

Research Article

The Effect of Upcycled Brewers' Spent Grain on Consumer Acceptance and Predictors of Overall Liking in Muffins

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The brewing industry generates large amounts of food waste including brewers' spent grain (BSG) and leftover malted grains from beer production. BSG compositions can vary but consistently include high levels of protein and fiber. The potential nutritional and health benefits of BSG have sparked recent interest for food fortification. However, the challenges associated with BSG addition can impact food quality due to increases in fiber and protein content and reduction in starch content. Consumer testing was conducted to evaluate muffins containing varying levels of BSG (0, 20, 30% wt:wt flour) to determine the highest acceptable concentration on overall likeability, appearance, texture, moistness, sponginess, and taste attributes. Significant differences were found within appearance ($F=7.728$, $P=.001$) and taste ($F=4.947$, $P=.008$) ratings across all muffins. Control and 20% BSG muffins were rated significantly higher for appearance (6.74 ± 0.18 ; 6.64 ± 0.18) than 30% BSG muffins (6.11 ± 0.18). Muffins containing 20% BSG (7.15 ± 0.17) received significantly higher taste ratings than 30% BSG muffins (6.56 ± 0.22) and control muffins (6.49 ± 0.19). However, 30% BSG muffins maintained acceptance for all attributes showing higher allowable BSG substitutions than previously reported. Bivariate correlation analyses found that all attributes across each muffin variation were strongly, positively correlated ($r > 0.6$) with overall likeability excluding appearance ($r = 0.359$, $P < 0.001$) and moistness ($r = .466$, $P < 0.001$) in control muffins. Significant predictors of overall likeability were appearance ($\beta = 0.088$, $P = 0.005$), texture ($\beta = 0.181$, $P < 0.001$), sponginess ($\beta = 0.226$, $P < 0.001$), and taste ($\beta = 0.494$, $P < 0.001$). Brewers' spent grain consumer acceptance results will guide the development of test food products for future human diet intervention compliance.

1. Introduction

In 2019, the US beer market generated over 191.2 billion barrels of beer, equivalent to \$116 billion in annual sales [1]. As a result, the beer industry generates large amounts of food waste by-products in the forms of spent hops, surplus yeast, and brewers' spent grain (BSG) [2]. BSG is the residue left after separation of liquid wort during the brewing process. Spent grains are the most abundant by-product of beer manufacturing representing around 85% of the waste created by the brewing industry with approximately 40 million tons produced worldwide each year [3]. Due to sustainability initiatives, efforts have been made to valorize BSG in nonfood sectors as a source of feedstock, compost, biogas, and substrate for cultivation of high-value microorganisms

[4–6]. Additional discoveries have expanded its usage by extracting bioactive constituents such as arabinoxylans [7, 8], protein hydrolysates [9, 10], and phenolic compounds [11]. Reusing BSG as a value-added food source for human consumption is of interest because it increases protein, fiber, vitamin, and mineral content in grain-based products while decreasing starch and caloric content [12, 13].

BSG is a lignocellulosic rich material consisting of the outer layers from the original brewing grains and chemically comprised with approximately 70% fiber, 28% lignin, 20% protein, and 17% cellulose [14, 15]. Scanning electron microscopy has shown the microstructure of BSG mainly as husks, fiber filaments, and the remains of the endosperm with starch granules nearly gone due to hydrolysis during the brewing process [16]. The nutritional profile of BSG will

vary depending on the grain and adjunct sources and the malting and mashing conditions [17]. However, BSG consistently contains higher protein, fiber, and antioxidant contents making it ideal for food fortification. Spent grains have been successfully substituted from 5 to 50% of the flour content into baked and extruded snacks [18], traditional and sourdough breads [12, 19], breadsticks [20], cookies [21], pizza dough [22], and muffins [23] with significantly increasing nutritional value via dietary fiber, protein, and antioxidant content in a dose-dependent fashion. However, there are challenges involved with the addition of BSG into food due to potential losses in quality.

Key sensory issues from BSG addition are appearance, texture, and flavor due to its high fiber content weakening the gluten network and impacting quality and bran content along with darkening the appearance. One of the major challenges associated with BSG addition is maintaining the structure and loaf volume. Crumb texture, crumb grain structure, and loaf volume are reduced as a result of BSG addition because of increased density and high water-holding capacity of arabinoxylans and dietary fiber content preventing gluten development [16]. Shih et al. [23] found BSG fortification increased muffin batter viscosity, moisture content, and reduced volume index but no significant differences in overall liking, appearance, color, taste, and texture hedonic ratings were observed between BSG15 muffins (15 g/100 g flour mix) and control muffins. Other authors concluded that up to 30% BSG provides acceptable physicochemical characteristics, but the addition of 20% is considered better for developing snacks with properties similar to those commercially available [15]. Additional properties of BSG include its ease of blending, high water absorption capacity, low fat absorption, uniform color, bland flavor, and high fiber, protein, and mineral content [4]. Therefore, using BSG for food fortification is appealing because it provides an opportunity to reduce brewing industry waste while improving the nutritional content of food products.

Muffins are popular baked goods accepted by consumers of all ages that are ready-to-eat, affordable, and available in a variety of flavors [24, 25]. Muffins have been fortified with various plant by-products including grape [26–28], apple [29, 30], tomato [31], and cranberry and raspberry [25] pomaces all resulting in improved fiber and antioxidant content. Previously conducted focus groups determined handheld baked goods or snacks eaten on-the-go that maintained satiety and required little preparation were ideal BSG food products for college students [32]. In response to focus group findings, mini muffins were selected as the food for BSG incorporation. However, it is necessary to determine BSG inclusion concentrations for muffin acceptability. Consumer testing is a common sensory technique performed to determine consumer liking, preference, or acceptability of a product based on its sensory characteristics [33]. To date, one study has evaluated consumer acceptance of BSG-fortified muffins [23]. However, only one BSG fortification concentration was compared to control muffins preventing the determination of an upper limit for BSG acceptability from several concentrations. Therefore, the

TABLE 1: Ingredient analysis of control and brewers' spent grain (BSG) muffin formulations.

	Ingredient (g/100 g)		
	0% ¹ (control)	20% BSG	30% BSG
Brewers' spent grain	n/a	7.46	11.18
Flour, all-purpose	37.32	29.81	26.09
Applesauce	30.48	30.43	30.43
Sugar, granulated	14.31	14.30	14.30
Eggs, raw	6.22	6.21	6.21
Olive oil, light	6.22	6.21	6.21
Water	3.73	4.10	4.10
Salt	0.44	0.43	0.43
Baking soda	0.37	0.37	0.37
Vanilla extract	0.37	0.37	0.37
Cinnamon, ground	0.30	0.31	0.31
Sethness® OC 114 caramel color ²	0.24	n/a	n/a

¹% refers to percentage substitution of total all-purpose flour by brewers' spent grain flour. ²Sethness® OC 114 (certified organic caramel color manufactured from certified organic raw cane sugar; supplied by Sethness Products Company, Clinton, IA, USA).

aims of the present study were to (a) conduct affective, consumer testing to evaluate acceptance of mini muffins containing varying levels of BSG (0, 20, and 30% wt:wt flour content) to determine the highest concentration of BSG allowable while maintaining consumer acceptance based on the attributes: overall likeability, appearance, texture, moistness, sponginess, and taste and (b) determine how the evaluated sensory attributes were correlated and predicting overall liking of muffins. It was hypothesized that participants will rate all three muffin variations as acceptable based on a score of 5 or higher on a 9-point hedonic scale. Secondly, it was hypothesized that appearance, moistness, and taste will be positively correlated with texture and sponginess being negatively correlated to overall liking, and appearance and texture will be strong predictors of muffin overall liking.

2. Materials and Methods

2.1. Product Preparation. BSG was prepared using an American pilsner-style formulation composed of 2-row and 6-row barley with flaked corn adjuncts as these grains are used in top selling US large brewery beers (Bud Light, Coors Light, Budweiser) and top selling US craft brewery style beers like India Pale Ale. The spent grain formulation was designed to represent grain bills of beers largely contributing to BSG generation. BSG was prepared in the Texas Woman's University (TWU) Food Product Development lab using a common cooking protocol followed by craft breweries. Grain was added to a mesh bag for filtering purposes and mashed (steeped in water) for one hour at 65.5°C. Following mashing, BSG was removed from the water and dehydrated (Excalibur, Sacramento, CA, USA) at 49–54°C for approximately 14 hours. BSG was finely milled (KoMo, Hampton, NE, USA) to create the BSG flour with consistently sized particles. Milled BSG was passed through a

TABLE 2: Nutritional analysis¹ per serving² of control and brewers' spent grain (BSG) muffins.

	0% ³ (control)	20% BSG formulation	30% BSG formulation
Energy (kilocalories)	301.7	304.3	305.5
Carbohydrates (g)	52.0	51.5	51.2
Total fat (g)	8.1	8.5	8.7
Total protein (g)	5.3	5.7	6.0
Total dietary fiber (g)	1.8	4.1	5.2

¹Nutrition compositional analysis performed by analytical food labs, Grand Prairie, TX. ²Serving size is 110 g or 5 mini muffins. ³% refers to percentage substitution of total all-purpose flour by brewers' spent grain flour.

#35 (500 microns) stainless steel mesh sieve to remove the hulls and other indigestible materials that were not ground into the flour. Milled BSG was sealed in vacuumed polyethylene bags and stored at 0°C until further use. Proximate nutritional chemical analyses were performed by Analytical Food Labs (Grand Prairie, TX) on a sample of BSG created with the protocol described above. Results indicated the sample contained 69.67% total carbohydrates, 16.14% protein, 30.07% total dietary fiber, 5.31% fat, and 3.04% ash, which is similar to those previously reported [2, 34].

BSG was incorporated into mini muffins at varying percentages by replacing equivalent amounts of all-purpose flour with BSG flour. Muffins contained 7.5 g BSG (20% wt:wt flour), 11.2 g BSG (30% wt:wt flour), and 0 g BSG (control). As shown in Table 1, each muffin formulation contained the same ingredients except for BSG concentration. Mini muffins containing BSG consisted of all-purpose flour, BSG flour, unsweetened applesauce, sugar, olive oil, egg, leavening, spices, and natural flavors. Control muffins also contained certified organic caramel coloring (Sethness Products Company, Clinton, IA, USA) to mask color variations among the samples because TWU sensory labs are not equipped with red lights. The muffin formulations used in this sensory evaluation were designed to be simple with no extra dried fruit or nut inclusions and were not considered market-ready products.

All muffins were prepared by the principle investigator and culinary science students in the TWU Food Product Development lab. The muffin batter was prepared by combining all dry ingredients (all-purpose flour, BSG flour, sugar, leavening agent, and spices) in a bowl. In a separate bowl, all wet ingredients (unsweetened applesauce, olive oil, egg, and natural flavors and colors) were mixed together using an electric mixer at medium speed for 1 minute. The mixed dry ingredients were incrementally added to the wet ingredients while using an electric mixer at medium speed until fully combined (approximately 2 minutes). Paper muffin liners were added to muffin pans, and 15–16 g of batter added to each paper-lined well and baked at 350°F (177°C) in a convection oven (Blodgett, Burlington, VT) for 10 minutes (0% BSG), 11 minutes (20% BSG), and 14 minutes (30% BSG). Higher fiber contents can increase viscosity and influence the homogeneity of muffin batters, thereby requiring longer cooking times to bake BSG muffins completely. Different cooking time instances were applied to minimize textural and gummy consistency differences between the muffins. Each formulation created 50–54 muffins per batch. Fresh muffin samples were prepared 24 hours in

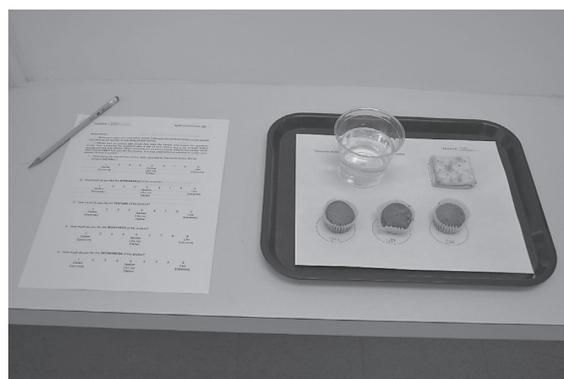


FIGURE 1: Sensory evaluation ballot and tray setup. Each panelist received a ballot, pencil, and tray with three muffin samples presented in a randomized and balanced order, two saltine crackers, and drinking water to cleanse their palates between each muffin sample.

advance of sensory testing and stored in sealed polyethylene bags at ambient temperature until testing. As shown in Table 2, each muffin formulation was analysed using the Nutrition Data System for Research (University of Minnesota, Minneapolis, MN, USA) to determine the nutritional analysis per serving.

2.2. Experimental Design. Panelists were recruited in March–April 2018 from Texas Woman's University (Denton, TX) through bulk emails sent to students, faculty, and staff, along with flyers posted on the TWU-Denton campus. Eligibility to participate included males and females between 18 and 60 years of age, who consumed whole grain muffins and/or baked goods, and did not have any known food allergy or intolerance, disease, illnesses or conditions that could reduce sensory sensitivity. Individuals who smoked, had an alcohol use disorder, or were pregnant were excluded from the study. Interested individuals completed and signed an online Google® prescreening form and consent agreement to determine eligibility and collect demographic information. Once all documents were received and verified, eligible panelists were notified via email that they had been accepted as a panelist for the sensory evaluation and were scheduled to participate in one of the seven testing dates. The panel consisted of 107 untrained, frequent users of muffin-type baked goods between 18 and 60 years of age.

Upon arriving at the TWU sensory lab, panelists were signed in and assigned a 3-digit code to maintain anonymity.

The primary investigator escorted panelists into individual sensory testing booths to discuss the booth setup, testing procedures, read the consent agreement, and have all panelists sign and date the agreement before proceeding. At this time, panelists were allowed to ask any questions. Once all questions were answered and there were no further questions, the panelists could begin sensory testing.

Muffins were presented to panelists using a side-by-side sample presentation protocol in a randomized and balanced manner under white light. A random number generator (Google® Random Number Generator) was used to create 3-digit random numbers that were assigned to each muffin variation to identify each sample while blinding subjects to the muffin and minimizing bias. Each panelist was presented a tray with all three muffin samples (8 g each), two saltine crackers, drinking water, a pencil, and ballot. The tray setup is shown in Figure 1. Panelists were instructed to sample one muffin at a time, take a bite of a cracker, and swish their mouths with water before sampling the next muffin. Muffins were stored at ambient temperatures in airtight food-grade storage containers until evaluation.

The score sheets included each panelist's 3-digit code and a series of questions per muffin sample. Panelists rated each attribute (overall liking, appearance, texture, moistness, sponginess, and taste) using balanced, 9-point category hedonic scales to determine their degree of liking for each muffin [35, 36]. Hedonic scales were presented with the following anchors (1 = dislike extremely; 9 = like extremely) and midpoint (5 = neither like nor dislike). Once the panelists finished the evaluations, they were thanked for their participation and received a \$5 gift card as an incentive. The sensory test session for each panelist was approximately 30 minutes long. Once consumer testing was complete, sensory data collected from test ballots were input into an Excel spreadsheet for statistical analysis. Approval of the study protocol and consent procedures was obtained from Texas Woman's University Institutional Review Board, Denton, TX, prior to study commencement.

2.3. Statistical Analysis. Data were analysed using descriptive and multivariate techniques. Frequencies and percentages were determined for demographics. Mean sensory ratings for each attribute within each muffin type (0, 20, 30%) were determined. One-way repeated measures multivariate analysis of variance (MANOVA) multivariate testing compared differences in mean sensory ratings among the three muffin types followed by one-way repeated measures analysis of variance (ANOVA) univariate testing and Tukey's honestly significant difference (HSD) post hoc analysis to determine significance among muffin attributes. Results achieved statistical significance for a value of $P < 0.05$. Pearson's bivariate correlation analysis was conducted to examine the relationships between muffin attributes among the three muffin types using XLSTAT 2019 (Addinsoft, New York, NY). Multiple linear regression was used to predict overall liking from appearance, texture, moistness, sponginess, and taste. All analyses, excluding

TABLE 3: Demographic characteristics of consumer test panelists.

Variables	Frequency (<i>n</i>)	Percentage
Gender		
Male	14	13.1
Female	92	86.0
Nongender specific	1	0.9
Age range		
18–22	51	47.7
23–30	39	36.4
31–40	7	6.5
41–50	5	4.7
51–60	5	4.7
Classification		
Undergraduate	83	77.6
Graduate	12	11.2
Post-baccalaureate	5	4.7
Faculty/staff	7	6.5

Person's correlation analysis, were performed using IBM SPSS Statistics 25 for Windows (SPSS Inc, Chicago, IL).

3. Results and Discussion

3.1. Nutrient Analyses. As shown in the ingredient analysis of each muffin formulation, 0 g, 7.46 g, and 11.18 g of BSG were added to the control, 20%, and 30% BSG muffins (Table 1), providing 1.8 g, 4.1 g, and 5.2 g of total dietary fiber, respectively (Table 2). Therefore, as the concentration of BSG was increased in the muffins, the dietary fiber content increased by 56% and 65%. Total protein increased from 5.3 g in the control formulation to 5.7 g and 6.0 g in the 20% and 30% BSG formulations, providing a 7% and 11.7% increase in protein, respectively. Protein was lower in our sample compared to others, but it increased similarly as previously reported [18]. Differences in protein content may result from variations in BSG grains and adjuncts, BSG mashing conditions, muffin cooking conditions, and BSG flour particle size. In addition, possible nutrient content claims could be made on the labeling of 20% and 30% BSG muffins with each considered a "good source" of protein and fiber because the serving size contains more than 10% of the recommended daily values for each nutrient [37].

3.2. Demographics. Adult men and women ($n = 107$) were recruited from Texas Woman's University to perform the consumer test of BSG-fortified muffins. Frequencies and percentages for the demographic characteristics of panelists are displayed in Table 3. Most participants were undergraduate (77.6%) females (86.0%) between the ages of 18 and 22 (47.7%). Panelists were recruited from the university for convenient sampling purposes. The study population does represent the population of Texas Woman's University but may not represent the overall population of muffin or whole grain baked goods consumers. Therefore, results presented from the present study can serve as a guideline for consumer acceptance of BSG muffins. Still, generalizing results to the entire consumer population should proceed with caution.

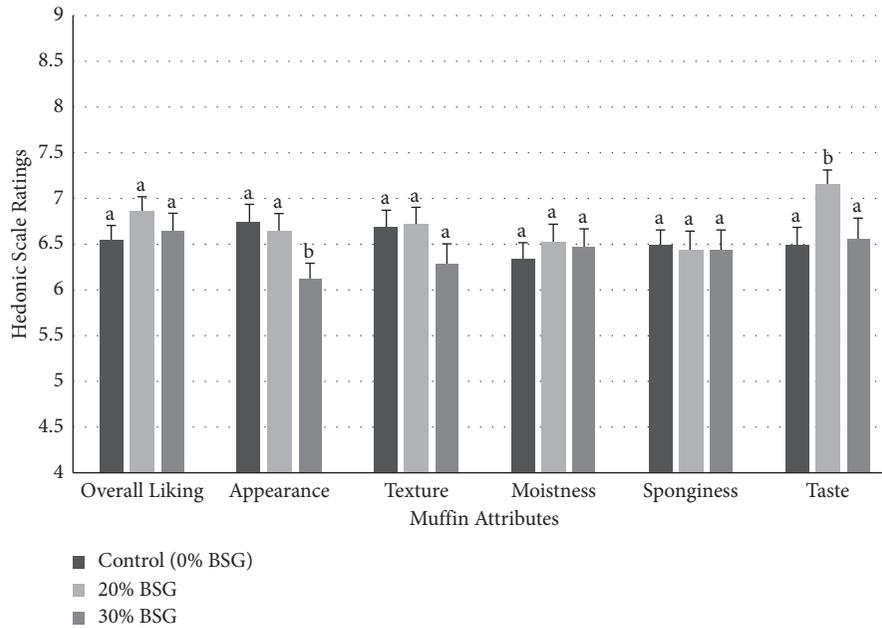


FIGURE 2: Mean hedonic ratings for muffins containing different percentages of brewers' spent grain. Mean consumer test ratings of muffin attributes for 0%, 20%, and 30% BSG muffins from one-way repeated measures MANOVA. Bars with different superscripts under the same attribute are significantly different ($n = 107$; $P < 0.05$, Tukey's honestly significant difference test). 1 = dislike extremely; 5 = neither like nor dislike; 9 = like extremely. Error bars indicate standard error of the mean (SEM).

3.3. Influence of BSG on Consumer Acceptance of Muffins.

A comparison of mean sensory ratings for all attributes within each muffin group is shown in Figure 2. Repeated measures MANOVA revealed significance ($F = 3.854$, $P < 0.001$). Univariate repeated measures ANOVA significance was found for appearance ($F = 7.728$, $P = 0.001$) and taste ($F = 14.134$, $P = 0.008$). Tukey's HSD revealed that consumers rated appearance significantly higher in 20% BSG muffins (6.64 ± 0.18) and control muffins (6.74 ± 0.18) than in 30% (6.11 ± 0.18). Specifically, 20% BSG muffins were rated 7.0% higher ($P < .001$) for appearance than 30% muffins. Taste was rated significantly higher for 20% BSG muffins (7.15 ± 0.17) than 30% BSG muffins (6.56 ± 0.22) or control muffins (6.49 ± 0.19).

Appearance is generally the first parameter consumers use to evaluate food because the product is seen prior to being tasted. BSG is shown to significantly reduce lightness (L^*) and increase redness (a^*) in food, which darkens the overall appearance of the product [21, 38]. Higher soluble sugar content and amino acids present in BSG doughs likely resulted in stronger Maillard browning reactions and caramelization, thereby darkening the muffins. Panelists may have perceived this as a negative attribute if the darker color was associated with burnt or overbaked muffins. However, a natural caramel color was added to control muffins to darken and reduce color variations between samples, but surface textural differences were not controlled for. BSG particulates can create surface texture variations that become more pronounced as BSG content is increased in food. Previous studies found higher sensory scores were achieved as BSG particle size was reduced [38]. If higher concentrations of BSG are needed to convey a biological response,

smaller particle sizes may be necessary to maintain consumer acceptance. Ratings may be reduced further for individuals who do not consume whole grain baked goods because they expect these products to be lighter in color due to the use of all-purpose or bleached flours.

Muffins with 20% BSG received higher ratings for taste than control and 30% BSG muffins. Lower taste ratings may result from control muffins lacking flavor, whereas 30% BSG muffins either lacked flavor or higher concentrations produced flavor off-notes. Mechanistically, enzymatic and fermentation activities are influenced by water availability and distribution. BSG fiber binds water limiting its availability for α -amylase activity, thus decreasing the release of maltose and glucose affecting fermentation [18]. Therefore, higher additions of BSG can limit the formation or release rates of aromatic and flavor compounds, reducing the overall taste and aroma of the finished baked good.

Interestingly, 20% BSG muffins were rated slightly higher (6.85 ± 0.169) for overall liking compared to the control (6.55 ± 0.150) and 30% BSG (6.64 ± 0.183) muffins, but there were no significant differences in overall liking scores among the three muffins demonstrating acceptability of all muffin variations. This is contradictory to previous studies that found overall acceptability was reduced in samples containing more than 10% BSG [39, 40]. Panelist inclusion criteria included individuals who regularly consume whole grain baked goods. Therefore, it is possible that the panelists preferred the sensory attributes of baked goods made with whole grains compared to all-purpose flour. This would explain the slight increase in the acceptability of 20% BSG muffins compared to the control muffins. Conflicting findings may also result from variations in BSG

TABLE 4: Correlations¹ between muffin attributes.

Variables	Overall liking	Appearance	Texture	Moistness	Sponginess	Taste
Overall liking	1	0.079	0.264	0.859	-0.847	0.980
Appearance	0.079	1	0.982	-0.443	0.463	0.275
Texture	0.264	0.982	1	-0.267	0.289	0.450
Moistness	0.859	-0.443	-0.267	1	-1.000	0.740
Sponginess	-0.847	0.463	0.289	-1.000	1	-0.725
Taste	0.980	0.275	0.450	0.740	-0.725	1

¹Pearson's correlation analysis ($n = 107$). **Values in bold are different from 0 with a significance level of $P = 0.5$.

concentrations or particle sizes evaluated. The present study did not evaluate concentrations below 20% BSG, whereas other studies focused on ranges between 5 and 50% BSG affording panelists the opportunity to prefer BSG additions lower than 20% [18, 21, 41, 42]. Muffins containing 30% BSG received acceptable ratings (mean score ≥ 5) on all attributes evaluated, supporting increased BSG fortification concentrations for future baked goods. However, these recommendations should be carefully considered because the muffins used in this sensory evaluation contain sugar and fat that may mask off-flavors.

There were no significant texture differences between the three muffin groups. However, Tukey's HSD showed that 20% muffins were rated on average 6.6% higher ($P = 0.044$) than 30% muffin ratings. Significant differences may be reached if larger sample sizes were explored as texture did not reach power in univariate testing. Figure 2 shows a similar trend between appearance and texture ratings, with 30% muffins receiving lower ratings compared to control and 20% muffin ratings. The primary cause of textural changes results from higher fiber contents, which increases the water holding capacity and dilutes the gluten network creating a closed, compact structure with increased hardness [22, 43].

Lastly, there were no significant differences perceived by the panelists in moistness or sponginess among the three muffin types. It is possible that these two attributes were not understood by the untrained consumer panelists, resulting in a halo effect where ratings for one attribute influence others leading to similar ratings for all muffins on moistness and sponginess. Additionally, untrained panelists tend to keep ratings in the central part of the scale minimizing sample differences [44]. This sensory verdict psychological factor is known as timidity.

3.4. Relationship between Overall Liking of Muffins and Appearance, Texture, Moistness, Sponginess, and Taste. Pearson's product-moment correlations and multiple linear regression were conducted to examine correlations among muffin attributes and predictors of muffin overall liking. The bivariate correlation analysis revealed moistness ($r = 0.859$), sponginess ($r = -0.847$), and taste ($r = 0.980$) were significantly correlated with overall liking (Table 4). Moistness and taste were strongly positively correlated with overall liking, while sponginess was strongly negatively corrected with overall liking. Appearance and texture were not significantly correlated with overall liking. The addition of caramel color

minimized visual variations between muffins, which may have resulted in the insignificant correlation of appearance and overall liking. BSG darkens the color of foods [18, 40] and can result in rejecting the food before taste or texture is experienced [5]. Caramel color was incorporated to minimize possible psychological bias of color on the overall appearance of muffins and other attributes being evaluated. Findings from this study will be used to support BSG usage rates in test muffins consumed in future feeding trials where participants will consume muffins each day for several weeks. Therefore, higher BSG concentrations that maintain palatability and promote compliance are needed to produce biological effects.

The overall model predicting muffin overall liking from appearance, texture, moistness, sponginess, and taste attributes was significant ($F(5, 315) = 220.88$, $P < 0.001$) and accounted for 77.8% of the variance (Table 5). Appearance ($\beta = 0.088$, $P = 0.005$), texture ($\beta = 0.181$, $P < 0.001$), sponginess ($\beta = 0.226$, $P < 0.001$), and taste ($\beta = 0.494$, $P < 0.001$) were significant predictors of overall liking. Taste obtained the highest unstandardized coefficient value of all predictors, meaning for each one unit increase on the 9-point hedonic scale, there is an increase in overall liking by nearly half ($B = 0.419$, $P < 0.001$) a hedonic scale rating unit. These findings are not surprising as taste is considered an important biological determinant of food choice [45]. Other studies evaluating the impact of BSG on consumer acceptance have found similar results. Torbica et al. [46] and Ktenioudaki et al. [18] reported taste and texture as predominant attributes influencing the panelist's acceptability of BSG food products. Earlier studies evaluating barley baked goods concluded flavor and texture were the most influential sensory variables from their strong relationship ($R^2 = 0.61$) with the overall acceptability of functional barley tortillas [47]. Using stepwise multiple linear regression, Omary et al. [48] found strong possibilities to predict overall acceptability and flavor from other sensory scores such as appearance, color, and texture. The authors concluded flavor and texture were the two primary parameters consumers consider when purchasing and consuming food. Consumer acceptance may be driven by muffin flavor and texture, but determining which specific descriptors drive higher ratings, thus increasing overall liking, is not within the scope of this study. Future studies should focus on sensory lexicon development to determine taste and flavor descriptors that drive overall liking and follow-up consumer testing using individuals that better represent the entire population.

TABLE 5: Multiple linear regression model¹ using sensory attributes to predict overall liking of muffins.

Predictor	Unstandardized		Standardized			95% CI	
	β	SE	β	<i>t</i>	<i>P</i>	<i>LL</i>	<i>UL</i>
Appearance	0.080	0.03	0.088	2.81	0.005	0.024	0.136
Texture	0.156	0.04	0.181	4.02	<0.001	0.079	0.232
Moistness	0.041	0.04	0.048	1.10	0.273	-0.033	0.115
Sponginess	0.118	0.04	0.226	4.54	<0.001	0.106	0.269
Taste	0.419	0.03	0.494	13.80	<0.001	0.359	0.479

¹Model predicting muffin overall liking, $F(5, 315) = 220.88$, $P < .001$, $R^2 = 0.778$, and adjusted $R^2 = 0.775$. The level of significance is at $P < 0.05$.

4. Conclusions

BSG is the largest by-product of the brewing industry, generating high volumes of wasted food with potential human nutrition benefits. Mini muffins containing varying amounts of BSG were developed from previous focus group discussions followed by sensory testing to evaluate the acceptance of muffins. Sensory testing is necessary due to organoleptic limitations of BSG addition to food. There were no significant differences found among the muffins for overall acceptance. However, control and 20% BSG muffins received significantly higher appearance ratings than 30% BSG muffins, and 20% BSG muffins received significantly higher taste ratings than control and 30% BSG muffins. These findings revealed that 20% BSG muffins received generally higher ratings than the other two muffins, but 30% BSG muffins maintained acceptable ratings on all attributes indicating panelists accepted muffins with higher quantities of BSG. With all three muffins maintaining consumer acceptance, the 30% BSG-fortified muffins shown here provide greater opportunities to elicit biological responses due to increased concentrations of protein, fiber, and antioxidants. These findings will support future human feeding trials involving BSG consumption and its impact on heart health benefits. Utilizing BSG for food fortification will address the need for healthier products in the market while aiding in the reduction of food waste and promotion of food sustainability.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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