



The Effect of Gluten Removal on The Physical & Sensory Attributes of Chocolate Chip Muffins

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ABSTRACT

Gluten-free diets are essential for individuals with celiac disease and other gluten-related disorders. However, the removal of gluten from baked goods often alters structure, texture, and overall acceptability. Muffins rely heavily on gluten for volume, crumb structure, and overall sensory quality, making them an effective model for evaluating gluten-free flour alternatives. The objective of this study was to determine how substituting all-purpose flour with gluten-free alternatives affects the physical characteristics, sensory attributes, and nutritional profile of chocolate chip muffins. Four muffin formulations were prepared using all-purpose flour (control), a commercial 1-to-1 gluten-free flour blend, a homemade (DIY) gluten-free flour blend, and cassava flour. All formulations followed a standardized recipe, with flour type serving as the only experimental variable. Objective physical measurements included muffin volume and height. Sensory evaluation was conducted by an untrained panel ($n = 7$) using a 7-point hedonic scale to assess overall liking, sweetness, moistness, and crumb density. Nutritional profiles were generated using a USDA-based nutrient analysis tool. Statistical analysis was performed using pairwise t-tests with a significance level of $\alpha = 0.05$. Results indicated that flour type influenced physical and sensory outcomes. Muffins prepared with all-purpose flour exhibited the greatest height, while the commercial 1-to-1 gluten-free formulation achieved comparable volume. Cassava flour muffins received significantly lower overall liking scores compared to the control ($p < 0.05$), whereas most other sensory attributes did not differ significantly among formulations. Nutritional analysis revealed reduced protein and iron content in gluten-free muffins, with cassava flour providing higher dietary fiber.

INTRODUCTION

Celiac disease is a chronic autoimmune disorder in which ingestion of gluten triggers an abnormal immune response in genetically susceptible individuals. This results in inflammation of the small intestine and progressive damage to the intestinal mucosa, often leading to villous atrophy and impaired nutrient absorption (Kowalski et al., 2025a). Because even trace amounts of gluten can provoke symptoms and intestinal injury, management of celiac disease requires strict, lifelong dietary avoidance of gluten. In addition to individuals who are formally diagnosed, many people experience gluten sensitivity or intolerance without meeting full diagnostic criteria, suggesting that a larger population is affected by gluten-related disorders than

is currently reported (Kowalski et al., 2025b). From a public health perspective, celiac disease represents a significant and ongoing concern due to its prevalence, underdiagnosis, and lifelong treatment burden. It is estimated to affect approximately 1 in 100 individuals worldwide; however, only a minority of cases are properly diagnosed, indicating that many individuals remain untreated or misdiagnosed (Celiac Disease Foundation, n.d.). Celiac disease may develop at any age following the introduction of gluten into the diet, and untreated disease is associated with increased risk of long-term health complications, including nutrient deficiencies and other chronic conditions. Strict dietary adherence is currently the only effective treatment. This means the availability, quality, and acceptability of gluten-free food products are critical components in supporting dietary compliance and long-term health outcomes for affected individuals.

Chocolate chip muffins were selected as the model food product for this study because they are a widely consumed baked good that relies heavily on gluten-containing flour for structural integrity, volume, and overall sensory appeal. In traditional muffin formulations, the wheat in all-purpose flour provides gluten which contributes to batter viscosity, gas retention during baking, and the final texture and crumb structure of the product. For individuals who must adhere to a strict gluten-free diet, muffins and other baked goods often present sensory and physical challenges due to the absence of gluten's functional properties. In this experiment, all-purpose flour served as the control, while three gluten-free alternatives were evaluated: a commercial 1-to-1 gluten-free flour blend, a homemade gluten-free flour blend, and cassava flour. The homemade gluten-free blend was prepared using a mixture of white rice flour (2.8 oz), potato starch (1.28 oz), and tapioca flour (0.53 oz), which was thoroughly combined and then portioned to match the experimental conditions. To minimize variability and isolate the effect of flour type, all flour treatments were standardized by weight, with 4.0 oz of flour used in each muffin formulation. This controlled approach ensured that differences observed in objective measurements (volume and height) and sensory attributes (overall liking, sweetness, moistness, and crumb density) could be attributed primarily to flour composition rather than differences in ingredient quantity.

Substituting gluten-containing flour with gluten-free alternatives is essential for individuals with celiac disease, as strict and lifelong avoidance of gluten is the only effective treatment currently available. Even minimal gluten exposure can trigger intestinal inflammation

and mucosal damage, making traditional wheat-based baked goods unsuitable for this population (Kowalski et al., 2025a). However, baked products like muffins are commonly consumed and culturally significant, which can make long-term dietary adherence challenging when acceptable gluten-free options are limited. Developing gluten-free formulations that closely resemble conventional products in texture, structure, and sensory quality may help improve dietary compliance and overall quality of life for individuals with celiac disease. By evaluating gluten-free flour alternatives in a familiar baked product, this study addresses both the clinical necessity of gluten avoidance and the practical challenges associated with maintaining a restrictive diet.

Gluten plays a critical functional role in baked goods by forming a viscoelastic protein network that contributes to batter structure, gas retention, and overall product volume. During mixing and baking, gluten proteins hydrate and interact to create elasticity and strength, allowing the batter to trap carbon dioxide produced by leavening agents and expand uniformly. Removal of gluten disrupts this network, often resulting in reduced volume, decreased height, increased crumb density, and altered texture in baked products. Gluten-free formulations therefore rely on alternative flours and starches to partially replicate these functional properties, but these substitutions vary widely in their ability to provide structure and moisture retention (Ho et al., 2019; Park & Kim, 2023).

Several gluten-free flour alternatives were selected for this study to reflect both commercially available options and common home-baking practices. A commercially available 1-to-1 gluten-free flour blend was included because it is widely marketed as a direct replacement for all-purpose flour and is commonly used by consumers following a gluten-free diet. A DIY gluten-free flour blend composed of white rice flour, potato starch, and tapioca flour was formulated to represent a customizable alternative frequently used in gluten-free baking. These ingredients were specifically chosen because they are among the primary components commonly found in commercial 1-to-1 gluten-free flour blends, allowing for a more direct comparison between a standardized commercial product and a simplified, home-prepared formulation. Rice flour provides bulk and a neutral flavor, while potato starch and tapioca flour contribute to moisture retention, tenderness, and structure – partially compensating for the absence of gluten (Ho et al., 2019; Park & Kim, 2023). Cassava flour was included due to its increasing use as a gluten-free and grain-free alternative with functional properties that more closely resemble all-

purpose flour, including higher starch content and water-binding capacity (Chisenga et al., 2019; Sangpueak et al., 2022). To isolate the effects of flour type on physical and sensory outcomes, all four formulations were standardized by weight, with 4.0 oz of each flour used in the muffin formulations, allowing differences in volume, height, crumb density, and sensory attributes to be attributed primarily to flour composition rather than formulation variability. Here are the following hypotheses:

- **H₁:** If gluten-containing flour is replaced with gluten-free flour alternatives, then the nutritional profile of the muffins will differ from the control formulation, because gluten-free flours vary in fiber and micronutrient content compared to all-purpose flour.
- **H₂:** If muffins are prepared using gluten-free flour alternatives instead of all-purpose flour, then they will exhibit lower overall volume, because the absence of gluten limits gas retention and structural expansion during baking.
- **H₃:** If muffins are prepared using gluten-free flour alternatives instead of all-purpose flour, then they will have reduced height, because gluten provides the structural strength required for vertical rise during baking.
- **H₄:** If muffins are prepared using gluten-free flour alternatives instead of all-purpose flour, then they will receive lower overall liking scores, because changes in texture and crumb structure may negatively affect consumer acceptability.
- **H₅:** If muffins are prepared using different gluten-free flour formulations, then perceived sweetness will differ among samples, because variations in starch composition can influence sweetness perception despite identical sugar content.
- **H₆:** If muffins are prepared using gluten-free flours with higher starch content, then they will be perceived as more moist, because alternative starches have greater water-binding capacity than all-purpose flour.
- **H₇:** If muffins are prepared using gluten-free flour alternatives instead of all-purpose flour, then they will be perceived as having greater crumb density, because the absence of gluten reduces crumb elasticity and crumb openness.

MATERIALS AND METHODS

The materials and methods used in this study are described in detail to allow for replication of the experiment procedure. This section outlines the ingredients, equipment, and

preparation methods used to produce four muffin formulations differing only by flour type.

Objective measurements and sensory evaluations were conducted to assess the effects of gluten removal on physical characteristics and consumer perception. Ingredients and their sources are summarized in Table 1, equipment used during product preparation and evaluation is listed in Table 2, and the standardized muffin recipe used across all treatments is provided in Table 3. These tables are followed by a detailed description of product preparation, objective and sensory measurements, and statistical analysis.

Table 2: Equipment Used During Product Preparation and Evaluation			
Equipment	Specification/Description	Quantity	Manufacturer (if known)
Muffin pan	Standard 8-cup pan	8	Lab provided
Mixing bowls	Used for wet and dry ingredients	8	Lab provided
Rubber spatula	Mixing ingredients	4	Lab provided
Whisk	Batter mixing	4	Lab provided
Digital scale	Weighing flour (oz)	1	Lab provided
Measuring cups	1/2 cup, 1/3 cup	2	Lab provided
Measuring spoons	1 tsp, 1/4 tsp	2	Lab provided
Cookie scoop	Portioning batter evenly	4	Lab provided
Muffin liners	Paper liners	32	Lab provided
Oven mitts	Removing pans from oven	1 pair	Lab provided
Oven	Baking muffins	1	Lab provided
Toothpicks	Doneness testing	As needed	Lab provided
Beakers	Volume displacement	Multiple	Lab provided
Graduated cylinders	Volume measurement	Multiple	Lab provided
Rice	Volume displacement	450 mL	Lab provided

Table 1: Ingredients and Sources Used in Muffin Preparation		
Ingredient	Amount Used	Ingredient Source (Brand, Location)
All-purpose flour	4.0 oz	Lab provided (brand unknown), New Brunswick, NJ
1-to-1 gluten-free flour	4.0 oz	Bob's Red Mill, Milwaukie, OR
Cassava flour	4.0 oz	Otto's Naturals, San Diego, CA
White rice flour	2.8 oz*	Bob's Red Mill, Milwaukie, OR
Potato starch	1.28 oz*	Bob's Red Mill, Milwaukie, OR
Tapioca flour	0.53 oz*	Bob's Red Mill, Milwaukie, OR
Baking powder	0.57 oz	Lab provided (brand unknown), New Brunswick, NJ
Brown sugar	7.1 oz	Domino Sugar, Yonkers, NY
Vegetable oil	10.64 fl oz	Lab provided (brand unknown), New Brunswick, NJ
Oat milk, unsweetened	10.64 fl oz	Planet Oat, Louisville, KY
Vanilla extract	0.67 oz	Kirkland Signature, Issaquah, WA
Mini chocolate chips	12.0 oz	Bowl & Basket (ShopRite), Keasbey, NJ
Salt	0.22 oz	Morton Salt, Chicago, IL
Eggs	4 large	Grocery store source, New Brunswick, NJ
*Combined and mixed to form DIY gluten-free flour blend; 4.0 oz of the blended mixture was used per formulation		

Product Preparation

Chocolate chip muffins were prepared using four different flour formulations: all-purpose flour (control), a commercial 1-to-1 gluten-free flour blend, a homemade gluten-free flour blend, and cassava flour. All muffin formulations followed the same base recipe, with flour type serving as the only experimental variable. To maintain consistency across treatments, flour was weighed using a digital scale, and 4.0 oz of flour was used for each formulation. The standardized chocolate chip muffin recipe, including ingredient quantities and preparation steps, is provided in Table 3.

Table 3: Original Chocolate Chip Muffin Recipe (Standardized Across Treatments)			
Ingredient	Home Measure	Equivalent Amount	Notes
Flour (all-purpose or gluten-free alternative)	1 cup	4.0 oz (wt)	Flour type varied by treatment
Baking powder	1 tsp	0.57 oz	
Salt	1/4 tsp	0.22 oz	
Dark brown sugar, packed	1/3 cup	7.1 oz	
Dairy-free milk	1/3 cup	10.64 fl oz	Oat milk used
Vegetable oil	1/3 cup	10.64 fl oz	
Egg	1 large	—	
Vanilla extract	1 tsp	0.67 oz	
Semisweet chocolate chips	1/2 cup	12 oz	Mini chips

Preparation Instructions	
Steps	Procedure
Oven preparation	Oven was preheated to 375°F; rack positioned in the center
Pan preparation	Standard muffin pan lined with paper liners
Dry mixing	Flour, baking powder, salt, and brown sugar were combined until uniform
Wet mixing	Milk, oil, egg, and vanilla were whisked until homogeneous
Batter formation	Wet ingredients were gently incorporated into dry ingredients until just combined
Chocolate chips	Folded evenly into batter
Portioning	Batter portioned evenly into muffin liners
Baking	Muffins baked at 375°F for 18 minutes
Doneness	Toothpick inserted; minimal crumbs observed
Cooling	Muffins cooled in pan for 10 minutes at room temperature

The homemade gluten-free flour blend was prepared by combining white rice flour (2.8 oz), potato starch (1.28 oz), and tapioca flour (0.53 oz). These ingredients were thoroughly mixed to form a uniform blend, after which a 4.0 oz portion of the mixture was weighed and incorporated into the muffin batter to match the flour weight used in all other treatments.

For each formulation, dry ingredients – including flour, baking powder, salt, and brown sugar – were combined in a mixing bowl and mixed until evenly distributed. Wet ingredients –

consisting of eggs, oat milk, vegetable oil, and vanilla extract – were combined separately and whisked until homogeneous. The wet ingredients were then added to the dry ingredients and mixed gently until a uniform batter formed. Mini chocolate chips were folded into the batter as the final step.

Muffin pans were lined with paper liners, and batter was portioned evenly into each liner using a cookie scoop to ensure consistent portion size across samples. Each formulation yielded eight muffins. Muffins were baked under identical conditions for all treatments and allowed to cool at room temperature prior to objective and sensory evaluation.

Objective Physical Measurements

Objective measurements were performed to evaluate differences in muffin volume and height across flour treatments. All measurements were conducted after muffins had cooled to room temperature.

Muffin height was measured using a ruler by determining the vertical distance from the base of the muffin liner to the highest point of the muffin dome. Measurements were recorded in millimeters (mm) for each individual muffin, and an average height was calculated for each flour treatment. Muffin volume was determined using the seed displacement method with dry rice. Each muffin was placed into a graduated container, partially filled with rice, and the volume of rice displaced was recorded in milliliters (mL). This method was selected to accommodate the irregular shape of muffins and to ensure consistent measurement across samples. Volume measurements were collected for each muffin and averaged by treatment group.

Sensory Evaluation

Sensory evaluation was conducted to assess perceived differences in appearance, texture, flavor, and overall liking among the four muffin formulations. A panel of untrained participants ($n = 7$) evaluated the samples using a standardized sensory ballot with a 7-point hedonic scale, where 1 represented the least favorable perception and 7 represented the most favorable perception (Figure 1).

Each panelist evaluated coded muffin samples for exterior appearance (golden-brown color), interior appearance (crumb uniformity), crumb density, texture (graininess and moistness), sweetness, flavor characteristics, and overall liking. Samples were labeled using three-digit randomized codes to minimize bias, and evaluations were completed independently. Panelists were instructed to cleanse their palate between samples as needed. Completed sensory ballots were collected, and scores were recorded for statistical analysis.

		Rate the samples from 1 (LEAST) to 7 (MOST)			
		Sample ID			
Category	Rated For	372	619	845	504
Appearance (Exterior)	Golden brown color	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Appearance (Interior)	Even Crumb	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Appearance Crumb	Dense	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Texture	Grainy	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Texture	Moist	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Taste	Sweet	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Flavor	Earthy	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Presence of after taste?	Yes/No, Describe				
Overall Liking		1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Comments					

Figure 1: Sensory evaluation ballot used to assess appearance, texture, flavor, and overall liking of muffin samples using a 7-point hedonic scale.

Statistical Evaluation

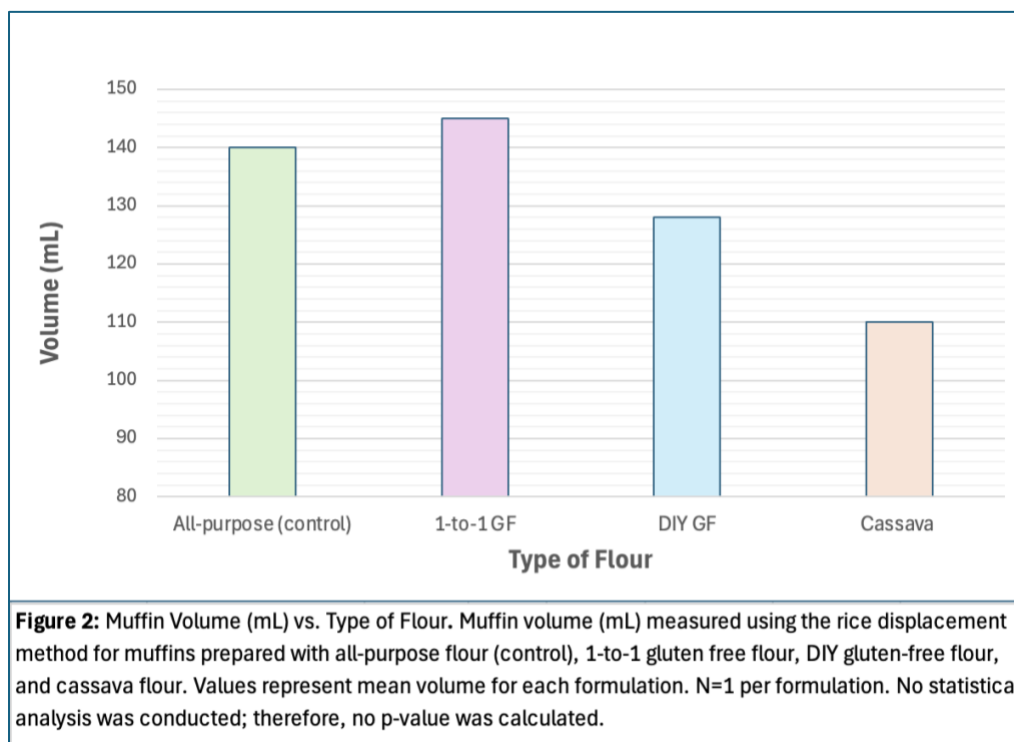
Statistical analysis was performed to determine whether differences among muffin formulations were statistically significant. For objective physical measurements (volume and height), mean values were calculated for each flour treatment. Sensory data were analyzed using mean hedonic scores and standard deviations for each attribute, including overall liking, perceived sweetness, moistness, and crumb density.

Pairwise comparisons between formulations were conducted using two-tailed t-tests. The all-purpose flour muffin served as the primary control for comparisons with gluten-free formulations. Additional pairwise comparisons among gluten-free treatments were performed where appropriate. Statistical significance was determined using a significance level of $\alpha = 0.05$. Differences were considered statistically significant when p-values were less than 0.05, and not statistically significant when p-values exceeded 0.05.

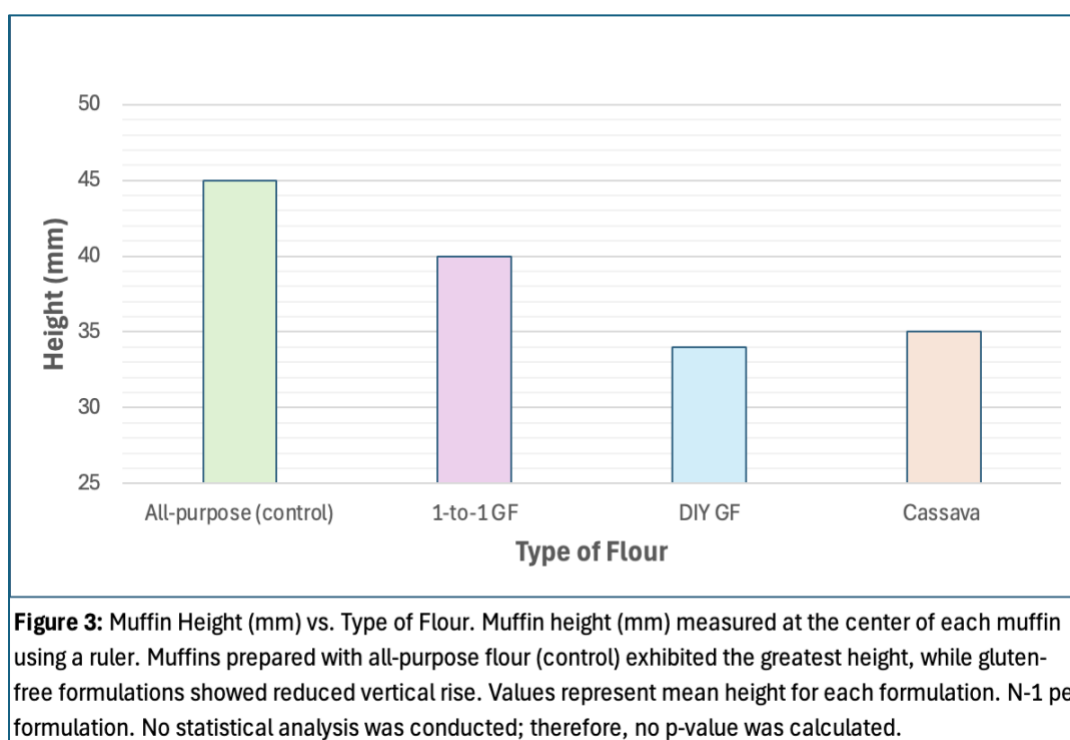
RESULTS

Objective Physical Measurements

Objective physical measurements were conducted to evaluate the effects of flour type on muffin volume and height. Mean values for volume (mL) and height (mm) are presented in Figures 2 and 3, respectively. Muffin volume varied across flour treatments (Figure 2). The commercial 1-to-1 gluten-free flour produced the greatest mean volume (145 mL), exceeding that of the all-purpose flour (140 mL). The DIY gluten-free formulation resulted in a moderate volume (128 mL), while cassava flour produced the lowest mean volume (110 mL). These results indicate that gluten removal did not universally reduce muffin volume, as the commercial gluten-free blend showed slightly greater expansion in comparison to the all-purpose flour.



Muffin height followed a different trend (Figure 3). The all-purpose flour produced the tallest muffins, with a mean height of 45 mm. Muffins prepared with the 1-to-1 gluten-free flour showed a modest reduction in height (40 mm), while the DIY gluten-free formulation exhibited the lowest mean height (34 mm). Cassava flour muffins displayed a mean height of 35 mm, slightly greater than the DIY formulation but still substantially lower than the control. These findings indicate that while some gluten-free formulations were able to achieve adequate volume, vertical rise was more consistently reduced in the absence of gluten.

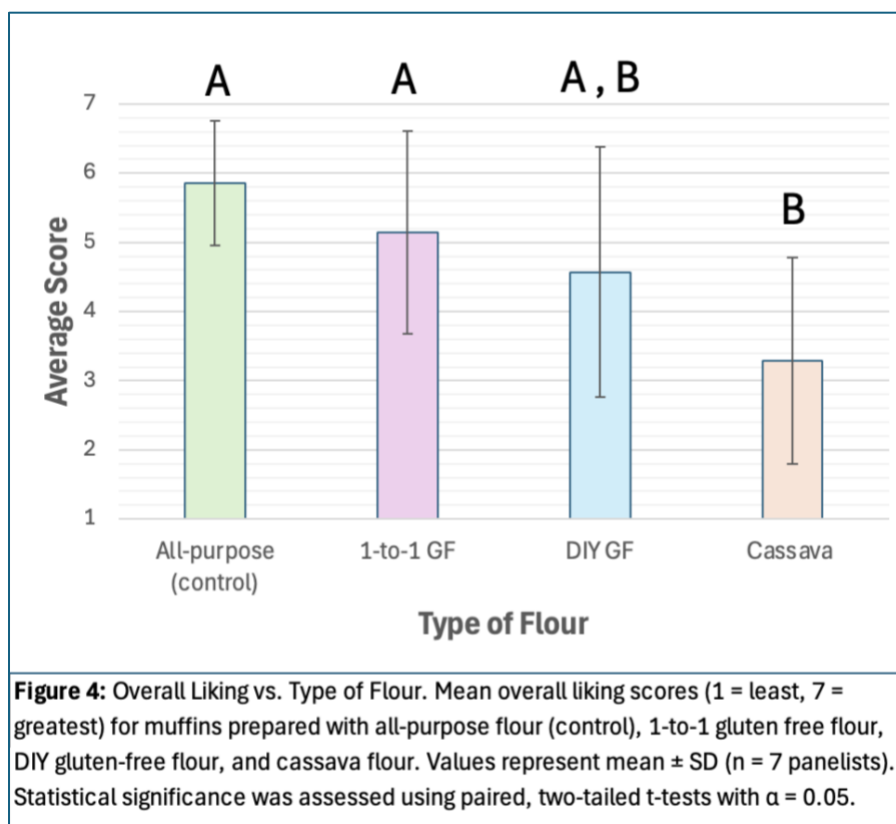


Sensory Evaluation Results

Sensory evaluation was conducted to assess perceived differences in appearance, texture, flavor attributes, and overall liking among the four muffin formulations. Mean sensory scores \pm standard deviations are presented in Figures 4 – 7.

Overall Liking

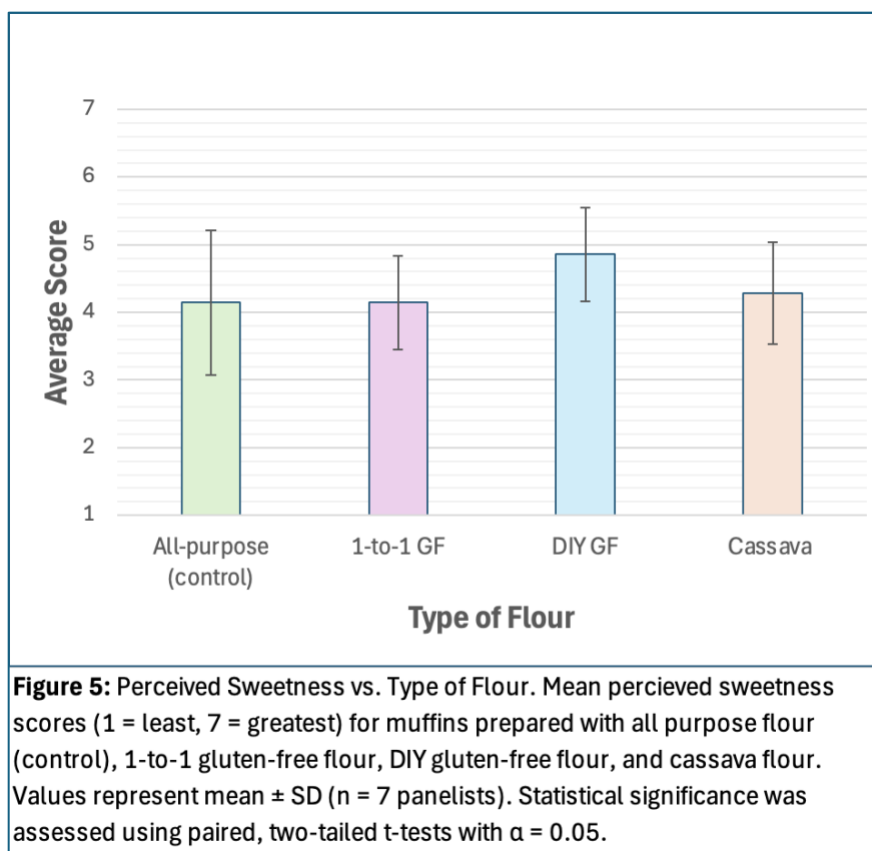
Mean overall liking scores differed across flour treatments (Figure 4). The all-purpose flour (control) received the highest average score (5.86 ± 0.90), followed by the 1-to-1 gluten-free formulation (5.14 ± 1.46), and the DIY gluten-free formulation (4.57 ± 1.81). Cassava flour muffins received the lowest overall liking score (3.29 ± 1.50).



Statistical analysis revealed that cassava flour muffins were rated significantly lower in overall liking compared to the control ($p = 0.002$) and the 1-to-1 gluten free muffins ($p = 0.04$). No statistically significant differences were observed between the control and either the 1-to-1 gluten free or DIY gluten-free formulations ($p > 0.05$).

Perceived Sweetness

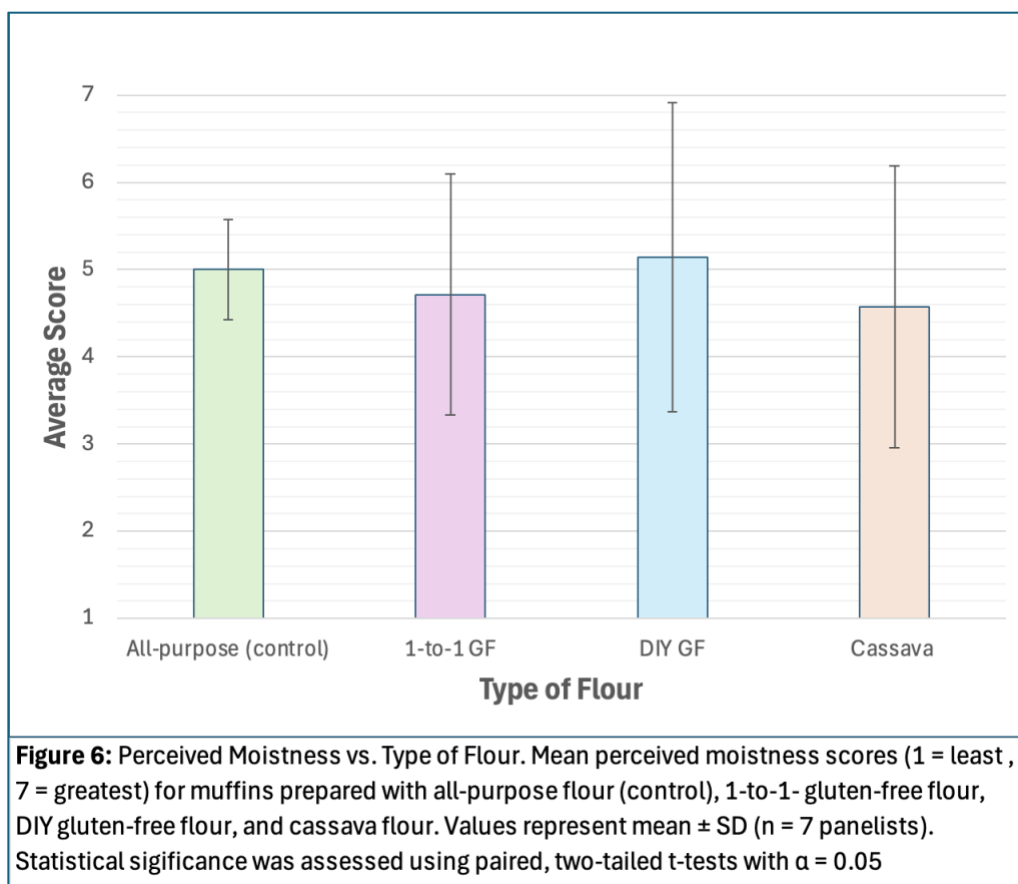
Perceived sweetness scores were relatively consistent across treatments (Figure 5). The DIY gluten-free formulation received the highest mean sweetness score (4.86 ± 0.69), while the control and 1-to-1 gluten free muffins both received identical average scores (4.14 ± 1.07 and 4.14 ± 0.69 , respectively). Cassava flour muffins had a mean sweetness score of 4.29 ± 0.76 .



Statistical comparisons indicated no significant differences in perceived sweetness between the control and any gluten-free formulation ($p > 0.05$). These findings suggest that flour type did not significantly influence sweetness perception, despite differences in starch composition among formulations.

Perceived Moistness

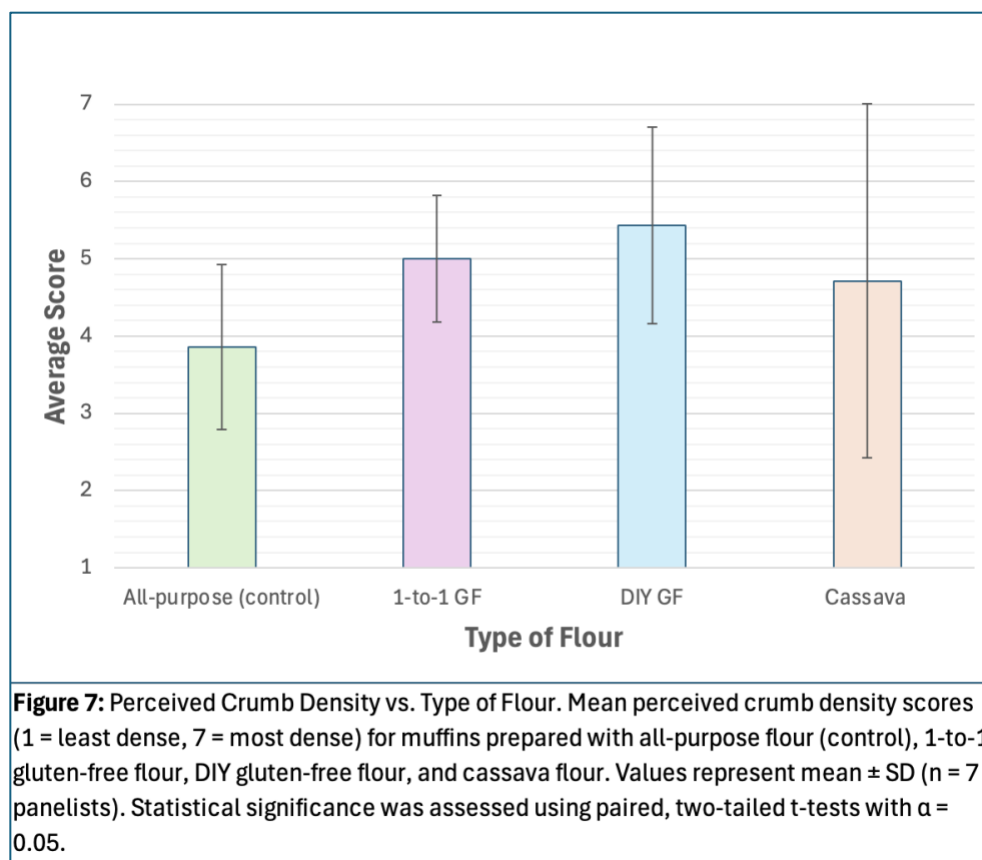
Mean moistness scores are presented in Figure 6. The DIY gluten-free formulation received the highest average moistness score (5.14 ± 1.77), followed by the control (5.00 ± 0.58), the 1-to-1 gluten-free formulation (4.71 ± 1.38), and cassava flour (4.57 ± 1.62).



No statistically significant differences in moistness were observed between the control and any gluten-free formulation ($p > 0.05$). Although numerical differences were present, particularly for the DIY gluten free muffins, variability among panelist responses likely contributed to the lack of statistical significance.

Perceived Crumb Density

Perceived crumb density scores differed across treatments (Figure 7). The control received the lowest average crumb density score (3.86 ± 1.07), indicating a less dense crumb. Higher crumb density scores were observed for the gluten-free formulations, with the DIY gluten-free muffins receiving the highest average score (5.43 ± 1.27), followed by the 1-to-1 gluten-free (5.00 ± 0.82) and cassava flour muffins (4.71 ± 2.29).



Despite these numerical differences, statistical analysis showed no significant differences in perceived crumb density between the control and gluten-free formulations ($p > 0.05$). This suggests that while panelists perceived textural differences, these differences were not consistent enough across evaluations to reach statistical significance.

Nutritional Analysis

Nutritional differences among muffin formulations were evaluated using nutrition facts labels generated through Cronometer, a USDA-based nutrient analysis tool (Figure 8). All formulations were standardized to a serving size of one muffin to allow for direct comparison.

Muffin: All-Purpose Flour	Muffin: 1-to-1 Gluten-Free Flour	Muffin: DIY Gluten-Free Flour	Muffin: Cassava Flour
Nutrition Facts Serving Size 1 Muffin Amount Per Serving Calories 228.9 % Daily Value* Total Fat 13 g 17 % Saturated Fat 3.3 g 17 % Trans Fat 0 g Cholesterol 24.4 mg 8 % Sodium 148.3 mg 6 % Total Carbohydrate 27.1 g 10 % Dietary Fiber 1.2 g 4 % Total Sugars 14.3 g Added Sugars 0 g 0 % Protein 3 g Vitamin D 0.3 mcg 2 % Calcium 60.7 mg 5 % Iron 1.9 mg 11 % Potassium 95.7 mg 2 % <small>* The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.</small> Full Info at cronometer.com </>	Nutrition Facts Serving Size 1 Muffin Amount Per Serving Calories 225.6 % Daily Value* Total Fat 12.8 g 16 % Saturated Fat 3.3 g 16 % Trans Fat 0 g Cholesterol 24.4 mg 8 % Sodium 151.8 mg 7 % Total Carbohydrate 27.7 g 10 % Dietary Fiber 1.1 g 4 % Total Sugars 14.2 g Added Sugars 0 g 0 % Protein 2.3 g Vitamin D 0.3 mcg 2 % Calcium 59.5 mg 5 % Iron 1.1 mg 6 % Potassium 99 mg 2 % <small>* The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.</small> Full Info at cronometer.com </>	Nutrition Facts Serving Size 1 Muffin Amount Per Serving Calories 225.8 % Daily Value* Total Fat 13 g 17 % Saturated Fat 3.3 g 17 % Trans Fat 0 g Cholesterol 24.4 mg 8 % Sodium 148.8 mg 6 % Total Carbohydrate 27.6 g 10 % Dietary Fiber 1 g 4 % Total Sugars 14.2 g Added Sugars 0 g 0 % Protein 2.1 g Vitamin D 0.3 mcg 2 % Calcium 59.5 mg 5 % Iron 1.2 mg 6 % Potassium 85.2 mg 2 % <small>* The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.</small> Full Info at cronometer.com </>	Nutrition Facts Serving Size 1 Muffin Amount Per Serving Calories 224.5 % Daily Value* Total Fat 12.8 g 16 % Saturated Fat 3.3 g 16 % Trans Fat 0 g Cholesterol 24.4 mg 8 % Sodium 148 mg 6 % Total Carbohydrate 28.6 g 10 % Dietary Fiber 2.1 g 7 % Total Sugars 14.2 g Added Sugars 0 g 0 % Protein 1.9 g Vitamin D 0.3 mcg 2 % Calcium 72.1 mg 6 % Iron 1.1 mg 6 % Potassium 113.2 mg 2 % <small>* The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.</small> Full Info at cronometer.com </>

Figure 8: Nutrition facts labels for muffins prepared with all-purpose flour (control), 1-to-1 gluten-free flour, DIY gluten-free flour, and cassava flour. Labels were generated using Cronometer (USDA-based database) and reflect nutrient composition per muffin. Circled values highlight differences associated with flour substitution.

Protein content was highest in the all-purpose flour (3.0 g per muffin) and decreased across gluten-free formulations, with the lowest protein content observed in the cassava flour muffins (1.9 g per muffin). This reduction reflects the absence of gluten-containing proteins in the gluten-free flours. Iron content was also greater in the all-purpose flour formulation compared to gluten-free alternatives, most likely due to the enrichment of all-purpose flour.

Dietary fiber content varied among gluten-free formulations, with cassava flour muffins exhibiting the highest fiber content (2.1 g per muffin), compared to both the all-purpose flour and other gluten-free treatments. This increase is consistent with the naturally higher fiber content of cassava flour. Calcium and potassium levels were also slightly higher in the cassava formulation, indicating modest micronutrient differences associated with flour type.

Total caloric content and macronutrient distribution remained relatively consistent across all formulations, suggesting that flour substitution primarily influenced specific micronutrients and protein content rather than overall energy density.

DISCUSSION

The purpose of this study was to evaluate the effects of substituting all-purpose flour with gluten-free alternatives on the physical characteristics, sensory attributes, and nutritional profile of chocolate chip muffins. Gluten plays a critical functional role in baked goods by contributing to structure, gas retention, and crumb elasticity during baking. This means that the removal of gluten can pose both technical and sensory challenges. By comparing all-purpose flour (control) to a commercial 1-to-1 gluten-free flour blend, a homemade gluten-free flour, and cassava flour, this study aimed to assess how different gluten-free formulations perform in a familiar baked product. Overall, the results demonstrated that flour type significantly influenced muffin structure, sensory perception, and select nutritional characteristics, with outcomes that both aligned with and deviated from initial expectations.

Differences observed in objective physical measurements highlight the functional importance of gluten during baking. As expected, muffins prepared with all-purpose flour exhibited the greatest height, supporting the hypothesis that gluten is essential for vertical rise and structural strength. Gluten's viscoelastic protein network allows batter to trap carbon dioxide during baking, resulting in greater expansion and lift. Unlike the all-purpose flour, muffins prepared with the DIY gluten-free blend and cassava flour exhibited a reduction in height most likely due to the absence of a protein network capable of supporting vertical expansion. It's important to note that muffins made with the commercial 1-to-1 gluten-free flour achieved a volume similar to, and slightly greater than, the control. This unexpected result suggests that commercially formulated blends may effectively compensate for the absence of gluten through the inclusion of refined starches and other functional ingredients designed to improve gas retention and batter viscosity.

Sensory evaluation results further illustrated how flour composition influences consumer perception. Overall liking scores were highest for the all-purpose flour (control), which was expected due to gluten's contribution to texture and crumb structure. However, the commercial 1-to-1 gluten-free muffins were not rated significantly lower than the control, hinting that commercially available gluten-free blends may provide acceptable sensory quality for individuals following a gluten-free diet. However, cassava flour muffins received significantly lower overall liking scores, suggesting that while cassava flour may offer functional and

nutritional benefits, the sensory properties may be less desirable in this application. These findings partially support the hypothesis that gluten-free muffins would receive lower liking scores, while also demonstrating that not all gluten-free formulations perform equally.

Perceived crumb density and texture differed among formulations in a manner consistent with gluten functionality. Gluten-free muffins were generally rated as more dense than the control, especially those prepared with the DIY blend. This trend aligns with the known role of gluten in forming an elastic network that supports an open crumb structure. Without gluten, starch-based flours often gelatinize without forming interconnected networks, resulting in denser products. Although differences in crumb density were not statistically significant, the overall trend suggests that flour formulation influences textural perception, even when variability among panelists limits statistical significance.

Perceived sweetness and moistness did not differ significantly across treatments, despite differences in flour composition. Although muffins prepared with the DIY gluten-free blend received slightly higher mean sweetness and moistness scores, identical sugar and fat content across all formulations likely minimized sensory differences for these attributes. These findings suggest that sweetness perception and moistness in this product were driven primarily by standardized ingredients rather than flour type alone. This outcome opposes the initial hypothesis that starch composition may greatly influence sweetness perception, indicating that flour effects may be more evident for texture-related attributes than flavor perception in muffins.

Nutritional analysis revealed modest, but meaningful, differences among formulations that reflect ingredient composition rather than overall energy content. Protein content was highest in the all-purpose flour (control) and consistently lower in the gluten-free formulations – as expected due to the removal of gluten-containing proteins. Iron content followed a similar trend, most likely reflecting the enrichment of the all-purpose flour. However, muffins prepared with cassava flour displayed higher dietary fiber, calcium, and potassium content – supporting the hypothesis that gluten-free substitutions can alter micronutrient profiles. These findings highlight a potential trade-off between sensory acceptability and nutritional composition when selecting gluten-free flour alternatives.

There are several limitations that should be considered when interpreting the results of this study. The sensory panel consisted of a small number of untrained participants, which may

have contributed to the variability in sensory responses and limited the detection of statistically significant differences for some attributes. Individual differences in texture and flavor preference may have also influenced ratings. Additionally, despite standardized procedures, minor variation in mixing, portioning, or baking conditions may have affected final product characteristics.

Further studies could strengthen these findings by increasing the number of sensory panelists and incorporating trained evaluators to reduce the variability. Repeating each flour treatment across multiple baking trials would improve reliability and allow for a stronger statistical analysis. Instrumental texture analysis could also provide an objective insight into crumb firmness and elasticity, further supporting the sensory observations. Additionally, future work could explore the inclusion of binders or thickeners in homemade gluten-free blends to improve structure and sensory quality.

CONCLUSION

In conclusion, this study demonstrated that gluten-free flour substitutions influence the physical structure, sensory perception, and nutritional composition of chocolate chip muffins – with the outcomes dependent on the specific flour formulation used. Commercial gluten-free blends performed more similarly to all-purpose flour in terms of volume and sensory acceptability, while cassava flour provided nutritional advantages at the expense of overall liking. These findings emphasize the importance of formulation choice in gluten-free baking and highlight opportunities to balance sensory quality with nutritional considerations when developing gluten-free baked goods.

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