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Thokachichu, Sadhana. ***Optimization of Brewers Spent Grain Fortification to Develop Value-Added Breakfast Cereal Using a Single Screw Extrusion Process Based on Physicochemical, Nutritional, and Sensory Properties***

Abstract

The brewers spent grain (BSG) is a food waste (byproduct) of the brewing industry produced after wort production in the brewing process. It contains approximately 20% protein and 70% fiber. Currently, BSG is primarily utilized as animal feed or disposed of as a landfill, but it has great potential for utilization in the food sector because of its nutritional composition and health benefits. Therefore, the study's main goal was to optimize the maximum BSG levels in extruded breakfast cereal made of soya, rice, and quinoa flour blend along with other ingredients. The formulation of extrudates was varied with 0,5,10, 20, and 30% of BSG to develop five different extrudates. The physicochemical, nutritional, and sensory properties of those exudates were determined. To evaluate consumer acceptability. The results reveal that the fortification of BSG in the cereal mixture had increased protein, fiber, ash content, hardness, color L-value, color difference and piece density whereas decreased the expansion ratio, porosity, crispiness, lipid content, water-soluble index, and rehydration ratio significantly (p<0.05). The results also revealed that the true density, water activity, and moisture content of the examined samples did not differ significantly (p>0.05). The sensory analysis revealed that 10 -20% BSG could be added to extrudate formulation which improved the overall acceptability by the consumers. The findings of this study are expected to help in finding a sustainable solution for the brewing processing industry by producing nutritionally dense breakfast cereals.

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Chapter I: Introduction

The most prominent solid byproduct of the barley brewing process is BSG. It is expected to be generated more than 38 million tons per year with most of it being utilized as animal feed or disposed of in landfills. These wastes are difficult for manufacturers to dispose of, but they are appropriate for utilization in the food sector because of their nutritional composition (Rachwał et al., 2020). BSG is considered a protein-rich fibrous diet that can help individuals with mild to severe ulcerative colitis and improve their endoscopic score due to the availability of glutamine-rich protein, non-cellulosic polysaccharides, and soluble dietary fibers (Mussatto, 2013). It has been found to contain around 28% non-cellulosic polysaccharides, predominantly arabinoxylans, 28% lignin, and 17% cellulose. In addition to fiber, oven dried BSG contains 24.2 percent protein, 3.9 percent fat, and 3.4 percent ash (Mussatto, 2013; Santos et al., 2003). Over 9 billion people are anticipated to live on the planet by the year 2050, which will worsen famine. BSG is a low-cost component which is having a high nutritional value and fiber content that may be utilized in food production. Nutritional cereals are becoming increasingly popular as they have a significant link to people's nutritional health. Shelf-stable, nutrient-dense foods are thought to be beneficial for combating malnutrition in underdeveloped countries (Shah et al., 2018). It's important to consider protein- and fiber-rich breakfast cereals as substitutes for the highly processed, carbohydrate-rich cereals that are currently widely accessible in the market. This alternative product helps in providing both macro and micronutrients.

According to Markets & Market Research (Markets and Markets, 2020), the market for gluten-free goods will increase from USD 5.6 billion to USD 8.3 billion by 2025. According to the FAO, the use of composite flour in numerous food items would be economically advantageous if wheat imports could be decreased or even eliminated. Soy, rice, corn, sorghum, teff, quinoa etc. are some of the less expensive alternatives to wheat (Moreno et al., 2014). Advanced extrusion technologies have cleared the path for the utilization of a variety of nutrient-dense ingredients in the creation of appealing goods. High-temperature short-time process in the production of fiber-rich food is critical. It gives the user a lot of control over the processing settings, which significantly affects the output quality of finished products (Leonard et al., 2019). Extruded foods' functional qualities, which include water absorption index, the expansion ratio of product to die, piece density, texture, and porosity play a vital influence in their acceptance (Alam et al., 2016).

There are several studies conducted to incorporate spent grain into food systems which did not give satisfactory results with incorporation levels above 10% as flavor, sweetness, and sensory properties got adverse impacts (Öztürk et al., 2012; Waters et al., 2012; Sobukola et al., 2012). Few reports utilize brewers' grain in developing extruded snacks and bakery products prepared with flour mixture made of single cereal grains such as rice, wheat, or maize. Therefore, this study is conducted with a hypothesis to optimize the best maximum BSG levels to add to an extruded breakfast cereal made from a combination of soy, rice, and quinoa flour. And study all the required functional properties of the product to evaluate consumer acceptability. The study mainly aims to extrudate products with higher nutritional content and outstanding sensory characteristics which can be a sustainable solution for the brewing processing industry.

Statement of the Problem

In this modern living, people are looking for quick foods which will soothe their taste buds, reduce their hunger, and provide the required nutrition, especially protein and fiber. But the problem is that existing cereals are lacking dense nutrition and have certain drawbacks in terms of health aspects like high sugar content. With the increase in health concerns like diabetes, obesity, and digestive disorders customers are choosing healthy alternatives. Due to ever-changing customers' needs and interests, we as food scientists also need to evolve and create food rich in nutrition with protein and fiber. Currently, available nutrient-dense products in the market are of premium cost due to processing technology, and usage of healthy, organic, non-GMO raw materials. But the cost of such products is reduced through byproduct utilization in food industries.

Purpose of the Study

1. To develop a nutrition (protein and fiber) rich breakfast cereal without compromising on sensory and taste aspects and optimizing the best formula
2. To understand the BSG potential to use as a value-added product in breakfast cereal development by studying the product's physicochemical properties, nutritional properties, and sensory properties.
3. To research how extrusion settings affect the product's functional qualities.

Assumptions of the Study

1. Change in customers' food habits and increase in the market for healthier options, especially high-protein foods.
2. Vacuum in breakfast cereal market in providing healthy alternative options and there is scope for innovation.
3. Study might be susceptible to the fluctuation of temperature the in extruder and drier.

Limitations of the Study

1. Fewer formulation combinations were tested by incorporating 5 levels of BSG to conclude the best level.

2. Time taking and high energy consumption of preprocessing BSG (Conversion from wet to dry) before adding it into the breakfast cereal formulation.
3. Procurement of Barley BSG is a bottleneck if the supply chain is unorganized.

Chapter II: Literature Review

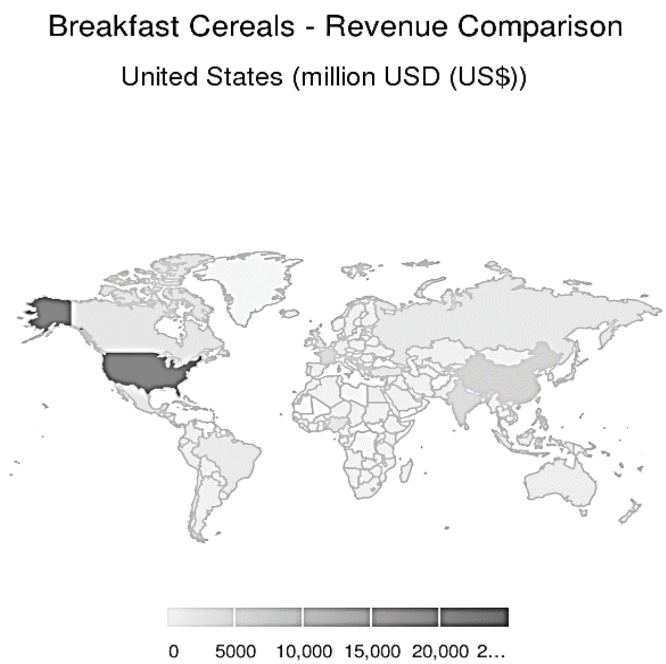
Upcycling the food waste is needed for ever-growing planet. The market for products that are made of industrial waste is expected to grow at a CAGR of 6.2% from 2022-2031. The market value is expected to soar 97 billion in 2031 (Amit, 2023). The usage of the right technology helps in converting industrial waste into world-class products. The products can be nutritious, versatile, delicious, and functional depending on the processing conditions and pretreatments. However, value-added foods are not cost-effective as conventional foods. Nutritional loss during the primary processing of the material is the flip side of the utilization aspect (Moshtaghian et al., 2021). Therefore, there is a significant scope of research in this area to explore and find ways to incorporate valuable waste into the food system which improves food security.

Overview of Breakfast Cereal Products

Cooked cereals like wheat, oat, and barley in the form of porridge is very popular in many countries and has been for hundreds of years. The ready-to-eat cereals gained popularity is new and gained popularity in later years. The first breakfast cereal was produced by W.K Kellogg in the United States. Today the consumption of breakfast cereals is about 3 million tons word wide. The popularity of breakfast cereals is due to their nutritional value, it can provide about 300-400 KCal/100g. With the raising concerns on health and nutrition today food consumers designers and manufacturers are giving importance to the food that provides health benefits. This led to the innovation happening by incorporating functional (dietary fiber) and nutritional components like Vitamins and minerals (Lorenz & Kulp, 1991). As shown in Figure 1 the top five countries that generated the most revenue in 2022 are the United States 20,590.00, China 5,615.00, India 4,151.00, France 4,098.00, and Canada 2,041.00. Compared to other countries, the United States generates the most revenue ($20,590.00m in 2022) (Statista, 2023).

Figure 1

Worldwide Revenue Comparison of Breakfast Cereals



Note. Source: Statista, "Breakfast Cereals", Retrieved October 17, 2022. https://www.statista.com/outlook/cmo/food/bread-cereal-products/breakfast-cereals/worldwide

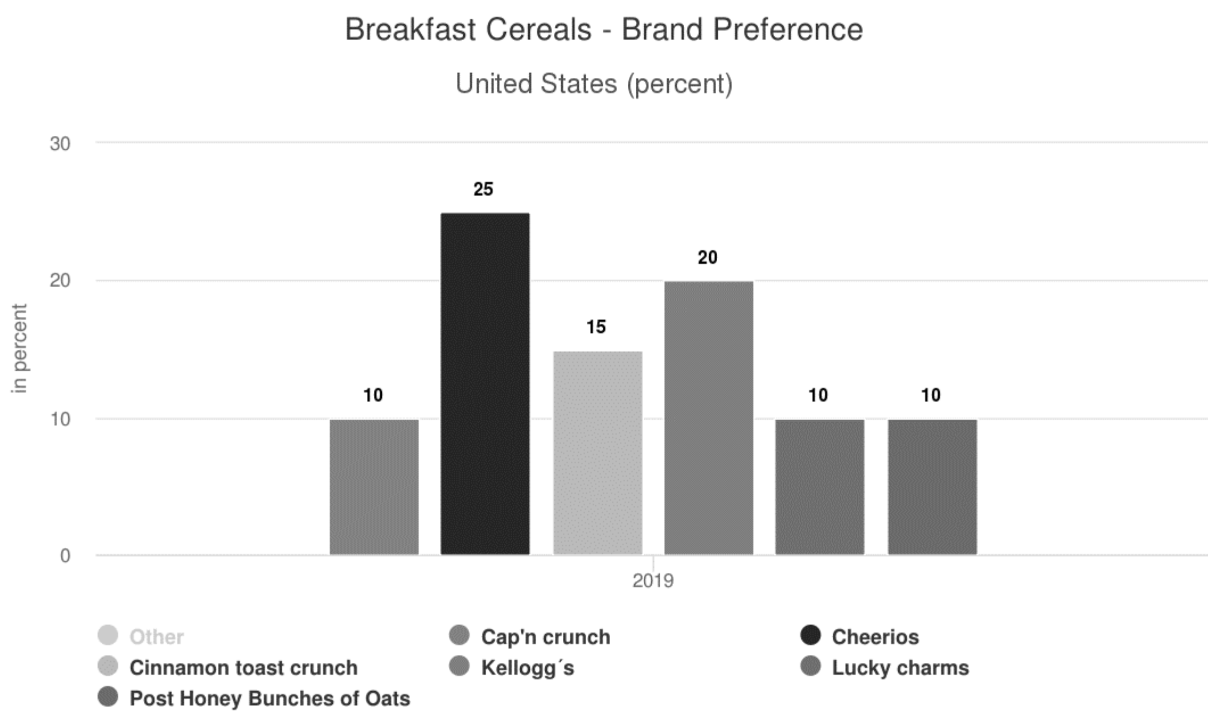
Market

A bowl of cereal is not just the food to break the fast rather it is consumed as a meal for lunch or dinner by half of the American public (Hislop, 2017). But it's more likely the RTE cold cereal Category over the hot cereal contributed to the sales according to Information Resources, Inc. The breakfast Cereal market is an Oligopoly. There are only fewer companies that dominate this segment (Nevo, 2003). that About 79% of sales in 2017 are from food companies like

Kellogg's, General Mills and Post as seen in Figure 2. They dominate most of the cereal market. Cheerios brand manufactured by General Mills is popular and accounts for about 25% share in brand preference by customers according to a study followed by Kellogg's as the second most popular brand that is preferred by customers.

Figure 2

Breakfast Cereal Brand Preference in the Year 2019



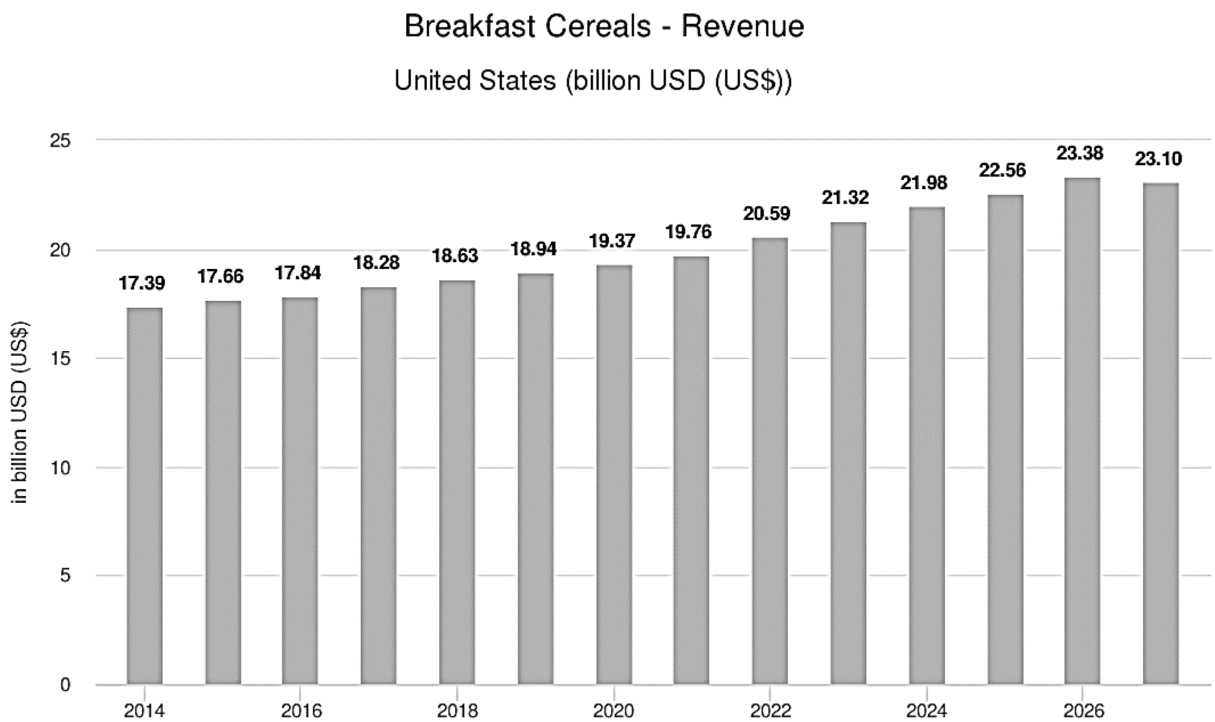
Note. Source: Statista, "Breakfast Cereals" as, Retrieved October 17, 2022. https://www.statista.com/outlook/cmo/food/bread-cereal-products/breakfast-cereals/worldwide

Statistics

In 2022, the Breakfast Cereals market will generate $20.59 billion in revenue (Figure 3). The market is anticipated to expand by 2.33% yearly according to compound annual growth rate 2022-2027 from (Statista, n.d.). Despite the healthy figures and continuous growth, there is a decline in the popularity of cereals. This might be due to a decline in dairy consumption in households. And turn away from protein over carbohydrates. It can also be because of sugar; the cereal industry is the largest player in sugar consumption. The sugar-to-cereal ratio is 1:3. To counter the decline and increase varieties the companies are introducing healthier options to consumers.

Figure 3

Average Revenue of Breakfast Cereal Generated at Different Years



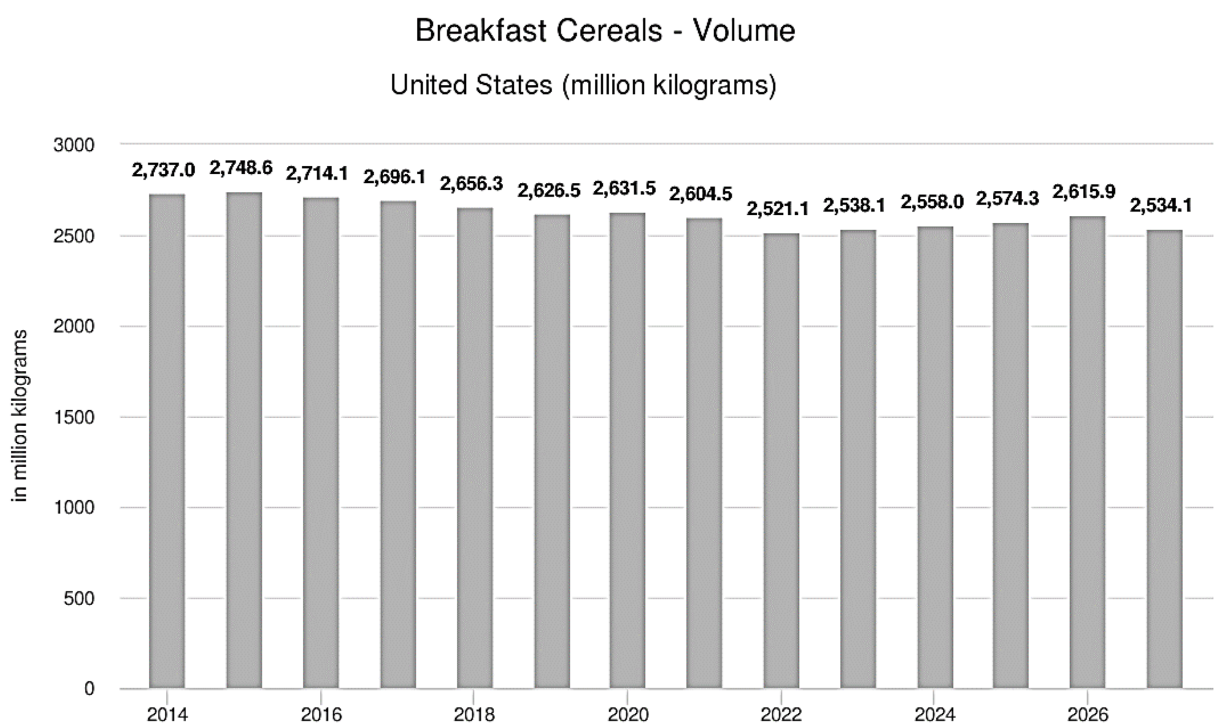
Note. Source: Statista, “Breakfast Cereals”, Retrieved October 17, 2022.

https://www.statista.com/outlook/cmo/food/bread-cereal-products/breakfast-cereals/worldwide

As shown in figure 4 by 2027, the volume of breakfast cereals is anticipated to reach 2,534.1 million kilograms. In 2023, it is anticipated that the breakfast cereals market will have a volume growth of 0.7%. In 2022, per-person earnings of US$61.51 are produced based on population statistics.

Figure 4

Average Amount of Sales of Breakfast Cereals at Different Years

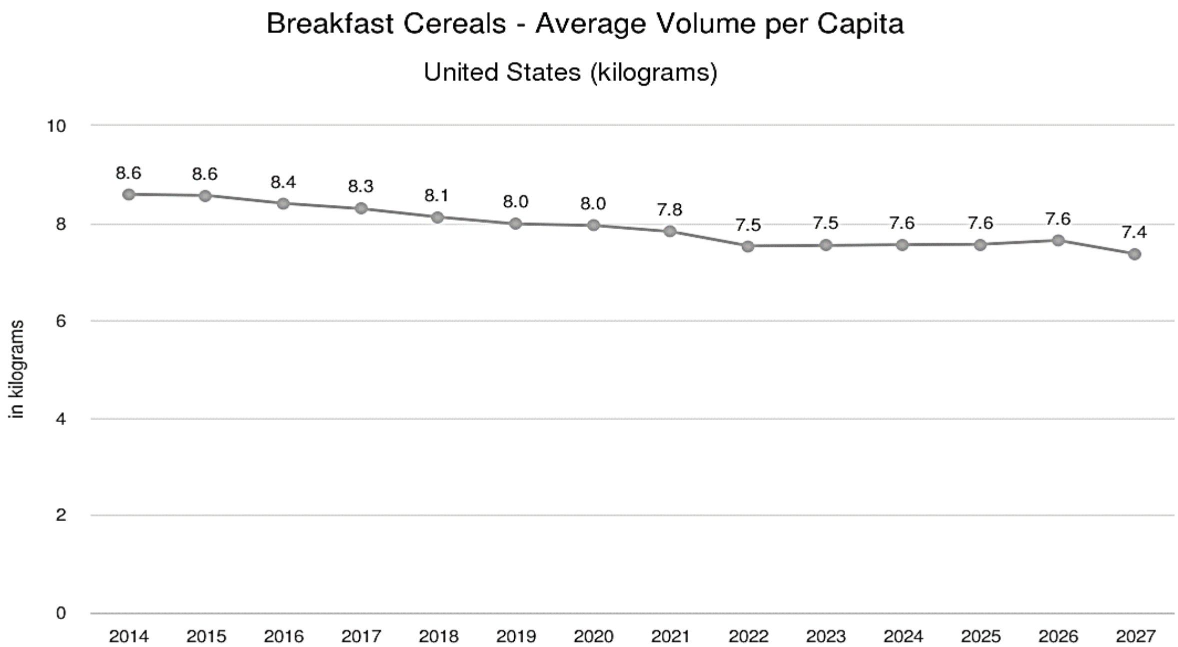


Note. Source: Statista, “Breakfast Cereals”, Retrieved October 17, 2022. https://www.statista.com/outlook/cmo/food/bread-cereal-products/breakfast-cereals/worldwide

In the category of breakfast cereals, in 2022, the volume of consumption for each person is projected to reach kilograms. As shown in figure 5 and Table 1 the average unit price of the cereal tends to be increased every year. The sale channels also impact the growth of the product, and it observed that purchases online are increasing day by day which is 3.1% and is anticipated to increase to 7.2% by 2025. And interestingly the mode of online purchase being mobile is gaining popularity according to Statista the leading provider of consumer and market data.

Figure 5

Average Unit Price of Breakfast Cereal



Note. Source: Statista, "Breakfast Cereals", Retrieved October 17, 2022.

https://www.statista.com/outlook/cmo/food/bread-cereal-products/breakfast-cereals/worldwide

Table 1

Average Unit Price of Breakfast Cereal

Year	Average Unit Price
2014	6.35
2015	6.42
2016	6.57
2017	6.78
2018	7.01
2019	7.21
2020	7.36
2021	7.59
2022	8.17
2023	8.40
2024	8.59
2025	8.76
2026	8.94
2027	9.12

Note. Source: Statista, “Breakfast Cereals”, Retrieved October 17, 2022.

https://www.statista.com/outlook/cmo/food/bread-cereal-products/breakfast-cereals/worldwide

Nutrition

Most of the cereals are highly processed with high added sugars, trans fat, less protein, and fiber. One of the major brands of breakfast cereals Kellogg’s has released nutritional information for all its cereal products. The data shows that most of them have 1.4-6.8% of protein and less than 7% of fiber content except for bran varieties and more than 12% of added sugars (see Appendix). A few special cereals like Nutri-Grain, Special K, and All Bran, have very high protein and fiber under Kellogg’s. Therefore, there is need to develop healthy alternate cereals that can provide more health benefits. The potential for enrichment in cereal is a crucial factor as it helps to eliminate or greatly reduce several dietary deficits in the United States.

Ingredients for Cereal Products

Most of the cereals are made using cereal grains, since cereal goods are frequently the sole food eaten during breakfast, they are vitamins and minerals used as a supplement to boost the nutrient benefit. Additives are added to change the textural characteristics and sensory and functional properties improvement. Inclusion of a precise portion of the daily intake for adults based on these substances. Some of the cereals used for making include wheat, oat, corn, rice in the form of flakes, puffed, shredded, granules, granola etc. Some of the commonly used additives in cereal products include dextrose, dicalcium phosphate, disodium phosphate, ferric phosphate, fructose, gelatin, glycerin, guar gum, gum arabic, inverted sugar, lecithin, malic acid, modified corn starch, maltodextrins, monosodium dihydrogen phosphate, oils or fats, papain, salt, sodium alginate, sodium bicarbonate, and sorbitol (Lorenz and Kulp, 1991). A conventional flaked cereal might contain 90% cereal ingredients plus 8% sugar, 1% malt, and 1% salt in its formulation. Multiple bowls of cereal have been used in recently produced flaked breakfast cereals. Combinations of formulations and cereals with other grain seeds, like soybean. R&D on gluten-free products has increased significantly in recent years. To reduce the likelihood of these sensory abnormalities, food manufacturers typically add additives, some of which can be sources of sodium (Cindy Beeren, 2019). The addition of the usually deficient vitamins B1, B2, B3, and B9 to grain flour is also naturally practiced (Garg et al., 2021).

Byproducts

The country's overall economy is heavily influenced by the ineffective utilization of byproducts and improper disposal of garbage. The evolution of the food industry is significantly influenced by the beneficial components found in agricultural byproducts, such as healthful bioactive compounds, flavoring compounds, phytochemicals, and proteins, lipids, and fibers.

Most of the waste is produced in various food industries like dairy, fruit and vegetable, grain processing, brewing, winery, marine, and meat industries. Fruit and vegetable processing food wastes include trimmings left over after oil, starch, juice, and sugar extraction, as well as peelings, stems, seeds, and shells (Helkar et al., 2016)**.** The number of byproducts produced from processing tropical exotic crops may be comparable to or even greater than that of the respective valued product, which will have an impact on how profitable it is to grow tropical exotic crops (Ayala-Zavala et al., 2011)**.**

Utilization of Brewery Byproduct

The brewing sector is discharging a significant amount of waste with about 137–173 tons of solids waste per 1000 tons of beer. BSG comprises up to 85% of all brewery waste. The use of BSG protein in health and nutrition is of special interest because of its great nutritional value, notably in terms of protein content (Naibaho & Korzeniowska, 2021). Different protein contents according to different authors are shown table 2. BSG typically contains 20% protein, 70% fiber, 3-12% starch, and 3-6% fats. Since most of the starch in regular barley is removed during the mashing phase of brewing, BSG lacks most of it. Protein extraction from the BSG was aided by several pre-treatments including shearing, enzymatic treatment, ultrasonication, pulsed electric field, and hydrogen peroxide use. It is difficult to transport and store BSG since it has a high-water content (77-81%) at the place of manufacturing. Drying and the use of preservatives contributed to extending stability (Jaeger et al., 2021; Mussatto et al., 2006). BSG is mostly used in food categories like biscuits, bread, snacks, and beverages.

Table 2

Protein Content of BSG According to Various Literatures

Sources	Protein content of BSG (%) w/w dry material
Meneses et al (2013)	24
Santos et al (2003)	31
Mussato and Roberto (2006)	15
Xiros et al (2008)	14
Waters et al (2012)	22
Celus et al (2006)	27
Kanauchi et al (2001)	23

Note. Source: Jaeger et al., 2021. https://doi.org/10.3390/foods10061389

According to the study conducted by waters BSG has an essensial amino acid Histadine in highest percentage while in barley whole grain it is lysine. The other amino acids and percentages are shown in table 3.

Table 3

Some Essential Amino Acids and Non-Essential Amino Present

Amino acids	BSG %	Barley %
Lysine	14.31	2.52
Leucine	6.12	0.3
Phenylalanine	4.64	0.2
Isoleucine	3.31	0.17
Histidine	26.27	1.59
Glutamic acid	16.59	0.85
Aspartic acid	4.81	0.19
Valine	4.61	0.23
Arginine	4.51	0.21
Alanine	4.12	0.22

Note. Source: Waters et al., 2012. https://doi.org/10.1007/s00217-012-1805-9

Technology in Cereal Processing

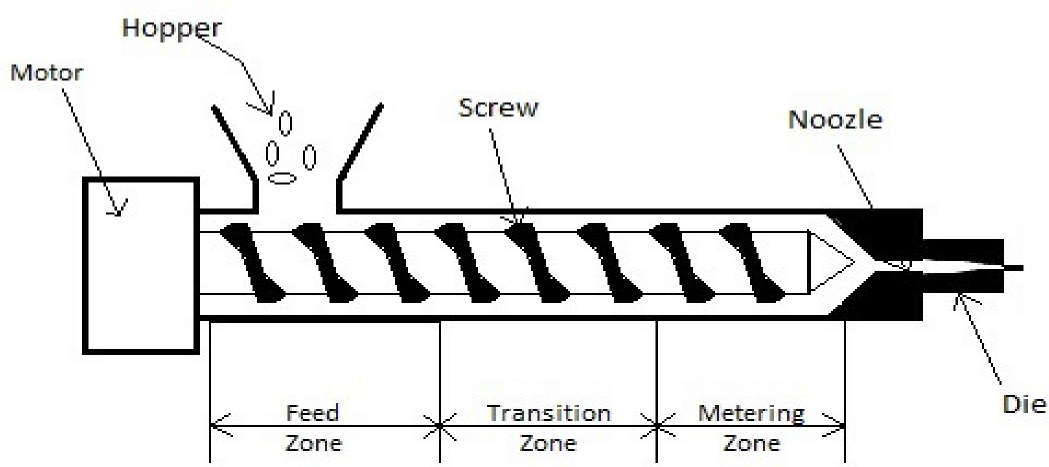
We need to examine the production processes for each type of cereal to better comprehend the technology and equipment used by the cereal manufacturing sector. the most popular form of cereal is flakes. The grain is allowed to cook and temper. The grains are then air-dried after being flattened between two big metal rollers under intense pressure. For puffing, the grain is allowed to soak and flatten before puffing. After being dried, the slightly flattened rice is put in an extremely hot oven to expand called guns. The extruded pellets or grain are first tempered and then rolled between two solid rollers to create shredded cereal. The rollers used have one flat and the other roller has grooves. All the ingredients like nuts, fruits, flavors, oil, and sweetener are heated and bound together to form granola. These are then broken into the required size. Another continuous method used for manufacturing is extrusion. It transforms the fundamental dense grain compositions into crisp and light things that are nourishing and enjoyable to people (Fast & Caldwell, 1990, chapter 2).

Extrusion History and Overview

With a long history spanning from the food industry to the manufacture of rubber and plastics, screw extrusion is today used in a variety of industries, including compounding, fiber spinning, film production, blow molding, and injection molding. Sausages were first produced using extruders in the 1870s. The 1930s saw the development of the single-screw extruder, which was used to manufacture pasta by combining semolina flour and water. It was also used to form hot, precooked dough while producing ready-to-eat cereals. The shear rate was minimal in both instances. Expanded corn products were produced in the late 1930s and early 1940s utilizing extruders, which had very high shear rates. In the middle of the 1950s, the first patent for a twin-screw extrusion application was submitted. Since then, there has been a significant advancement, expansion, and growth in the use of extrusion techniques in the food processing industry (Choton et al., 2020)**.** Consumers today prefer quick, easy-to-prepare meals that are therapeutically effective and nutrient-dense. Thus, extrusion technology is employed to satisfy consumer demand. Because it is one of the most economical methods, extrusion technology has grown in importance in the food processing industries (Sakai, 2013). Extruders consist of five major components: The systems shown in Figure 6 include: a) the motor, b) the pre-conditioning unit, c) the hopper, c) the screw, d) the barrel, e) the die, and f) the cutter.

Figure 6

Schematic View of Extruder Machine



Note. Source: Chaturvedi et al., 2017. https://doi.org/10.1016/j.matpr.2017.02.006

Principle of Extrusion Technology

The single-screw extruder and the twin-screw extruder are the two types of hot extruders available for extruded food products. Single-screw extruders are the most frequently used extruders in the food industry. Process or equipment characteristics can be used to define single-screw extruders, such as the amount of conditioning moisture (dry or wet), whether the screw is solid or segmented, the required amount of shear, and the heat source. Twin-screw extruders are used for manufacturing products with higher concentrations of ingredients including moisture fibers, lipids, and other ingredients. (Maskan & Altan, 2012). Feed material is transferred to the extruder during the extrusion process using a screw feeder and ends up in the feeding zone. The primary functions of the screw in this zone are to transport and homogenize the raw material while also exhibiting increasing depth & pitch of a screw flight. The material is transported. Reduced screw depth and pitch in the compression zone are accompanied by a rise in shear rate, temperature (110–180°C), and pressure (20–30 atm). In this region, the transition from a solid to a liquid melt begins to take place. When the material is ejected through the die under high pressure and encounters atmospheric temperature and pressure, it expands to take on its final form and quickly cools through water flash-off. (Maurya & Said, 2014)

Processing Variable

Extrusion is a method of processing food that combines several unit activities, such as blending, kneading, cooking, shearing, reshaping, and forming, to enhance the value of food commodities. Extrusion cooking is a high-temperature and pressure combination cooking method wherein the combined effects of ideal moisture content and product components rapidly cook food ingredients in a barrel. Raw material composition feed rate, length and diameter ratio of a barrel**,** screw profile, residence time, temperature, pressure, die cutting speed, die design, and physical shear also affect the process. Extrusion causes molecular transitions, textural changes, gelatinization, protein degradation, and bond disruption, which produces foods with novel shapes and textures (Sobowale et al., 2018; Frame, 1995)**.**

Formulation

Different sources of starches, milk-based products, non-gluten proteins, gums, probiotics and emulsifiers, prebiotics, and combinations of gluten substitutes, and a variety of approaches have been used to enhance the acceptability, structure, taste, and shelf life of bakery goods made without gluten (Gallagher et al., 2004). Thorvaldsson (2020) have utilized fermented spent grain up to 30% for developing breakfast cereal. Sobukola et al.,(2012) studied the impacts of 100-110℃ barrel temperature and 100–140 rpm screw speed with brewers spent grain addition of 5-15% level on the functional characteristics of yam-based extruded pasta. The BSG of six malts barley, wheat, Vienna, Munich, Pilsner, and Weyermann carafe malts were measured for starch in the spent grains, the degree of gelatinization, the number of phenolic compounds, and the content of the antioxidant activity.

Quality Parameters

Schwartz et al. (2008) observed the apparent nutritional variations among cereals that are marketed primarily to children vs cereals that are not. Each nutrient's concentration for a gram of cereal was tested for calories, salt, sugar, carbs, fiber, protein, fat, and cholesterol. Loh & Mannell, (1990) explained rheology applications in the breakfast cereal industry. He explained that the product structure and crispy texture of the product are developed due to expansion and drying. A descriptive analysis of a Ready-To-Eat sweet potato breakfast cereal was conducted for sensory Characterization by Dansby & Bovell-Benjamin, (2006). Twelve perceived sensory characteristics were tested to distinguish between sweet potato cereal appearance, texture, and flavor. Kince et al. (2017) test the physical, sensory, and microbiological qualities of breakfast cereals made with sprouted cereal. Limitations were assessed during storage. The key quality indicators like spoilage microbes, moisture content, water activity, and water absorption, as well as the sensory characteristic like taste, flavor, firmness, and appearance, were all analyzed using standard measurements.

Chapter III: Methodology

This chapter deals product development of breakfast cereal along with optimization studies of product formulation, and analytical procedures for measuring the functional and textural properties. Data collection and analysis procedures. It consists of materials and methods used for analyzing and studying various factors related to the objectives of the study.

Materials

Barley spent grain was provided by Leinenkugel Brewer, a Brewing company in Chippewa Falls, WI. Soy flour was brought from Cargill, purchased rice flour from PGP International Inc and quinoa flour was from Bobs Red Mill Natural Foods Inc. Monoglyceride was purchased from Danisco Ingredients (Kansas City, MO), maltodextrin was from Bulk Supplements, baking powder was from ACH Food Companies Inc, soya lecithin was from Texture Star, Canada. Canola oil, milk powder, and sugar were brought from Great Value, and the salt used was of Morton Salt Inc.

BSG Flour Preparation and Breakfast Cereal Formulation

BSG was stored in the freezer until it was dried. The sample was dried in small batches in a preheated Lindberg/Blue M, Model: MO1450SA-1 mechanical oven in a thin layer at 55 ^{o}C overnight to reduce the moisture content from 76 percent to 3 percent. The dried BSG was ground using a Nutri Ninja Pro blender and sieved through a mesh size of 40 (425 µm). Until it is used, the BSG powder is kept at room temperature in polyethylene bags.

The composite flour is substituted by dehydrated BSG flour at different levels (0%,5%,10%, 20%, 30%). Total 5 formulations were prepared as shown in table 4. The flour mixture for extrusion is prepared by weighing and mixing dry ingredients monoglyceride (1%), maltodextrin (4%), baking powder (1%), soya lecithin, milk powder (2%), sugar (5%), and salt

(1%) followed by wet ingredients Canola oil (1%) and water. The moisture of 20% was added to the mixture and blended in a Hobart A-200T Series mixer for 20 minutes before extrusion.

Table 4

The Formulations for Soy Flour, Rice Flour, Quinoa Flour, and BSG Mix Breakfast Cereal

Formulation % wt. basis	Soya	Rice	Quinoa	BSG
F1	33.3	33.3	33.3	0
F2	31.6	31.6	31.6	5
F3	30	30	30	10
F4	26.6	26.6	26.6	20
F5	23.3	23.3	23.3	30

Extrusion

Five formulations were extruded using The American Extrusion International Tiger 20 Bake single screw extruder made in Illinois, USA. Barrel with a 0.241 m length and 0.076 m diameter (3.2:1.0 L/D ratio) and die hole of 3.82 mm diameter. The temperature for extrusion cooking was set to 150°C as the barrel temperature zone and 300 rpm was chosen as the screw speed. The sample was fed manually at approximately a feed rate of 12 kg/h. Extrusion was followed by drying at 80°C for one hour which brings down the moisture content of the product below 5%. Dry extrudates were cooled and packed in polyethylene bags for up until a subsequent product analysis, at room temperature.

Physical Properties

The physical properties of food products are important for consumer appeal, taste, and satisfaction. They also impact shelf life, processing efficiency, and nutrient availability. Controlling these properties ensures high-quality, visually appealing, and nutritious food products.

Expansion Ratio

The Radial expansion is calculated by taking the average diameter of 15 extrudates. To determine the product's cross-sectional diameter, a digital vernier caliper is used. By taking the average diameter of the product (D_e) to the diameter of the die (D_d) the expansion ratio was determined (Zhou et al., 2021).

$$Expansion\ Ratio(ER) = \frac{Extrudate\ diameter(\mathrm{De})}{\text{Diameter of the die(Dd)}}$$

Piece Density

The Piece density of the sample is determined by AACC (2001) method. 10 grams of sample is filled in a 50ml graduated cylinder. Latter rapeseed is filled up to the mark in the cylinder and continuously tapped to ensure there were no air gaps. The volume of the sample is measured by quantifying the displaced volume of rapeseed. Three replicates of the sample are taken, and the value is calculated using the following equation.

$$Piece\ density = \frac{Weight\ of\ extrudates(\mathrm{g})}{\text{Volume of extrudates(mL)}}$$

True Density

True density is measured by grinding the sample to a uniform particle size (250µm). The ground sample is later filled in a 5mL graduated cylinder to measure the volume of the sample and tapped to ensure there are no air pockets. The weight of the sample is divided by the true volume occupied to calculate the value. The experiment is conducted in triplicates (Mitra et al., 2022b; Webb, 2001).

$$True\ density = \frac{Weight\ of\ ground\ extrudates(\mathrm{g})}{\text{Volume (mL)}}$$

Porosity

By dividing the difference between true density and piece density by true density, porosity is determined (Boukouvalas et al., 2006; Thymi et al., 2005).

$$Porosity = \frac{\text{True density} - \text{Piece density}}{\text{True density}}$$

Rehydration Ratio

The rehydration ratio was determined according to the method described (Mitra et al., 2020b; Yu et al., 2012). The experiment was performed at room temperature. The 20g extrudate was rehydrated in 500mL distilled water for 2 hrs. Later the excess water is drained, and the final weight of the sample is measured. The value was calculated using the formula below by calculating the difference in weights, final to the initial weight of the sample (Marabi & Saguy, 2004; Zhou et al., 2021).

$$Rehydration\ Ratio(\%) = \frac{\text{Final weight} - \text{Initial weight}}{\text{Initial weight}} \times 100$$

Water Activity

The Aqua Lab 4TE water activity meter from Decagon was used to measure the water activity of the sample in triplicates. The samples are calculated in triplicates for an accurate reading.

Color

Color is determined by using Hunter *45/0 ColorFlex EZ* colorimeter based on *L, a, and b* values (L stands for lightness/darkness, for color (red/green), and b for color (blue/yellow), respectively). Firstly, the instrument was standardized using white and black tiles and then the Sample is placed in the sample holder to calculate the lightness value(L), and the total difference in color of the product before and after extrusion of the product is measured using the following equation. A sample is measured 20 times and an average is taken for accuracy and precision.

$$\Delta E = \sqrt{(L_0 - L)2 + (a_0 - a)2 + (b_0 - b)2}$$

Water Soluble Index

A slightly modified version of the approach described by (Mitra et al., 2022a) was used to calculate the extrudates' water solubility index (WSI). The 50 mL centrifuge tube was filled with 25 ml of distilled water and two grams of finely ground extrudate material. The samples were constantly mixed in a Sheldon Manufacture 1217 Water Bath at 30 °C for a total of 30 minutes. The solution was then centrifuged inside a Beckman Coulter 6KR Centrifuge at 5000 rpm for 15 minutes. After being removed from the centrifuge tube and weighed over an aluminum dish, the supernatant was dried at 140°C for two hours. The weight of the resulting dry solid was determined, and WSI was calculated repeatedly using the formula below:

$$WSI = \frac{Weight\ of\ solid\ in\ dried\ supernatant}{Weight\ of\ sample} \times 100$$

Proximate Analysis

The proximate composition of extruded breakfast cereal was calculated according to the procedures given by the Association of Official Analytical Chemists (Horwitz & Latimer, 2005). Moisture, Fat, ash, and total nitrogen of the sample with a 6.25 conv3edersion factor was used for determining the protein content of samples. Carbohydrates were calculated by the difference from total nutrients calculated. All were quantified in triplicate for measuring the standard deviation. The results reported were the means of triplicates.

Texture Profile Analysis

Textural properties were measured by using a two-cycle compression test on Instron Machine (Instron Corporation, Norwood, USA) it is the same as used in the Mitra et al. (2019) study. The samples were placed on a cylinder with a 35 mm parallel stainless-steel surface that was coupled to a 500 N load cell. The test was performed at a speed of 1mm/s and the sample was compressed to 40% of strain. (Stojceska et al., 2008). The Force deformation curve was generated to measure hardness and crispiness using the Bluehill 3 software (Sun et al., 2015). The test was repeated 20 times for each sample.

Sensory Analysis

The evaluation was conducted at the sensory lab in Heritage Hall, University of Wisconsin-Stout, Menomonie, Wisconsin. Fifty untrained panelists evaluated the product using the Compusense® program for color, taste, texture, and general acceptability. The Hedonic scale, which ranges from 1 to 5, was used to grade each characteristic, with 1 denoting "Dislike Extremely" and 5 denoting "Like Extremely". Warm milk was offered to each participant to add to their cereal cup before the test. Data was captured using a computer.

Statistical Analysis

The influence of independent variables (level of BSG) on response variables (Expansion Ratios, True Density, Piece Density, Porosity, Rehydration ratio, Texture- Hardness, Texture – Crispiness, Water Activity, Moisture Content, Lipid, Ash, Protein, Fiber, Carbohydrates, and Color) was investigated using the Tukey test. Each data point was given as a mean and standard deviation for the statistical analysis. The information was analyzed using SPSS version 21.0, which stands for Statistical Program for Social Sciences. The response variables were examined using a one-way ANOVA with a 0.05 alpha level. The major differences between the various formulations and treatments' quality criteria were compared using the Tukey test. Data from 40 people’s sensory evaluations were subjected to a two-way ANOVA.

Chapter IV: Results

This chapter deals with the physicochemical, textural, and sensory analysis of extruded cereal products. It provides details about a comparative study of five different cereal samples to evaluate consumer acceptability. It also discusses the optimized level of incorporation of barley waste grain as a functional ingredient into breakfast cereal for developing protein and fiber-rich products based on various tests conducted such as moisture content, water activity, piece density, true density, expansion ratio, porosity, rehydration ratio, water solubility index. Nutritional properties like carbohydrates, protein, fiber, fat, and ash content, and textural properties like hardness, and crispiness.

Expansion Ratio

Extruded snacks' expansion is an essential component of their quality. The range of the entire expansion was 1.13 to 1.04 (See Figure 7). The expansion ratio indicates the change in the circumference of the sample because of the puffing process when passed through the die. With an increase in BSG content in the feed, the expansion ratio lowered. The rupturing of the cell wall by the fiber particle which leads to poor air bubble formation may be reason for low expansion (Lotfi Shirazi et al., 2020; Liu et al., 2006). The five formulas differed significantly ($p < .001$) in terms of overall axial expansion. The formulation with the lowest total expansion of 1.04 had the largest BSG concentration (30%). As demonstrated in Figure 7, the formulation with 0% BSG had the largest overall expansion of 1.13.

Figure 7

Expansion Ratios of Different Formulas

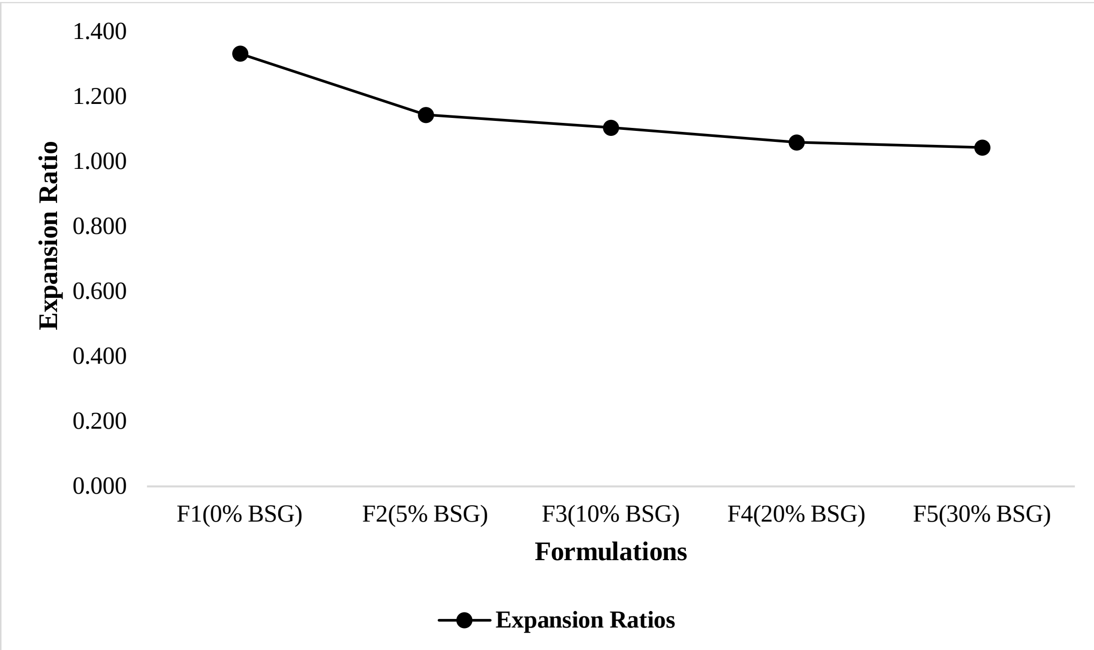


Table 5 shows the results of all physico chemical properties along with the standard deviation in values for all the five formulations.

Table 5

Physicochemical Parameters

Test parameter	F1 0% BSG	F2 5% BSG	F3 10% BSG	F4 20% BSG	F5 30% BSG
True density	0.9[a]±0.04	0.91[a]±0.05	0.91[a]±0.1	0.92[a]±0.03	0.92[a]±0.08
Piece density	0.6[ab]±0.03	0.66[ab]±0.05	0.69[ab]±0.05	0.72[c]±0.009	0.75[a]±0.06
Porosity	14.18[ab]±1.97	11.48[ab]±1.38	11.41[a]±7.31	11.38[a]±2.91	8.74[b]±0.92
Water soluble index	10.1 [a] ±0.37	11.22 [ab] ±0.64	11.06 [ab] ±1.27	12.83 [ab] ±0.69	13.42 [b] ±0.66
Rehydration ratio	292.36[b]±9.5	287.28[ab]±22.01	284.82[ab]±13.04	262.65[a]±17.99	244.08[b]±12.38
Water activity	0.07[a]±0.01	0.07[a]±0.01	0.07[a]±0.003	0.07[a]±0.003	0.07[a]±0.002

Table 6 shows the Analysis of Variance values for the results of all physico chemical properties for all the formulations.

Table 6

ANOVA for Physicochemical Parameters of Extrudates

Test parameter	Degree of freedom(df)	Sum of squares	Mean of squares	F value	$F_{critical}$ value	*p*-value
Expansion ratios	4	1.81	0.45	12.76	2.43	<0.01
True density	4	0.01	0.003	0.06	3.47	0.99
Piece density	4	0.04	0.01	4.96	3.47	0.018
Porosity	4	304.99	76.25	7.34	3.83	0.009
Water soluble index	4	14.85	3.71	5.99	5.19	0.003
Rehydration ratio	4	5297.57	1324.39	5.3	3.47	0.015
Water activity	4	0	0	1.01	2.86	0.425
Color	4	3420.744	855.18	497.72	2.46	<0.001
Color - delta E	4.000	119.76	29.92	17.93	2.46	<0.001

Note. *p*-value below 0.05 shows that there is significant difference between the formulations and *p*-value above 0.05 are non-significant to each other.

True Density and Piece Density

The relationship between piece density and true density to the extrudates' expansion ratio is inverse. In the research, the sample containing 30% BSG showed the highest piece density (0.754), whereas the control sample showed the lowest piece density (0.596). The lowest true density (0.901) was observed in the control sample, whereas the sample containing 30% BSG had the highest true density (0.919). Piece density increased significantly ($p<0.05$) as BSG concentration in the formulation rose from 0% to 30%, however, true density did not significantly show a difference ($p > 0.05$). It is evident from the ANOVA table that the piece density F-value was high compared to the F-critical level at $p < 0.005$. Various studies showed a direct relation between expansion ratio, density, and feed moisture. The confirmed decrease in gelatinization and rise in density of the extruded products are likely caused by a decrease in the dough's elasticity because of plasticizing the melt (Peluola & Idowu, 2014).

Porosity

One of the crucial quality factors for extruded snacks and cereal is porosity. The percentage of air pockets of different sizes and quantities which are formed leads to product expansion and crispiness (Singh et al., 2012). The porosity of the product showed direct relation with the expansion ratio and inverse relation with the density of the product. The highest porosity is observed in the control of 33.85% and the lowest was observed in the sample with the highest level of incorporation of BSG which is 21.36%. There is a significant difference ($p<0.05$) in porosity with an increase in the level of BSG in the formulation of breakfast cereal.

Water Soluble Index and Rehydration Ratio

The WSI determines how much polysaccharide will release from the granule when more water is added (Yousf et al., 2017)**.** The amount of dissolved polysaccharide discharged from the starchy component on extrusion, which is frequently employed as an indicator of molecular component degradation, reflects the degree of starch transformation during extrusion (Charunuch et al., 2011). The WSI was increased when 30% BSG was added to flour mix. The increase in WSI would be caused by structural changes involving Barley fiber. These changes may have encouraged interactions between starch and fiber, which would have increased solubility. The results obtained in this study are in line with Badrie & Mellowes, 1992. Extruded items' stickiness is correlated with high WSI.

The process of rehydrating dried foods includes wetting the surface, allowing water to enter the pores, adsorbing the matrix's surface, diffusing into the solid matrix, and equilibrating.

Breakfast cereals are usually rehydrated by cold or warm milk before consuming, therefore it is an important factor. According to the findings (Table 2), the extrudates' ability to rehydrate was considerably (p<0.05) impacted by their BSG content. The extrudates containing more BSG (F5) have a substantially lower rehydration ratio than those having a lesser level of BSG (F2, F3, and F4). The results are strongly correlated with product porosity which resulted in lesser rehydration due to lower void spaces formed in the product (Bisharat et al., 2013). An increase in the percentage of non-plasticizing substances, such as fibers, and a decrease in plasticizing materials like starch in the formula has led to lower expansion and lower rehydration capacity (Joy et al., 2012).

Texture

The texture is the fusion of food material properties related to the response of a structure of food to applied forces with the sensory senses involved to be vision, kinesthetic, and hearing (Kanojia et al., 2016). Consumer acceptance depends on the textural qualities of extruded products that demonstrate their worth and attractiveness. The finished product's textural characteristics are heavily reliant on crucial raw material parameters like blend ratio and feed moisture (Khanna et al., 2019). The rate of the feed, screw velocity, barrel temperature, and barrel pressure, as well as thermal power input, mechanical energy input, and product retention duration in any area also affects the texture of an extruded product (Anton & Luciano, 2007).

Hardness

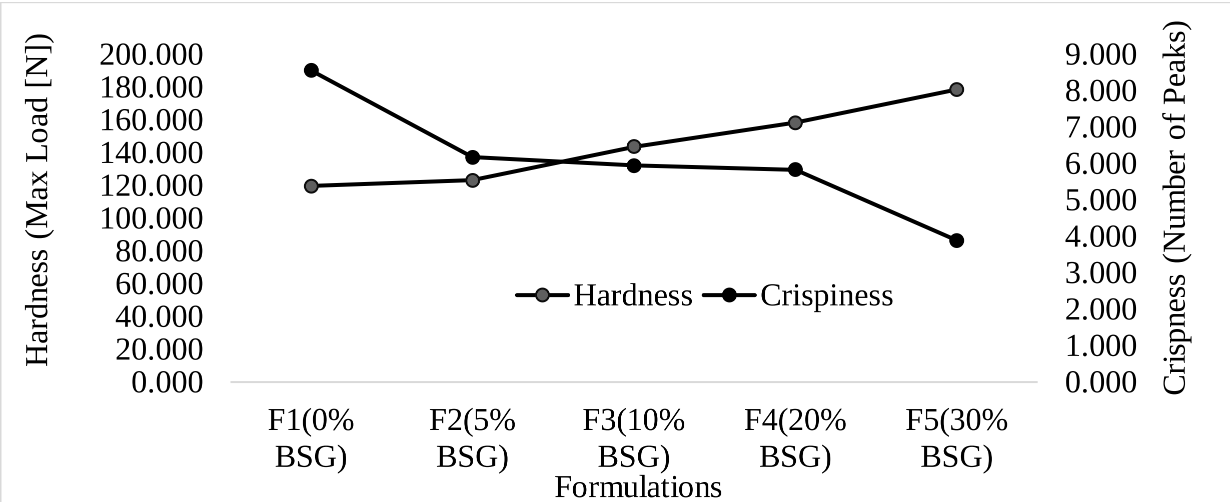
It was observed that the extrudates' hardness ranged from 119.7 N to 178.5 N. Hardness of the product was observed for products with high BSG content which is not very desirable. According to the results occurred we can say hardness and BSG were positively correlated. Extra protein from BSG may change the way that proteins are transformed, leading to less expansion and a harder product when it is added to cereal starch (Kanojia et al., 2016). The hardness of the cereal obtained showed a direct correlation with the density of the product and inverse relation to the product expansion ratio. Similar results were obtained by Gopirajah and Muthukumarappan, (2018) and Gambuś, (1999). Figure 8 depicts how BSG affected the hardness of the extrudates.

Crispiness

BSG showed a significant impact ($p<0.05$) on the crispiness of the product. Snacks' crispness is a characteristic associated with their low-density cellular structure, making them fragile and noisy when broken (Meste, 2002). And the results of this study proved it by showing the relation between product crispiness and product density. The formulation using 30% BSG had the lowest crispness value of 8.55 while the formulation using 0% BSG had the highest crispness value of 3.889. However, the control sample is more brittle compared to the other samples which is not a desirable property. Crispiness also showed inverse relation with the hardness of the product which might be due to less porous structure due to poor void air spaces formed during expansion (Gopirajah & Muthukumarappan, 2018). Figure 8 depicts how BSG affected the crispiness of the extrudates.

Figure 8

Texture Profile (Hardness and Crispiness)



Color

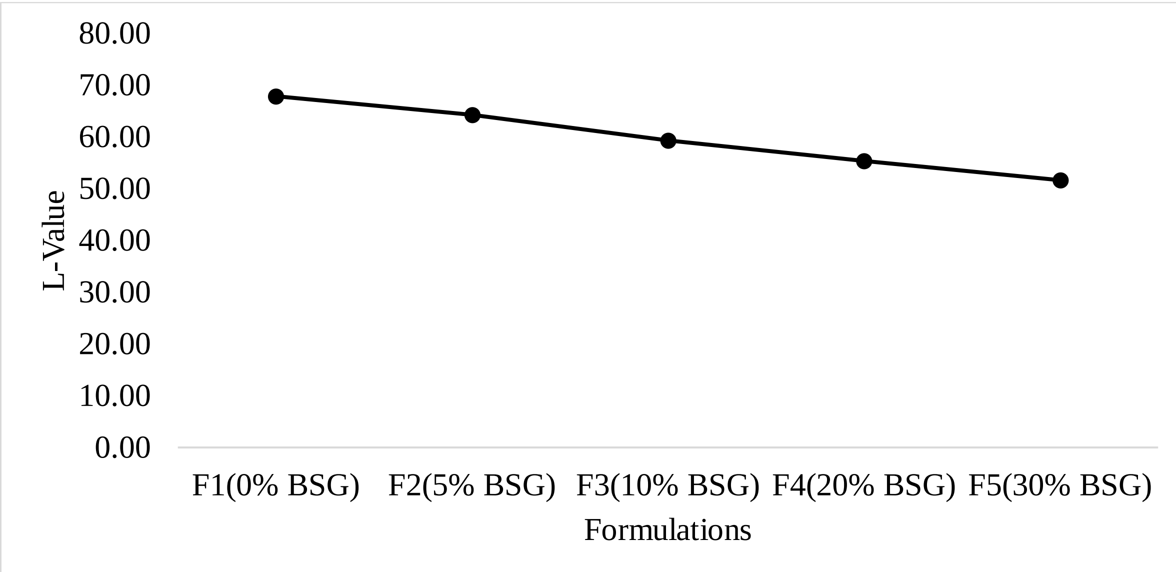
The color characteristics of the extruded cereal were determined by calculating the lightness value and total color difference value.

L- Value

The results from Figure 9 show that the intensity of lightness values of the five distinct formulations significantly differ (p<0.05). Results were presented along with Tukey group rankings. The formulation with 30% BSG had the lowest L value (51.62±0.74) and the formulation with 0% BSG had the greatest L value (67.84±1.55). Due to the increase in the concentration of spent grain, the darkness of the product increased and the lightness decreased. This might be due to brown melanin compounds present in the sample formed during the oxidation of phenolic compounds present in the barley (Glagoleva et al., 2022).

Figure 9

Color-Lightness Value

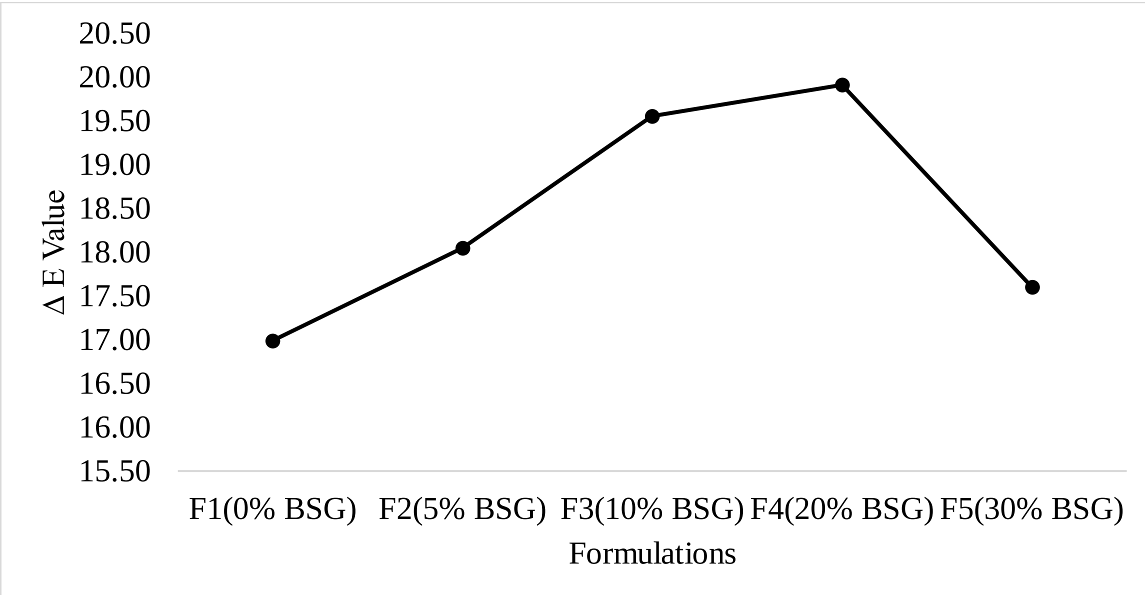


Total Color Difference (ΔE)

The overall color difference value (shown in Figure 10) shows the difference in color between the raw and processed samples. The findings revealed a significant change ($p<0.05$) between the color characteristics of the sample before and after extrusion. The formulation with 30% BSG had the highest total color difference (17.6±0.84), whereas the formulation with 0% BSG had the lowest (16.99±1.77). Additionally, the greater color variation may be caused by non-enzymatic melanin reactions, the process of caramelization, and pigment degradation during the extrusion process. (Ruiz-Armenta et al., 2018).

Figure 10

Color-Total Difference Value(ΔE)



Water Activity (a_w)

More microorganisms are typically found in environments with higher water activity; bacteria typically need water activity levels of at minimum 0.91, while fungi need at least 0.6. Each bacterium has a water activity threshold below which it cannot grow (Bilajac et al., 2012). Table 5 shows that all the formulations have water activity below 0.08 which makes it a very shelf-stable product. 30% BSG had the highest water activity of 0.08±0.002. The rest of the formulations showed no apparent variation. The results show that the modification in the powdered barley spent grain levels had no discernible (p>0.05) impact on the water's activity.

Nutritional Properties

The proximate composition of breakfast cereals made from mixtures of soybean, rice, and quinoa flours with BSG is shown in Table 7. The breakfast cereal developed has the moisture content not varied (p>0.05) greatly between formulations. As the amount of BSG in the formulations increased, the moisture of the samples also increased slightly. The extrudates from the control formulation had the lowest moisture content (3±0.1) while the formulation with 30% BSG had the highest (3.04±0.2) as shown in Table 7. An increase in the percentage composition of the factor variable may be the reason for the rise in moisture content (Edima-Nyah et al., 2019).

Results suggested that they would have a longer shelf life with low moisture content. BSG was added in increasing amounts in formulations (0-30%) increasing the protein content. The samples' protein content ranged from 4.51±1.79 to 12.39±0.3%. And the findings revealed a significant difference ($p<0.05$) between formulations. With an increase in BSG in the composition of the breakfast cereals, the fat content dropped ($p<0.05$). This might be caused by a drop in the formulation's soy flour, which is the main factor in the sample's high-fat content. The percentage of fat ranged from 2.07 ± 0.38 to 1.52±0.15 % percent. The sample with a high BSG formulation had the least amount of fat, while the control sample had the most. Ash is a sign of the presence of minerals in food products. With increasing amounts of BSG flour added to the formula the ash content increased. The Ash content of the breakfast cereals differed significantly ($p< 0.05$) and ranged from 2.38±0.3 to 3.57±0.22 %. The calculated breakfast cereals' crude fiber content values ranged from 5.01±1.11 to 7.75±0.3 %. At $p<0.05$, all samples were shown to differ significantly. Compared to controls without BSG, breakfast cereal with a 30% formulation had the highest value. Breakfast cereals had a carbohydrate composition that ranged from 83.09±3.54 to 71.74±0.03%. As BSG was added to the blend formulations in increasing amounts, the number of carbohydrates increased noticeably. All samples differed from each other considerably ($p<0.05$). The sample with the highest BSG had a low carbohydrate value while the control formulation had a high one. This might be due to a decrease in flour composition (rich in carbohydrates) with an increase in the BSG levels in the formula.

Table 7

Nutritional Parameters

Nutritional property	F1 0% BSG	F2 5% BSG	F3 10% BSG	F4 20% BSG	F5 30% BSG
Moisture content	3^{a}±0.1	3.02^{a}±0.56	3.01^{a}±0.04	3^{a}±0.30	3.04^{a}±0.2
Lipid	2.07^{ab}±0.38	1.97^{ab}±0.06	1.88^{ab}±0.11	1.59^{a}±0.1	1.52^{b}±0.15
Ash	2.38^{a}±0.3	3.19^{a}±0.02	3.21^{a}±0.17	3.41^{a}±0.02	3.57^{a}±0.22
Protein	4.51^{ab}±1.79	6.98^{ab}±1.39	7.05^{bc}±0.92	10.29^{c}±0.43	12.39^{a}±0.3
Fiber	5.01^{b}±1.11	7.64^{b}±0.08	7.69^{b}±0.05	7.71^{b}±0.11	7.75^{a}±0.3
Carbohydrates	83.09^{ab}±3.54	77.2^{ab}±0.64	77.16^{a}±1.04	74.01^{a}±0.9	71.74^{b}±0.03

Table 8 shows the Analysis of Variance values for the results of all nutritional properties for all the formulations.

Table 8

ANOVA for Nutritional Parameters of Extrudates

Test parameter	Degree of freedom(df)	Sum of squares	Mean of squares	F value	$F_{critical}$ value	*p*-value
Moisture Content	4	0.004	0.001	0.1	3.47	1
Lipid	4	0.70	0.17	4.36	3.47	0.027
Ash	4	2.33	0.58	16.59	3.47	<0.01
Protein	4	76.65	19.16	15.15	5.19	0.005
Fiber	4	11.54	2.885	10.55	5.19	0.012
Carbohydrates	4	132.6	2.976	11.14	5.19	0.011

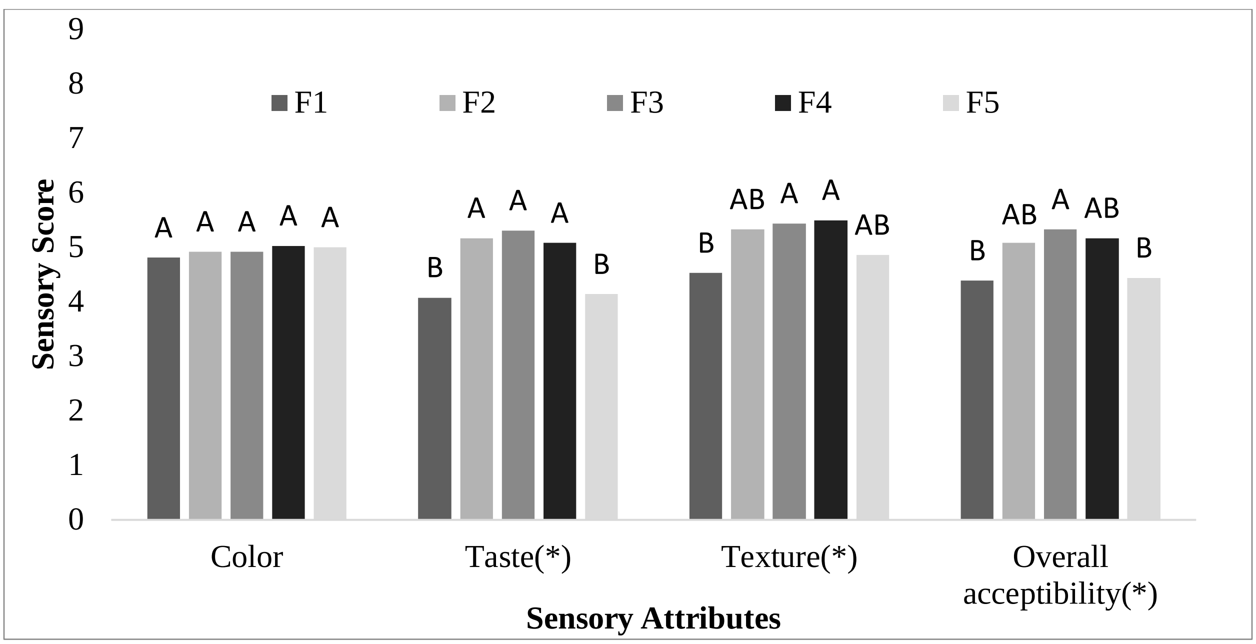
Note. *p* value indicates probability. $p < 0.05$ is statistically significant and *p* value > 0.05 is statistically not significant. F-value in ANOVA determine whether the differences between the means of two populations are significant.

Sensory Evaluation

Significant differences in texture, flavor, and general product approval exist between the samples ($p<0.05$). There was no evident variation *(p>0.05) between* samples in terms of color. Most of the panelists are neutral in their choice with respect to color, they neither liked nor disliked the colors of the sample. In terms of the taste of the product, most of the tasters choose the sample with 20% BSG over other samples. Both 10% and 20% BSG samples received the highest score in the texture of the product followed by 30%. The overall acceptability of the 20% BSG sample received the highest mean score followed by the 10% BSG sample. From the results, it is evident that the BSG incorporation from 10-20% will be well accepted by customers in terms of sensory. The mean score of each attribute is shown in Figure 11.

Figure 11

Sensory Evaluation- Mean Scores



Research Questions

The research was conducted to find possible best solutions to develop a healthy breakfast cereal. Following are the few questions on which this research was focused and centered around.

1. Is Barley Spent Grain a good intervention for developing a nutritious breakfast cereal?
2. How do the final product's functional properties get affected by incorporating different levels of BSG into the formula?
3. What will be the shelf life of the product?
4. Will this new product be successful and accepted by customers in the real world?

Chapter V: Discussion, Conclusion, and Recommendations

The previous chapters were compiled in this chapter. It also includes details on the research findings from the current work, conclusions that were made as a result, and recommendations for future research.

Discussion

The expansion ratio is one of the important properties that affect other properties like texture and density. One of the potential causes of the low expansion during extrusion with the fiber particle is the disruption of the cell wall, which results in poor air bubble formation. (Lotfi Shirazi et al., 2020; Liu et al., 2006). In this product, the expansion ratio decreased with an increase in the BSG content in the feed.

Several research found a direct correlation between feed moisture, density, and expansion ratio. The confirmed reduction in gelatinization and increase in density of the extruded products were most likely the results in the studies conducted by (Peluola & Idowu, 2014). The densities of this product were directly affected by poor expansion ratio. In the research, the sample containing 30% BSG showed the highest piece density (0.754), whereas the control sample showed the lowest piece density (0.596). The lowest true density (0.901) was observed in the control sample, whereas the sample containing 30% BSG had the highest true density (0.919). The product's porosity exhibited a direct correlation with the expansion ratio and an inverse correlation with the product's density. The highest porosity is observed in the control of 33.85% and the lowest was observed in the sample with the highest level of incorporation of BSG which is 21.36%.

The WSI was increased when 30% BSG was added to the flour mix. WSI would rise because of structural changes impacting barley fiber. These modifications might have promoted interactions between starch and fiber, increasing solubility. Similar results were obtained by Badrie & Mellowes (1992).

The product's hardness is not particularly acceptable for products with a high BSG content. Because we can infer from the data that the level of BSG and hardness were positively associated. The Crispiness of products showed an inverse relation with hardness. The formulation utilizing 0% BSG had the highest crispness value, 3.889, while the formulation using 30% BSG had the lowest, 8.55. When added to cereal starch, protein from BSG alters how proteins are converted during extrusion, resulting in less expansion and a tougher product (Kanojia et al., 2016). Gopirajah & Muthukumarappan, 2018 and Gambuś, 1999 proved the same while studying the effect of extrusion process conditions on the physical properties of tef-oat healthy snack extrudates.

Due to brown melanin compounds present in the sample, the product became darker and due to an increase in the concentration of BSG. The formulation with 30% BSG had the lowest L value (51.62±0.74) and highest total color difference (17.6±0.84), whereas the formulation with 0% BSG had the greatest L value (67.84±1.55) and lowest (16.99±1.77). The formulation with 30% BSG had the highest total color difference (17.6±0.84) (Ruiz-Armenta et al., 2018).

As the amount of BSG in the formulations increased, the moisture of the samples also increased slightly. The rise in moisture content could be caused by a change in the percentage composition of a contributing variable. (Edima-Nyah et al., 2019). And the findings revealed a statistically significant difference (p<0.05) between formulations for a protein content range of 4.51-1.79 to 12.39-0.3%. With an increase in BSG in the composition of the breakfast cereals, the fat content dropped (p<0.05). The percentage of fat ranged from 2.07 ± 0.38 to 1.52±0.15 % percent. Ash is a sign of the presence of minerals in food products. Ash is a marker that food goods contain minerals. Ash content rose as BSG wheat was added to the mixture in increasing amounts (2.38±0.3 to 3.57±0.22 %). The calculated breakfast cereals' crude fiber content values ranged from 5.01±1.11 to 7.75±0.3 %. Breakfast cereals had a carbohydrate composition that ranged from 83.09±3.54 to 71.74±0.03%. The number of carbs significantly increased as BSG was increasingly added to the blend formulations. All samples varied significantly from one another at $p<0.05$.

Most of the sensory panelists gave high scores for 10% and 20% BSG samples for the texture of the product followed by 30%. The overall acceptability of the 20% BSG sample received the highest mean score followed by 10% BSG sample. From the results, it is evident that the BSG incorporation from 10-20% will be well accepted by customers in terms of sensory.

Conclusions

The efficiency of BSG to use as value-added raw material in developing breakfast cereal was studied in this research. Extrusion technology was proven to be the most effective processing method that can be utilized in manufacturing cereal-like products. Preliminary processing of BSG has helped the product to blend well with the other raw materials and support in achieving smooth processing conditions. The effects of various BSG concentrations (0%, 5%, 10%, 20%, and 30%) on the physical, chemical, nutritional, and sensory characteristics of the extruded product showed that adding BSG to the cereal mixture increased protein, fiber, ash content, hardness, color variation, and piece density while significantly ($p<0.05$) lowering expansion ratio, porosity, crispiness, lipid content, water-soluble index, and rehydration ratio. BSG incorporation considerably ($p<0.05$) decreased the color L* value and raised the lightness value. Additionally, the results demonstrated that there were no variations in actual density, water activity, or moisture content across the samples with various amounts of BSG insertion

($p>0.05$). The sensory test revealed that the overall acceptability of the product is significantly higher ($p<0.05$) for the product with 10-20% of BSG in the formula. Therefore, incorporation up to 20% BSG into breakfast cereal formula is recommended through this study in improving the product's both physio-chemical and sensory quality. This research is expected to be helpful to find a sustainable solution for the brewing processing industry by converting brewing grain wastes into value-added foods.

Recommendations

The following recommendations can be useful to further extend the study:

- Shelf-life studies and mathematical modeling can be conducted on the product for the selected formulations.
- There were different variables that affect the product during the extrusion. Studying these parameters like screw speed, screw temperature, die temperature, and feed rate in the future can also be considered.
- Different flavors and shapes can be experimented to bring a variety of products and their acceptance can be studied.
- Various kinds of cooking techniques like baking and frying can be studied to know their impact on the texture of the product.
- Prototyping with more natural ingredients like protein isolates for a protein source and natural sweeteners for flavors make the product more nutrient-dense and clean labeling.

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Appendix

Nutritional Data of Various Products in Kellogg's

nutrition information per serve
breakfast cereals

Product Name	Serve Size g	Energy (kJ)	Protein (g)
All-Bran®	45	620	6.8
All-Bran® Apple flavoured Crunch	45	680	4.7
All-Bran® Fibre Toppers	25	310	2.4
All-Bran® Wheat Flakes	40	570	5.2
All-Bran® Wheat Flakes Honey Almond	45	690	5.0
Coco Pops®	30	480	1.4
Coco Pops® Chex®	30	470	2.0
Corn Flakes	30	470	2.3
Crispix®	30	490	2.0
Crunchy Nut Clusters	30	520	2.2
Crunchy Nut Corn Flakes	30	500	2.0
Froot Loops®	30	490	1.9
Frosties®	30	480	1.4
Guardian®	30	430	2.8
Just Right® Clusters and 5 Grains	45	710	4.0
Just Right® Original	45	670	4.0
Mini-Wheats® 5 Grains	40	600	4.5
Mini-Wheats® Blackcurrant Flavour	40	600	3.5
Nutri-Grain®	30	480	6.6
Rice Bubbles®	30	480	1.9
Special K Advantage®	40	590	5.4
Special K®	30	470	5.9
Special K® Forest Berries	30	470	5.5
Special K® Fruit & Nut Medley	40	650	6.2
Special K® Honey Almond	30	500	5.3
Sultana Bran	45	640	4.3
Sultana Bran Buds®	45	630	3.8
Sultana Bran Extra™	45	660	3.2
Sustain®	45	710	4.0

PAGE 4

Total Fat (g)	Saturated Fat (g)	Carbohydrates (g)	Sugars (g)	Dietary Fibre (g)	Sodium (mg)
1.4	0.2	20.4	6.1	13.3	171
1.4	0.2	29.0	8.9	6.8	157
0.4	0.1	10.1	4.9	10.0	57
0.7	0.2	23.2	4.2	7.7	158
2.2	0.2	27.4	11.7	7.0	146
0.1	0.1	26.5	11.0	0.4	139
0.1	0.1	25.0	9.6	1.0	148
0.1	< 0.1	24.9	2.4	1.0	165
0.1	< 0.1	26.4	7.2	0.3	217
2.2	0.4	23.0	8.5	0.9	102
1.0	0.2	24.8	9.5	0.8	106
0.4	0.2	25.6	11.4	0.7	120
< 0.1	< 0.1	26.8	12.4	0.4	105
0.4	0.1	18.7	3.5	6.5	64
0.6	0.1	34.6	8.1	3.0	36
0.7	0.2	32.3	12.9	3.6	13
0.6	0.1	27.2	3.5	4.9	2
0.8	0.1	28.3	6.4	3.6	6
0.2	< 0.1	20.8	9.6	0.8	144
0.1	< 0.1	26.0	2.7	0.3	165
0.2	< 0.1	26.0	7.4	6.2	134
0.1	< 0.1	21.2	4.4	0.8	126
0.2	< 0.1	21.5	7.5	0.9	108
2.3	0.2	26.0	9.3	1.8	152
1.0	0.1	21.5	6.2	0.7	108
0.8	0.2	28.3	10.2	6.7	121
0.7	0.2	28.5	11.3	7.1	60
0.6	0.1	32.4	12.8	3.9	132
1.3	0.2	33.4	9.2	2.9	36

The information contained in these tables was correct at time of printing (August 2012).
For the most current nutrition information please refer to current packs on-shelf or contact the Kellogg Consumer Contact Centre.