*P-Value*
6%	*BSG+SPC*	*22.44 a*	*.0205*
16%	*BSG+SPC*	*19.46 ab*	
27%	*BSG+SPC*	*18.28 b*	
42%	*BSG+SPC*	*17.68 b*	

***Means within the same column accompanied by the same letter are not significantly different (P ≤ 0.05).**

Hue angle is defined as starting at the +a* axis in which is expressed as 0 = +a* (red), 90 = +b* (yellow), 180 = -a* (green), and 270 = -b* (blue) (Minolta, 2020).

There were no statistical differences observed among the Hue Angle for either of the spent grain chip formulation samples. The +a* and +b* values from the results indicate that using the standard calculation for hue [$\tan^{-1}$ (b*/a*)] will be generated in Quadrant I of the color diagram (McLellan, 1994).

Table 4.10 Statistical differences between the Hue Angle values for both BSGC & BSG+SPC samples. There were no significant differences between different BSG levels for either formulation.

Treatment	***Formulation***	***Average***	***P-Value***
8%	*BSGC*	*63.77 a*	*.0979*
18%	*BSGC*	*65.07 a*	
24%	*BSGC*	*65.90 a*	
32%	*BSGC*	*63.14 a*	
40%	*BSGC*	*57.64 a*	
6%	*BSG+SPC*	*64.13 a*	*.0998*
16%	*BSG+SPC*	*61.33 a*	
27%	*BSG+SPC*	*64.13 a*	
42%	*BSG+SPC*	*59.60 a*	

***Means within the same column accompanied by the same letter are not significantly different (P ≤ 0.05).**

According to Gómez (2003), the original color of ingredients can have some influence on the crust bread color, which is mainly associated with the Maillard and caramelization reactions. However, the crumb bread color is usually similar to the color of the ingredients because the crumb does not reach as high of a temperature as the crust.

This also appears to be also true for our chips. Although all-purpose flour was used as the base for our formulations, the darker color of the BSG flour still affected all samples. **Figures 4.5 & 4.6** show examples of chips from both the BSGC and BSG+SPC formulations and each of their treatments.

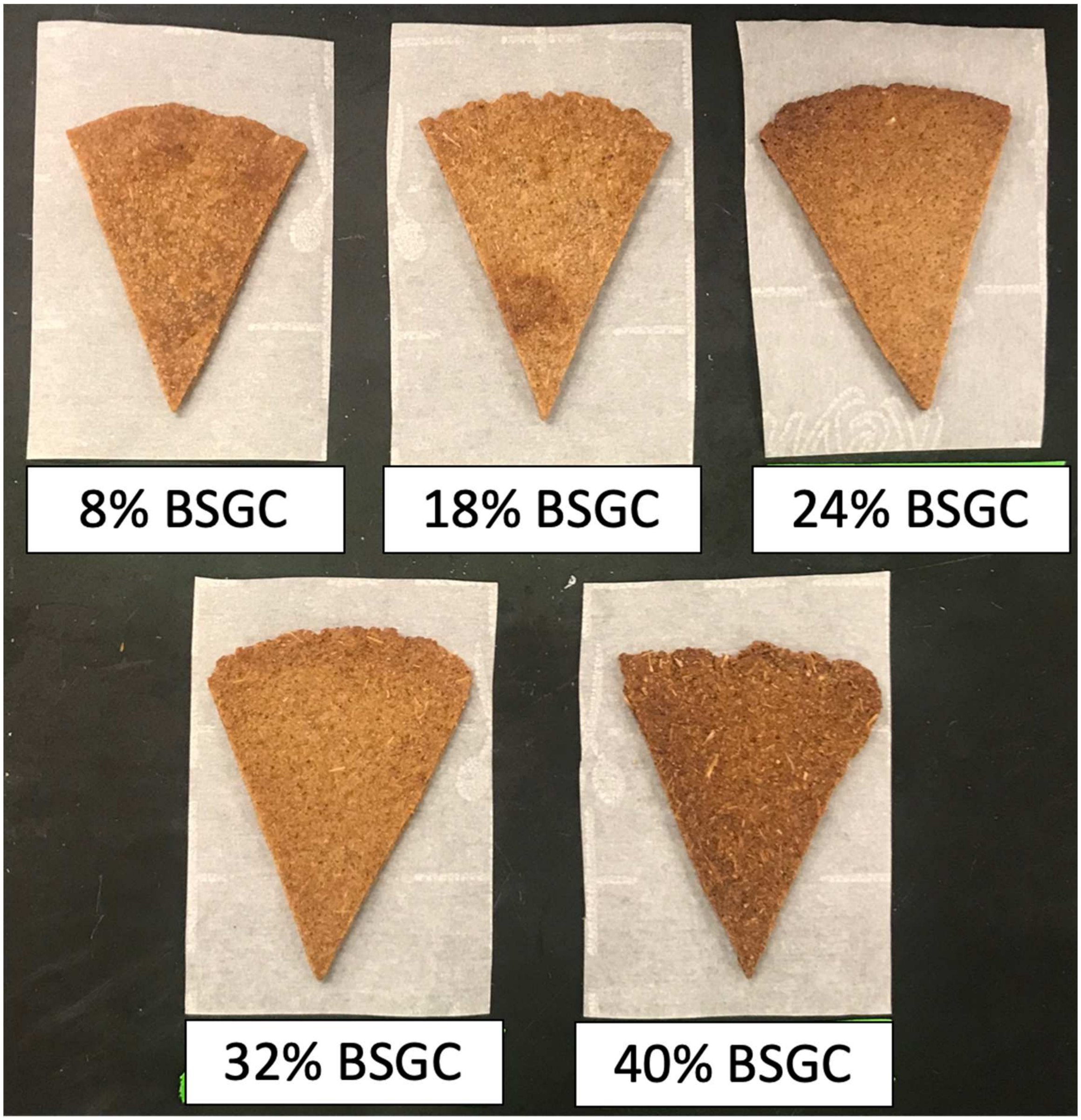

Figure 4.5 Brewer's spent grain chip samples with different BSG levels

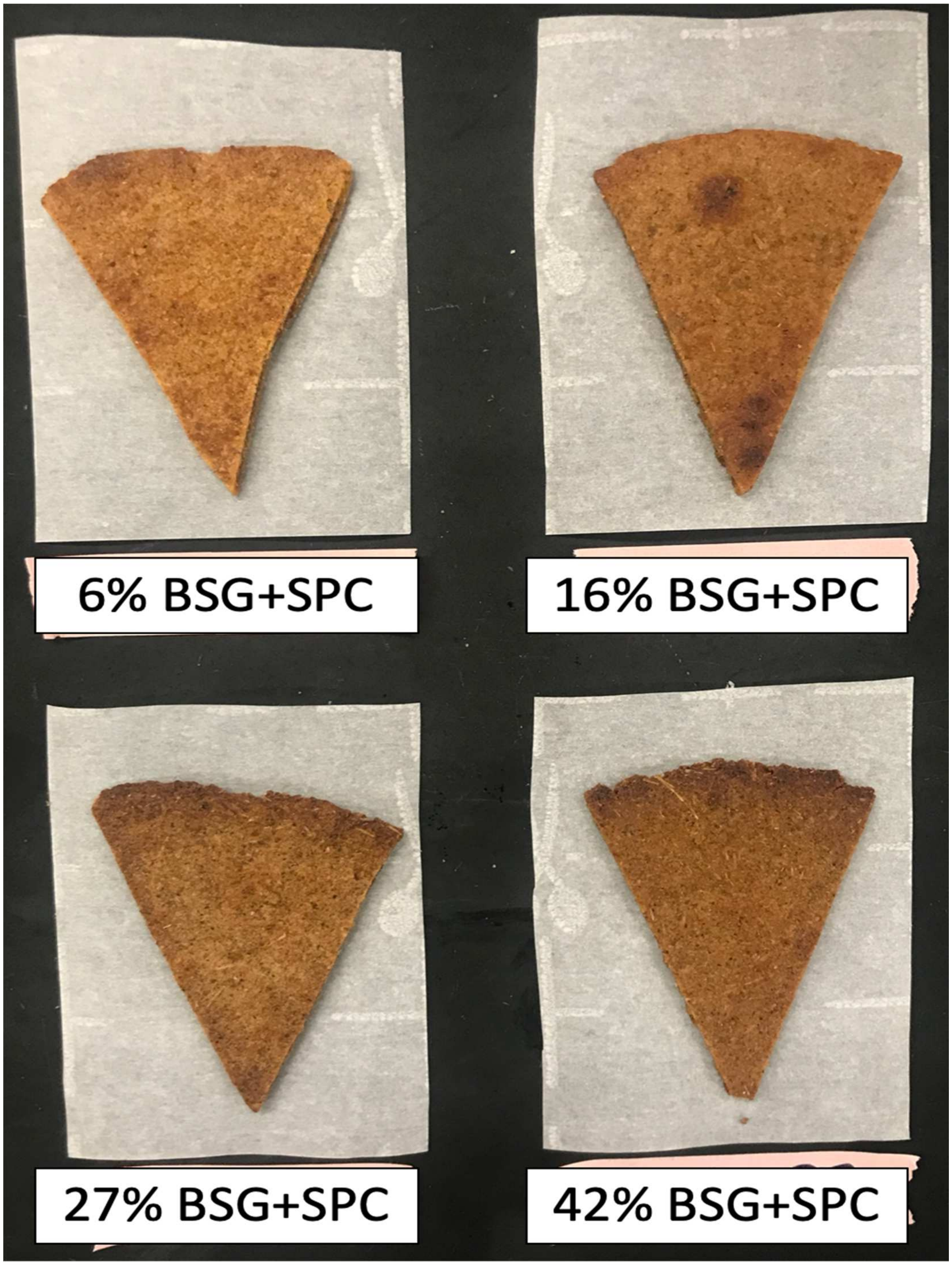

Figure 4.6 Brewer's spent grain + **sweet potato chip samples with different BSG levels.**

4.5 Texture Analysis

The mechanical properties of the BSG chips were assessed using a 3-point bend test to determine fracture force. Fracture force is the maximum force required to break samples (Kayacier, 2003). The peak force data was obtained from each chip, and analyzed using ANOVA, where the statistical significance was considered at $P \leq 0.05$. A Tukey Kramer procedure was performed were ANOVA analyzed significant differences. Figures 4.7 & 4.8 depict the average peak force and standard deviation for each chip formulation and their corresponding BSG percentages for both BSGC & BSG+SPC formulations.

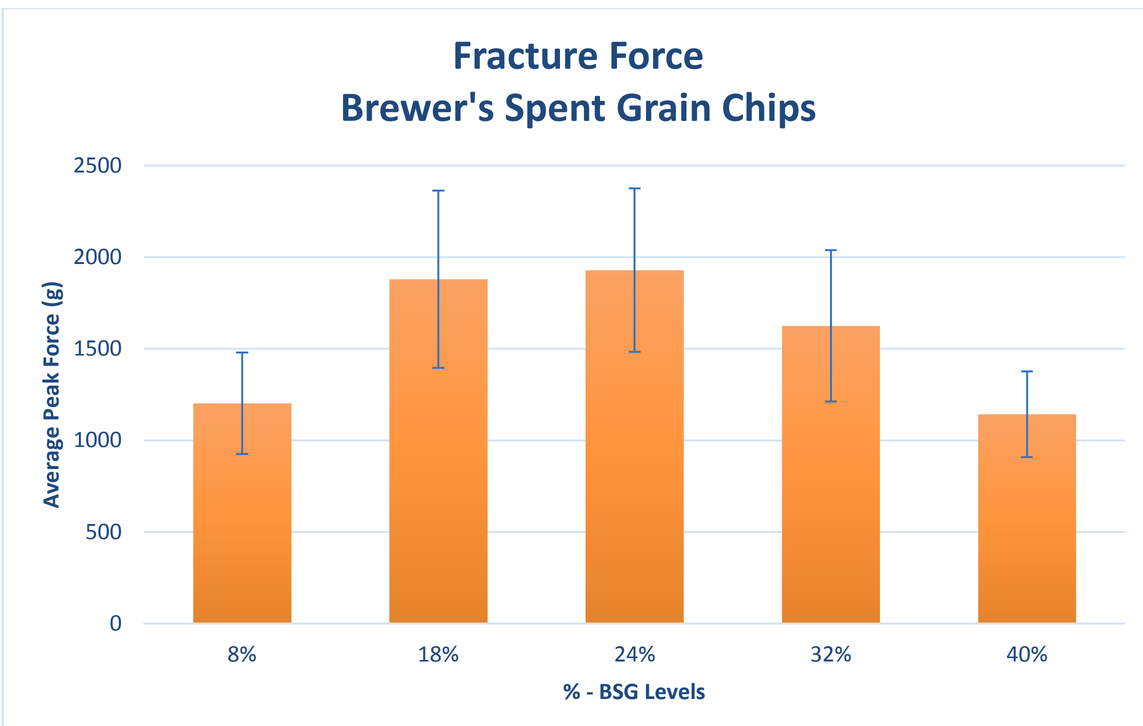

Figure 4.7 Three-point bend peak force averages of BSGC formulation with corresponding BSG percentages. The error bars indicate ±S.D. (n= 3 replications, 10 subsamples per treatment).

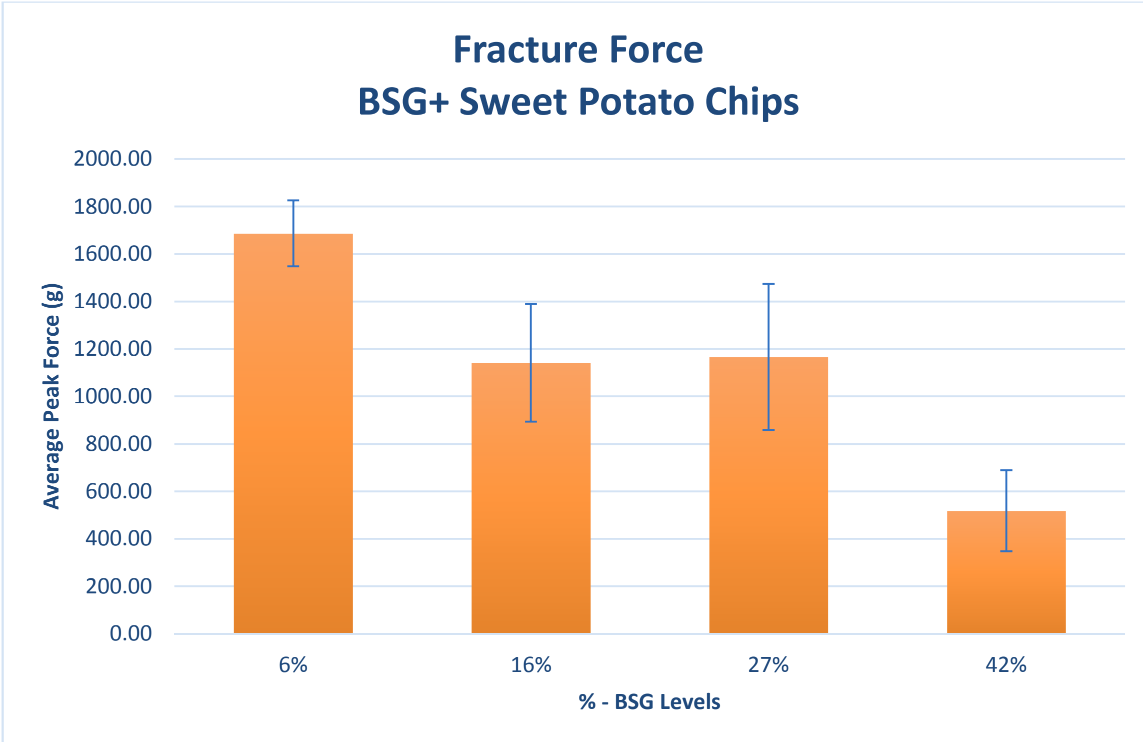

Figure 4.8 Three-point bend peak force averages of BSG+ SPC formulation with corresponding BSG percentages. The error bars indicate ±S.D. (n= 3, 10 subsamples per treatment)

There were differences among the peak force values for both BSGC & BSG+SPC. Tables 4.11 shows the results of the BSGC samples with a $p < .05$, Table 4.12 shows that the BSG+ SPC samples $p < .05$.

Table 4.11 Statistical differences in fracture force of BSGC samples.

Treatment	*Formulation*	*Average*	*P-Value*
8%	*BSGC*	*1203.45 bc*	*.0104*
18%	*BSGC*	*1880.34 ab*	
24%	*BSGC*	*1929.12 a*	
32%	*BSGC*	*1625.60 abc*	
40%	*BSGC*	*1143.18 ac*	

***Means within the same column accompanied by the same letter are not significantly different (P ≤ 0.05).**

There were significant differences observed within the data BSG+ sweet potato chip treatments shown in Table 4.12. Both the 6% BSG+SPC and 42% BSG+SPC treatments were significantly different from each other as well as the 16% BSG+SPC, 27% BSG+SPC. Chips containing sweet potato were not as hard as those in the BSGC formulations. The BSG+ sweet potato chips could be softer due to the tuber starch from the sweet potato.

Table 4.12 Statistical differences in fracture force of BSG+ SPC samples.

Treatment	*Formulation*	*Average*	*P-Value*
6%	*BSGC+SP*	*1681.73 a*	*.0002*
16%	*BSGC+SP*	*1123.91 b*	
27%	*BSGC+SP*	*1166.27 b*	
42%	*BSGC+SP*	*510.95 c*	

***Means within the same column accompanied by the same letter are not significantly different (P ≤ 0.05).**

The texture of chips with lower BSG inclusion were often tough, leathery, and fracture resistant. These results are common among baked goods made with flour containing higher amounts of fiber such as wheat bran. Ktenioudaki (2012) experienced similar results while assessing snap test results using breadsticks that contained various amounts of BSG.

Chips containing more than 32% BSG inclusion were crisper, but exhibited a lower force fracture. The BSG+ sweet potato chip data shows similar results in relation to the medium BSG levels conveying similar amounts of fracture force and a steady decline in fracture force as BSG inclusion increased.

4.6 Informal Sensory Analysis Panel

Evaluation of the BSG chips via a full sensory panel was approved February 11th, 2020 by The Oklahoma State University Institutional Review Board (Approval #: IRB-20-57). Due to the Coronavirus pandemic, a full sensory panel was not possible. Instead, an informal sensory analysis was conducted. Participants were approached individually, and social distancing protocols were followed. Participation in this study was voluntary, and subjects were free to withdraw without penalty.

Panelists were asked to evaluate samples for color, texture, and whether they would buy the product, as shown in the survey in Figure 4.9 below.   A total of six different samples consisting of three different BSG levels in the brewer's spent grain chips and three different BSG levels in the brewer's spent grain + sweet potato chips were compared. Panelists were given two samples from each level of the following BSG inclusions: BSGC - 8%, 18%, & 40% and BSG+SPC - 16%, 27%, & 42% in plastic bags labeled 1-6.

Sample # _____

Chip Evaluation Survey

1. How do you feel about the texture of the chips?

   (1-very unsatisfied, 2-unsatisfied, 3-neutral, 4-satisfied, or 5-very satisfied)

   1 2 3 4 5

2. Did you like the flavor of the chips?

   (1-very unsatisfied, 2-unsatisfied, 3-neutral, 4-satisfied, or 5-very satisfied)

   1 2 3 4 5

3. Would you consider purchasing these chips from a store?

   (1-very unlikely, 2-unlikely, 3-neutral, 4-likely, or 5-very likely)

   1 2 3 4 5

Figure 4.9 Survey given to panelists to evaluate six different chip formulations. Each response is based on 5-point hedonic scale.

Table 4.13 Responses from informal sensory analysis of brewer's spent grain chip (BSGC) samples with three different BSG inclusion levels. Values show mean (n=10).

	BSG Inclusion Levels			
Treatment	8%	18%	40%	P-Value
Texture	1.8 a	3.9 b	4.3 b	< .0001*
Flavor	3.6 a	3.9 a	3.5 a	0.3841
Purchase	1.6 a	3.6 b	3.7 b	< .0001*

***Means within the same row accompanied by the same letter are not significantly different ($P \leq 0.05$)**

Table 4.13 shows the survey results for the brewer's spent grain chips. There were significant differences with the texture, flavor, and purchase all containing a $p < .05$. The 8% BSG was significantly different within the brewer's spent grain chip formulation treatment, and was least texturally favorable by panelist. However, the 18% BSG and 40% BSG did not yield significant differences.

Table 4.14 Responses from informal sensory analysis of BSG+ sweet potato chip (BSG+SP) samples with three different BSG inclusion levels. Values show mean (n=10).

	BSG Inclusion Levels			
Treatment	16%	27%	42%	P-Value
Texture	3.8 a	3.6 a	4.3 a	0.4615
Flavor	3.3 a	3.8 a	3.8 a	0.4738
Purchase	3.6 a	3.4 a	3.8 a	0.7570

***Means within the same row accompanied by the same letter are not significantly different ($P \leq 0.05$).**

Table 4.13 shows the survey results for the BSG+ sweet potato chips. There were no significant differences observed among the sensory analysis results for the BSG+SPC samples.

As discussed in the color analysis section, chips became darker as BSG inclusion rates increased. Some of the most prominent comments pertaining to the chips with higher BSG inclusion rates were that they were too dark, or looked burnt. Panelists also said that the 40% BSGC samples tasted more bitter than the previous samples. Two surveyors mentioned that 42% BSG+ sweet potato chips were too strong in flavor for them.

These formulations were created to fully welcome the otherwise distasteful attributes that BSG incorporation into baked goods have previously entailed. As the inclusion rates decreased, so did the ability of dough to expel the increased moisture it had experienced to accommodate BSG inclusion. This may be the main reason for the overall results with these BSG chips. The outer layer of 8% BSGC samples were lighter in color, had great flavor, and a slight crunch. However, the inner layer of the chips did not make for a good chewing experience due to their chewy, rough, and leathery texture. Chips with higher BSG levels were able to repel the large amounts of moisture in the dough, thus leaving a more chip-like crumb texture.

Researchers in the past have reported similar issues while baking breads and cookies. Their overall conclusions were that they enjoyed the lower levels of BSG in their formulations. Ainsworth (2007) reported that the quality was mainly affected with their extruded snacks, because of high fiber content of BSG, resulting in a decrease in volume, increase in crumb hardness, loss of crispiness, dense crumb grain structure, and reduced expansion.

Moreover, since the goal for this product was to be crisp and display a reduction in expansion; our panelists found the chip products that had increased levels of BSG to be more favorable.

CHAPTER V

CONSLUSIONS

5.1 Conclusions

The overall conclusion of this study is that a palatable chip product was able to be developed containing BSG inclusion levels up to 42%, which is very high compared to previous food products incorporating BSG.

Specific conclusions are as follows:

- Results from the Total ORAC analysis showed that two of the spent grain samples evaluated had antioxidant capacities in the range of 5000 μMTE/100g. In addition, there can be large variations in potential antioxidant capacities among spent grain samples, depending on the malt and adjunct additions used at breweries.
- Two different formulations were developed, with one containing sweet potatoes.
- In general, water activity of the BSG chips ranged from .25 - .41a_w, and higher levels of BSG incorporation into formulations decreased the overall water activity of finished products.

- The color of BSG chips became visibly darker as BSG levels increased in finished products, even though the differences in L*, a*, and b* values between many treatments were not statistically significant. The hue angle calculations showed that the chips were not perceived as significantly different.
- In general, texture fracture force levels decreased as BSG inclusion increased in both formulations. This is largely due to the fact that higher levels of BSG created a more brittle texture, allowing the chips to break sooner than the chips made with lower levels of BSG, which resulted in a more 'leathery' texture.
- Informal sensory analysis revealed that consumers preferred the chips with the higher levels of BSG and most would purchase those chips. In addition, decreases in fracture force were found to be more preferable to panelists as BSG levels increased in samples.

5.2 Future Recommendations

- Future research could involve going more into depth in regards to the utilization of different starches, and their effects on the texture of the spent grain chips.
- Research should be done to understand the effects of different levels of honey vs levels of molasses on the flavor and texture of the chips containing BSG.

- Further investigation into the swelling capacity of BSG flour, and differences in cooking methods such as frying should be conducted. Depending on the swelling capacity; chips with larger amounts of BSG incorporation may hold less fat than regular chips.
- Further development of more snack formulations using brewer's spent grain should be attempted. More snack options would allow brewers to continue to increase their profits as well as reduce waste.

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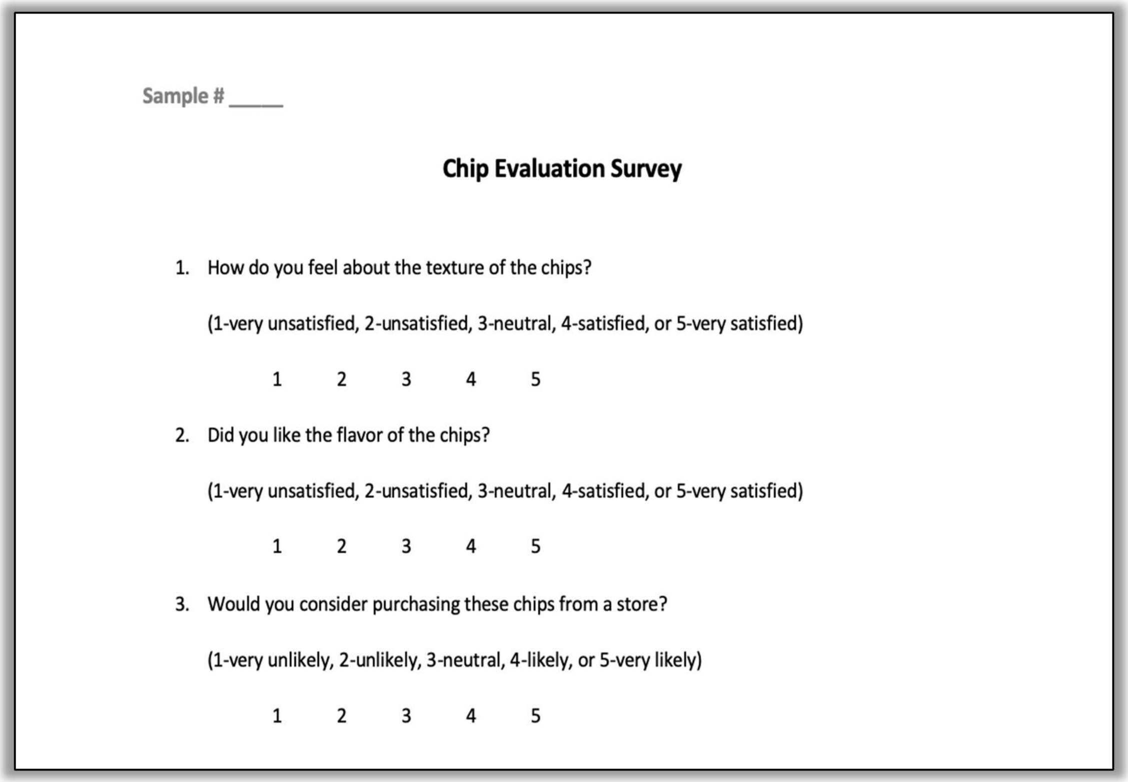
APPENDICES

Appendix 1: Informal sensory evaluation ballot



Sample # _____

Chip Evaluation Survey

1. How do you feel about the texture of the chips?

   (1-very unsatisfied, 2-unsatisfied, 3-neutral, 4-satisfied, or 5-very satisfied)

   1 2 3 4 5

2. Did you like the flavor of the chips?

   (1-very unsatisfied, 2-unsatisfied, 3-neutral, 4-satisfied, or 5-very satisfied)

   1 2 3 4 5

3. Would you consider purchasing these chips from a store?

   (1-very unlikely, 2-unlikely, 3-neutral, 4-likely, or 5-very likely)

   1 2 3 4 5

Appendix 2: Data Analysis for Chapter IV

Color analysis data

BSGC ANOVA ANALYSIS FOR L* VALUES

Oneway Analysis of L* By Treatment

Oneway Anova

Summary of Fit

Rsquare	0.454769
Adj Rsquare	0.236676
Root Mean Square Error	2.550652
Mean of Response	37.38933
Observations (or Sum Wgts)	15

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	4	54.26403	13.5660	2.0852	0.1577
Error	10	65.05827	6.5058		
C. Total	14	119.32229			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
8%	3	37.3300	1.4726	34.049	40.611
18%	3	39.8900	1.4726	36.609	43.171
24%	3	38.9900	1.4726	35.709	42.271
32%	3	36.1100	1.4726	32.829	39.391
40%	3	34.6267	1.4726	31.345	37.908

Std Error uses a pooled estimate of error variance

BSG+SPC ANOVA ANALYSIS FOR L* VALUES

Oneway Analysis of L* By Treatment

Oneway Anova

Summary of Fit

Rsquare	0.870981
Adj Rsquare	0.822599
Root Mean Square Error	1.636472
Mean of Response	36.5175
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	144.63189	48.2106	18.0022	0.0006*
Error	8	21.42433	2.6780		
C. Total	11	166.05622			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
6%	3	42.1800	0.94482	40.001	44.359
16%	3	36.0033	0.94482	33.825	38.182
27%	3	35.0900	0.94482	32.911	37.269
42%	3	32.7967	0.94482	30.618	34.975

Std Error uses a pooled estimate of error variance

BSG+SPC TUKEY- KRAMER HSD FOR L* VALUES

Oneway Analysis of L* By Treatment

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

q*	Alpha
3.20234	0.05

HSD Threshold Matrix

Abs(Dif)-HSD

	6%	16%	27%	42%
6%	-4.2789	1.8978	2.8111	5.1044
16%	1.8978	-4.2789	-3.3656	-1.0722
27%	2.8111	-3.3656	-4.2789	-1.9856
42%	5.1044	-1.0722	-1.9856	-4.2789

Positive values show pairs of means that are significantly different.

Connecting Letters Report

Level			Mean
6%	A		42.180000
16%		B	36.003333
27%		B	35.090000
42%		B	32.796667

Levels not connected by same letter are significantly different.

Ordered Differences Report

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
6%	42%	9.383333	1.336174	5.10444	13.66222	0.0005*
6%	27%	7.090000	1.336174	2.81111	11.36889	0.0032*
6%	16%	6.176667	1.336174	1.89778	10.45556	0.0074*
16%	42%	3.206667	1.336174	-1.07222	7.48556	0.1544
27%	42%	2.293333	1.336174	-1.98556	6.57222	0.3757
16%	27%	0.913333	1.336174	-3.36556	5.19222	0.9005

BSGC ANOVA ANALYSIS FOR A* VALUES

Oneway Analysis of a* By Treatment

Oneway Anova

Summary of Fit

Rsquare	0.128777
Adj Rsquare	-0.21971
Root Mean Square Error	0.913856
Mean of Response	8.894
Observations (or Sum Wgts)	15

Analysis of Variance

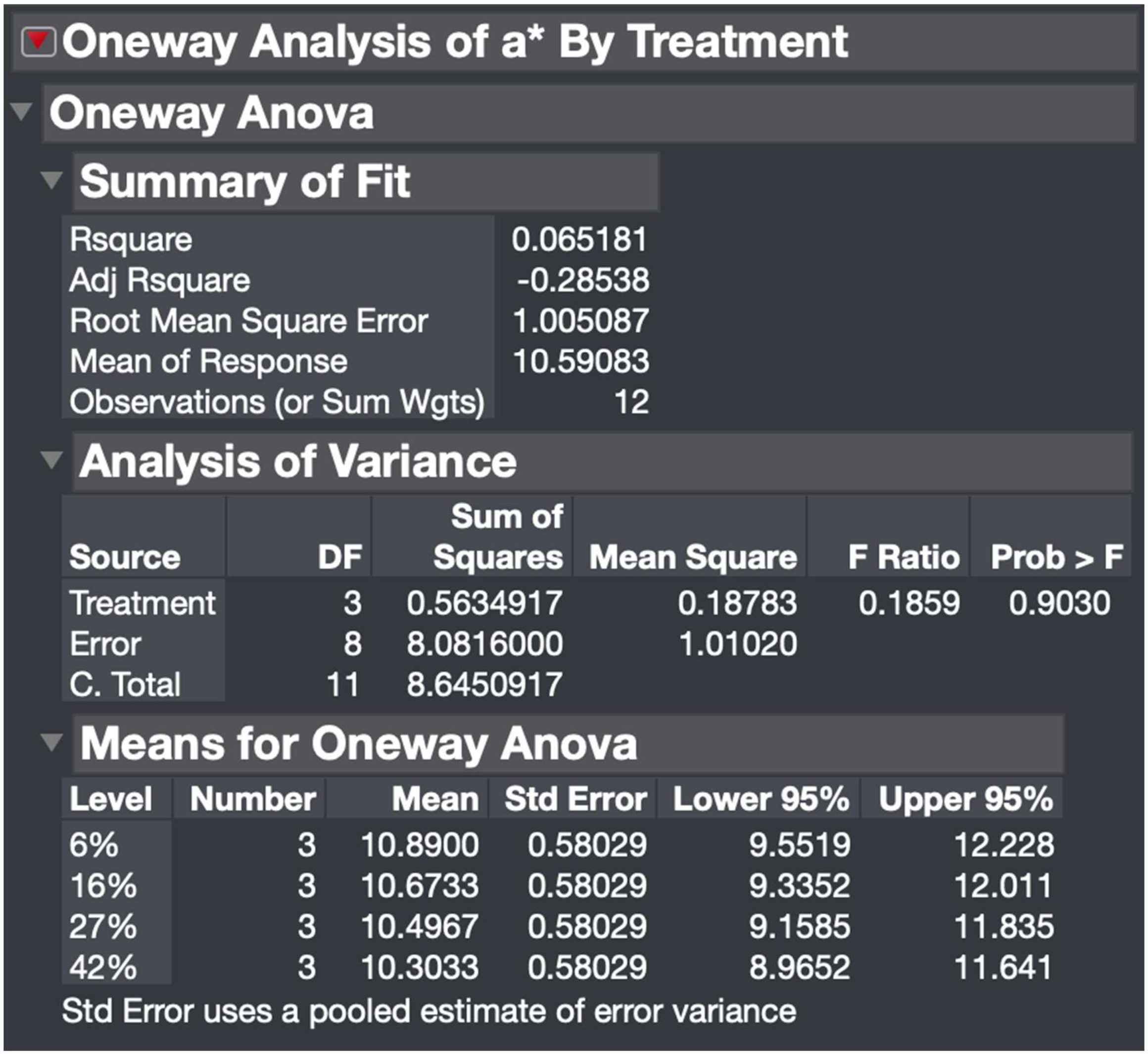
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	4	1.2344267	0.308607	0.3695	0.8251
Error	10	8.3513333	0.835133		
C. Total	14	9.5857600			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
8%	3	8.40000	0.52762	7.2244	9.576
18%	3	8.85333	0.52762	7.6777	10.029
24%	3	9.16000	0.52762	7.9844	10.336
32%	3	8.85667	0.52762	7.6811	10.032
40%	3	9.20000	0.52762	8.0244	10.376

Std Error uses a pooled estimate of error variance

BSG+SPC ANOVA ANALYSIS FOR A* VALUES



Oneway Analysis of a* By Treatment

Oneway Anova

Summary of Fit

Rsquare	0.065181
Adj Rsquare	-0.28538
Root Mean Square Error	1.005087
Mean of Response	10.59083
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	0.5634917	0.18783	0.1859	0.9030
Error	8	8.0816000	1.01020		
C. Total	11	8.6450917			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
6%	3	10.8900	0.58029	9.5519	12.228
16%	3	10.6733	0.58029	9.3352	12.011
27%	3	10.4967	0.58029	9.1585	11.835
42%	3	10.3033	0.58029	8.9652	11.641

Std Error uses a pooled estimate of error variance

BSGC ANOVA ANALYSIS FOR B* VALUES

Oneway Analysis of b* By Treatment

Oneway Anova

Summary of Fit

Rsquare	0.652296
Adj Rsquare	0.513214
Root Mean Square Error	1.004145
Mean of Response	18.04467
Observations (or Sum Wgts)	15

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	4	18.915907	4.72898	4.6900	0.0217*
Error	10	10.083067	1.00831		
C. Total	14	28.998973			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
8%	3	17.0867	0.57974	15.795	18.378
18%	3	19.1867	0.57974	17.895	20.478
24%	3	19.5767	0.57974	18.285	20.868
32%	3	17.5500	0.57974	16.258	18.842
40%	3	16.8233	0.57974	15.532	18.115

Std Error uses a pooled estimate of error variance

BSG+SPC ANOVA ANALYSIS FOR B* VALUES

Oneway Analysis of b* By Treatment

Oneway Anova

Summary of Fit

Rsquare	0.686781
Adj Rsquare	0.569324
Root Mean Square Error	1.514604
Mean of Response	19.46667
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	40.240067	13.4134	5.8471	0.0205*
Error	8	18.352200	2.2940		
C. Total	11	58.592267			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
6%	3	22.4367	0.87446	20.420	24.453
16%	3	19.4667	0.87446	17.450	21.483
27%	3	18.2833	0.87446	16.267	20.300
42%	3	17.6800	0.87446	15.663	19.697

Std Error uses a pooled estimate of error variance

BSG+SPC TUKEY- KRAMER HSD FOR B* VALUES

Oneway Analysis of b* By Treatment

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

q*	Alpha
3.20234	0.05

HSD Threshold Matrix

Abs(Dif)-HSD

	6%	16%	27%	42%
6%	-3.9602	-0.9902	0.1931	0.7964
16%	-0.9902	-3.9602	-2.7769	-2.1736
27%	0.1931	-2.7769	-3.9602	-3.3569
42%	0.7964	-2.1736	-3.3569	-3.9602

Positive values show pairs of means that are significantly different.

Connecting Letters Report

Level			Mean
6%	A		22.436667
16%	A	B	19.466667
27%		B	18.283333
42%		B	17.680000

Levels not connected by same letter are significantly different.

Ordered Differences Report

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
6%	42%	4.756667	1.236669	0.79643	8.716906	0.0205*
6%	27%	4.153333	1.236669	0.19309	8.113573	0.0402*
6%	16%	2.970000	1.236669	-0.99024	6.930239	0.1541
16%	42%	1.786667	1.236669	-2.17357	5.746906	0.5090
16%	27%	1.183333	1.236669	-2.77691	5.143573	0.7765
27%	42%	0.603333	1.236669	-3.35691	4.563573	0.9596

BSGC ANOVA ANALYSIS FOR HUE ANGLE

Oneway Anova

Summary of Fit

Rsquare	0.51277
Adj Rsquare	0.317878
Root Mean Square Error	3.255683
Mean of Response	62.90267
Observations (or Sum Wgts)	15

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	4	111.55076	27.8877	2.6310	0.0979
Error	10	105.99473	10.5995		
C. Total	14	217.54549			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
8%	3	63.7667	1.8797	59.579	67.955
18%	3	65.0700	1.8797	60.882	69.258
24%	3	64.9000	1.8797	60.712	69.088
32%	3	63.1367	1.8797	58.949	67.325
40%	3	57.6400	1.8797	53.452	61.828

Std Error uses a pooled estimate of error variance

BSG+SPC ANOVA ANALYSIS FOR HUE ANGLE

Oneway Anova

Summary of Fit

Rsquare	0.523236
Adj Rsquare	0.34445
Root Mean Square Error	2.043669
Mean of Response	61.3
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	36.669533	12.2232	2.9266	0.0998
Error	8	33.412667	4.1766		
C. Total	11	70.082200			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
6%	3	64.1267	1.1799	61.406	66.848
16%	3	61.3333	1.1799	58.612	64.054
27%	3	60.1367	1.1799	57.416	62.858
42%	3	59.6033	1.1799	56.882	62.324

Std Error uses a pooled estimate of error variance

DATA ANALYSIS FOR FORCE FRACTURE

BSGC ANOVA ANALYSIS FOR FRACTURE FORCE

Oneway Analysis of Fracture Force By Treatment

Oneway Anova

Summary of Fit

Rsquare	0.703508
Adj Rsquare	0.584911
Root Mean Square Error	262.2537
Mean of Response	1556.34
Observations (or Sum Wgts)	15

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	4	1631921.5	407980	5.9319	0.0104*
Error	10	687769.8	68777		
C. Total	14	2319691.3			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
8%	3	1203.45	151.41	866.1	1540.8
18%	3	1880.34	151.41	1543.0	2217.7
24%	3	1929.12	151.41	1591.8	2266.5
32%	3	1625.61	151.41	1288.2	1963.0
40%	3	1143.18	151.41	805.8	1480.5

Std Error uses a pooled estimate of error variance

BSGC TUKEY-KRAMER HSD FOR FRACTURE FORCE

Oneway Analysis of Fracture Force By Treatment

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

HSD Threshold Matrix

Abs(Dif)-HSD

	24%	18%	32%	8%	40%
24%	-704.72	-655.93	-401.20	20.96	81.23
18%	-655.93	-704.72	-449.98	-27.83	32.44
32%	-401.20	-449.98	-704.72	-282.56	-222.29
8%	20.96	-27.83	-282.56	-704.72	-644.45
40%	81.23	32.44	-222.29	-644.45	-704.72

Positive values show pairs of means that are significantly different.

Connecting Letters Report

Level				Mean
24%	A			1929.1233
18%	A	B		1880.3400
32%	A	B	C	1625.6067
8%		B	C	1203.4500
40%			C	1143.1800

Levels not connected by same letter are significantly different.

Ordered Differences Report

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
24%	40%	785.9433	214.1292	81.227	1490.660	0.0278*
18%	40%	737.1600	214.1292	32.443	1441.877	0.0395*
24%	8%	725.6733	214.1292	20.957	1430.390	0.0430*
18%	8%	676.8900	214.1292	-27.827	1381.607	0.0612
32%	40%	482.4267	214.1292	-222.290	1187.143	0.2366
32%	8%	422.1567	214.1292	-282.560	1126.873	0.3439
24%	32%	303.5167	214.1292	-401.200	1008.233	0.6313
18%	32%	254.7333	214.1292	-449.983	959.450	0.7572
8%	40%	60.2700	214.1292	-644.447	764.987	0.9984
24%	18%	48.7833	214.1292	-655.933	753.500	0.9993

BSG+SPC ANOVA ANALYSIS FOR FRACTURE FORCE

Oneway Analysis of Fracture Force By Treatment

Oneway Anova

Summary of Fit

Rsquare	0.907033
Adj Rsquare	0.87217
Root Mean Square Error	162.6892
Mean of Response	1120.71
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	3	2065865.2	688622	26.0174	0.0002*
Error	8	211742.2	26468		
C. Total	11	2277607.4			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
6%	3	1681.71	93.929	1465.1	1898.3
16%	3	1123.91	93.929	907.3	1340.5
27%	3	1166.27	93.929	949.7	1382.9
42%	3	510.95	93.929	294.3	727.5

Std Error uses a pooled estimate of error variance

BSG+SPC FRACTURE FORCE TUKEY-KRAMER HSD

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

q*	Alpha
3.20234	0.05

HSD Threshold Matrix

Abs(Dif)-HSD

	6%	27%	16%	42%
6%	-425.38	90.06	132.42	745.38
27%	90.06	-425.38	-383.03	229.94
16%	132.42	-383.03	-425.38	187.58
42%	745.38	229.94	187.58	-425.38

Positive values show pairs of means that are significantly different.

Connecting Letters Report

Level				Mean
6%	A			1681.7133
27%		B		1166.2667
16%		B		1123.9133
42%			C	510.9467

Levels not connected by same letter are significantly different.

Ordered Differences Report

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
6%	42%	1170.767	132.8352	745.383	1596.151	0.0001*
27%	42%	655.320	132.8352	229.936	1080.704	0.0050*
16%	42%	612.967	132.8352	187.583	1038.351	0.0075*
6%	16%	557.800	132.8352	132.416	983.184	0.0128*
6%	27%	515.447	132.8352	90.063	940.831	0.0196*
27%	16%	42.353	132.8352	-383.031	467.737	0.9879

DATA ANALYSIS FOR THE RESPONSES FROM INFORMAL SENSORY EVALUATION

BSGC ANOVA ANALYSIS FOR TEXTURE RESPONSE SAMPLES WITH 3 DIFFERENT BSG INCLUSION LEVELS

Oneway Analysis of Texture By Treatment

Oneway Anova

Summary of Fit

Rsquare	0.614773
Adj Rsquare	0.586237
Root Mean Square Error	0.914897
Mean of Response	3.333333
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	2	36.066667	18.0333	21.5442	<.0001*
Error	27	22.600000	0.8370		
C. Total	29	58.666667			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
8%	10	1.80000	0.28932	1.2064	2.3936
18%	10	3.90000	0.28932	3.3064	4.4936
40%	10	4.30000	0.28932	3.7064	4.8936

Std Error uses a pooled estimate of error variance

BSGC TUKEY- KRAMER HSD FOR TEXTURE RESPONSE SAMPLES WITH 3 DIFFERENT BSG INCLUSION LEVELS

Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

q*	Alpha
2.47942	0.05

HSD Threshold Matrix

Abs(Dif)-HSD

	40%	18%	8%
40%	-1.0145	-0.6145	1.4855
18%	-0.6145	-1.0145	1.0855
8%	1.4855	1.0855	-1.0145

Positive values show pairs of means that are significantly different.

Connecting Letters Report

Level			Mean
40%	A		4.3000000
18%	A		3.9000000
8%		B	1.8000000

Levels not connected by same letter are significantly different.

Ordered Differences Report

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
40%	8%	2.500000	0.4091545	1.48554	3.514465	<.0001*
18%	8%	2.100000	0.4091545	1.08554	3.114465	<.0001*
40%	18%	0.400000	0.4091545	-0.61446	1.414465	0.5970

BSGC ANOVA ANALYSIS FOR FLAVOR RESPONSE SAMPLES WITH 3 DIFFERENT BSG INCLUSION LEVELS

Oneway Analysis of Flavor By Treatment

Oneway Anova

Summary of Fit

Rsquare	0.068421
Adj Rsquare	-0.00058
Root Mean Square Error	0.661088
Mean of Response	3.666667
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	2	0.866667	0.433333	0.9915	0.3841
Error	27	11.800000	0.437037		
C. Total	29	12.666667			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
8%	10	3.60000	0.20905	3.1711	4.0289
18%	10	3.90000	0.20905	3.4711	4.3289
40%	10	3.50000	0.20905	3.0711	3.9289

Std Error uses a pooled estimate of error variance

BSGC ANOVA ANALYSIS FOR PURCHASE RESPONSE SAMPLES WITH 3 DIFFERENT BSG INCLUSION LEVELS

Oneway Analysis of Purchase By Treatment

Oneway Anova

Summary of Fit

Rsquare	0.597587
Adj Rsquare	0.567779
Root Mean Square Error	0.83666
Mean of Response	2.966667
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	2	28.066667	14.0333	20.0476	<.0001*
Error	27	18.900000	0.7000		
C. Total	29	46.966667			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
8%	10	1.60000	0.26458	1.0571	2.1429
18%	10	3.60000	0.26458	3.0571	4.1429
40%	10	3.70000	0.26458	3.1571	4.2429

Std Error uses a pooled estimate of error variance

BSGC TUKEY- KRAMER HSD FOR PURCHASE RESPONSE SAMPLES WITH 3 DIFFERENT BSG INCLUSION LEVELS

Oneway Analysis of Purchase By Treatment

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

q*	Alpha
2.47942	0.05

HSD Threshold Matrix

Abs(Dif)-HSD

	40%	18%	8%
40%	-0.9277	-0.8277	1.1723
18%	-0.8277	-0.9277	1.0723
8%	1.1723	1.0723	-0.9277

Positive values show pairs of means that are significantly different.

Connecting Letters Report

Level			Mean
40%	A		3.7000000
18%	A		3.6000000
8%		B	1.6000000

Levels not connected by same letter are significantly different.

Ordered Differences Report

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
40%	8%	2.100000	0.3741657	1.17229	3.027713	<.0001*
18%	8%	2.000000	0.3741657	1.07229	2.927713	<.0001*
40%	18%	0.100000	0.3741657	-0.82771	1.027713	0.9614

BSG+SPC ANOVA ANALYSIS FOR TEXTURE RESPONSE SAMPLES WITH 3 DIFFERENT BSG INCLUSION LEVELS

Oneway Analysis of Texture By Treatment

Oneway Anova

Summary of Fit

Rsquare	0.055675
Adj Rsquare	-0.01428
Root Mean Square Error	1.278019
Mean of Response	3.9
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	2	2.600000	1.30000	0.7959	0.4615
Error	27	44.100000	1.63333		
C. Total	29	46.700000			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
16%	10	3.80000	0.40415	2.9708	4.6292
27%	10	3.60000	0.40415	2.7708	4.4292
42%	10	4.30000	0.40415	3.4708	5.1292

Std Error uses a pooled estimate of error variance

BSG+SPC ANOVA analysis for flavor response samples with 3 different BSG inclusion levels

Oneway Analysis of Flavor By Treatment

Oneway Anova

Summary of Fit

Rsquare	0.053821
Adj Rsquare	-0.01627
Root Mean Square Error	1.041722
Mean of Response	3.633333
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	2	1.666667	0.83333	0.7679	0.4738
Error	27	29.300000	1.08519		
C. Total	29	30.966667			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
16%	10	3.30000	0.32942	2.6241	3.9759
27%	10	3.80000	0.32942	3.1241	4.4759
42%	10	3.80000	0.32942	3.1241	4.4759

Std Error uses a pooled estimate of error variance

BSG+SPC ANOVA analysis for purchase response samples with 3 different BSG inclusion levels

Oneway Anova

Summary of Fit

Rsquare	0.020408
Adj Rsquare	-0.05215
Root Mean Square Error	1.19257
Mean of Response	3.6
Observations (or Sum Wgts)	30

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	2	0.800000	0.40000	0.2812	0.7570
Error	27	38.400000	1.42222		
C. Total	29	39.200000			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
16%	10	3.60000	0.37712	2.8262	4.3738
27%	10	3.40000	0.37712	2.6262	4.1738
42%	10	3.80000	0.37712	3.0262	4.5738

Std Error uses a pooled estimate of error variance

VITA

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Master of Science

Thesis: DEVELOPMENT OF NEW CHIP PRODUCTS FROM BREWER'S SPENT GRAIN

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