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

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Independent Study – 489
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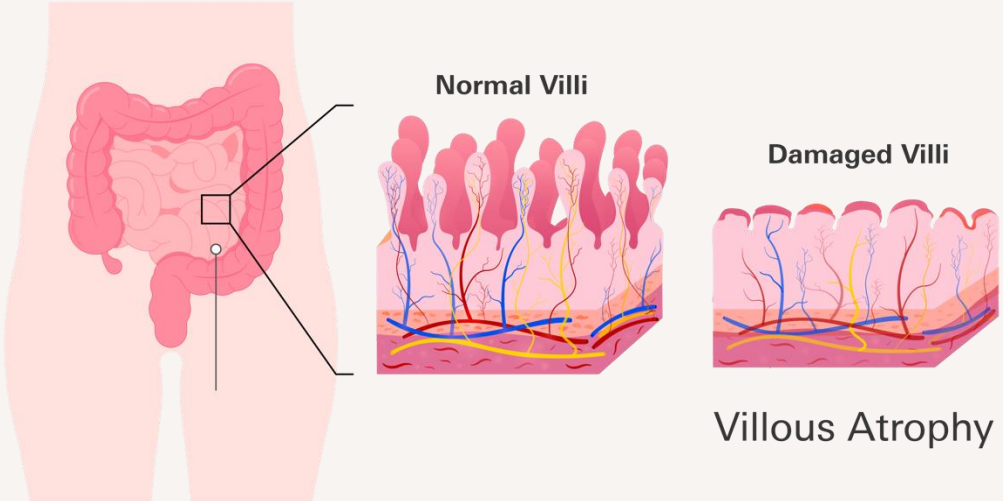
(Kowalski et al., 2025a; Celiac Disease Foundation, n.d.)

Clinical Condition

- Celiac disease is a chronic autoimmune disorder triggered by gluten ingestion
- Can cause immune-mediated damage to the small intestine (villous atrophy)
- Leads to malabsorption and nutrient deficiencies
- Requires strict, lifelong elimination of gluten from diet
- Even trace amounts of gluten can cause intestinal damage



Clinical Condition – Why is it important?

- Affects approximately 1 in 100 individuals worldwide
- Largely underdiagnosed → many cases remain untreated
- Can develop at any age, with gluten exposure
- Untreated celiac disease increases risk of:
  - Iron deficiency anemia
  - Osteoporosis
  - Other chronic health conditions

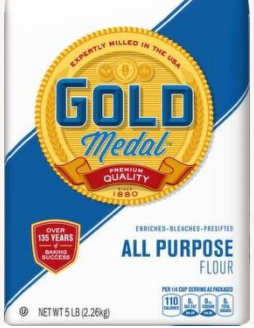
- Diet quality and acceptability of gluten-free products are critical for long term adherence

(Celiac Disease Foundation, n.d.; Kowalski et al., 2025a)

Food Product & Ingredient Replacement

- Food Product: Chocolate Chip Muffins
  - Quick bread (chemical leavening)
  - Batter-based system
  - Relies heavily on gluten for structure and gas retention
- Ingredient Replaced: All-purpose flour
  - Replaced due to gluten-content
- Independent Variable: Flour Type
  - All-purpose flour (control)
  - 1-to-1 commercial gluten-free flour
  - DIY gluten-free flour blend
  - Cassava flour
- Relevance: Supports dietary compliance for individuals with celiac disease

Food Product



Nutrition Facts

About 75 servings per container
Serving size ¼ cup (30g)

Amount per serving
Calories 110

	% Daily Value*
Total Fat 0g	0%
Saturated Fat 0g	0%
Trans Fat 0g	
Cholesterol 0mg	0%
Sodium 0mg	0%
Total Carbohydrate 23g	8%
Dietary Fiber less than 1g	3%
Total Sugars 0g	
Includes 0g Added Sugars	0%
Protein 3g	
Iron 1.5mg	8%
Thiamin 0.2mg	15%
Riboflavin 0.1mg	10%
Niacin 1.8mg	10%
Folate 90mcg/DFE (45mcg folic acid)	20%

Not a significant source of vitamin D, calcium, and potassium.

* 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.

Ingredients: Bleached Wheat Flour, Niacin (a B vitamin), **Iron, Thiamin Mononitrate** (vitamin B_1), **Riboflavin** (vitamin B_2), **Enzymes, Folic Acid** (a B vitamin).

Nutrition Facts

About 17 servings per container
Serving size 1/4 cup (37g)

Amount per serving
Calories 130

	% Daily Value*
Total Fat 0g	0%
Saturated Fat 0g	0%
Trans Fat 0g	
Cholesterol 0mg	0%
Sodium 10mg	0%
Total Carbohydrate 30g	11%
Dietary Fiber 1g	4%
Total Sugars 0g	
Includes 0g Added Sugars	0%
Protein 2g	
Vitamin D 0mcg	0%
Calcium 4mg	0%
Iron 0mg	0%
Potassium 59mg	2%

*The % Daily Value 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.

INGREDIENTS: Sweet White Rice Flour, Whole Grain Brown Rice Flour, Potato Starch, Whole Grain Sorghum Flour, Tapioca Flour, Xanthan Gum.

DIY Gluten-Free Flour

Ingredients:

White Rice Flour, Potato Starch, Tapioca Flour

(Cronometer, n.d.)

DIY Gluten-Free Flour

Nutrition Facts

Serving Size 1 — 37g

Amount Per Serving
Calories 130.7

		% Daily Value*
Total Fat	0.4 g	0 %
Saturated Fat	0.1 g	1 %
Trans Fat	0 g	
Cholesterol	0 mg	0 %
Sodium	2.1 mg	0 %
Total Carbohydrate	29.9 g	11 %
Dietary Fiber	0.7 g	3 %
Total Sugars	0 g	
Added Sugars	0 g	0 %
Protein	1.6 g	
Vitamin D	0 mcg	0 %
Calcium	4 mg	0 %
Iron	0.1 mg	1 %
Potassium	22.9 mg	0 %

* 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.

Full Info at cronometer.com </>

Nutrition Facts

About 14 servings per container
Serving size 1/4 cup (32g)

Amount Per Serving
Calories 110

	% Daily Value*
Total Fat 0g	0%
Saturated Fat 0g	0%
Trans Fat 0g	
Cholesterol 0mg	0%
Sodium 0mg	0%
Total Carbohydrate 28g	10%
Dietary Fiber 3g	11%
Total Sugars 0g	
Includes 0g Added Sugars	0%
Protein 1g	
Vitamin D 0mcg	0%
Calcium 32mg	2%
Iron 0mg	0%
Potassium 83mg	2%

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.

Ingredients: Cassava

Hypotheses

Nutrition

- **H_1**: 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.

Objective

- **H_2**: 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.
- **H_3**: 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.

Hypotheses (cont.)

Sensory

- **H_4**: 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.
- **H_5**: 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.
- **H_6**: 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.
- **H_7**: 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.

Methods: Production Preparation

- Standardized chocolate chip muffin recipe
- Flour was the only variable altered
- 4.0 oz flour used
- DIY blend: white rice flour, potato starch, tapioca flour
- Identical mixing, baking, and cooling conditions

Recipe & Preparation

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

Evaluation Methods

Objective

- Muffin height measured with ruler (mm)
- Muffin volume measured via rice displacement (mL)
- Measurements averaged per treatment

Sensory

- Untrained panel (n = 7)
- 7-point hedonic scale
- Attributes:
  - Overall liking
  - Sweetness
  - Moistness
  - Crumb density
- Samples labeled with randomized 3-digit codes

Sensory Ballot

		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					

Results


All-Purpose flour
Bob's Red Mill 1-to-1
DIY flour
Cassava flour


All-Purpose flour
Cassava flour
Bob's Red Mill 1-to-1
DIY flour

Muffin Volume

1-to-1 Gluten Free : 145 mL
All-purpose: 140 mL
DIY Gluten-Free: 128 mL
Cassava: 110 mL

Observation:

Commercial GF Flour achieved comparable volume to All-Purpose Flour (control)

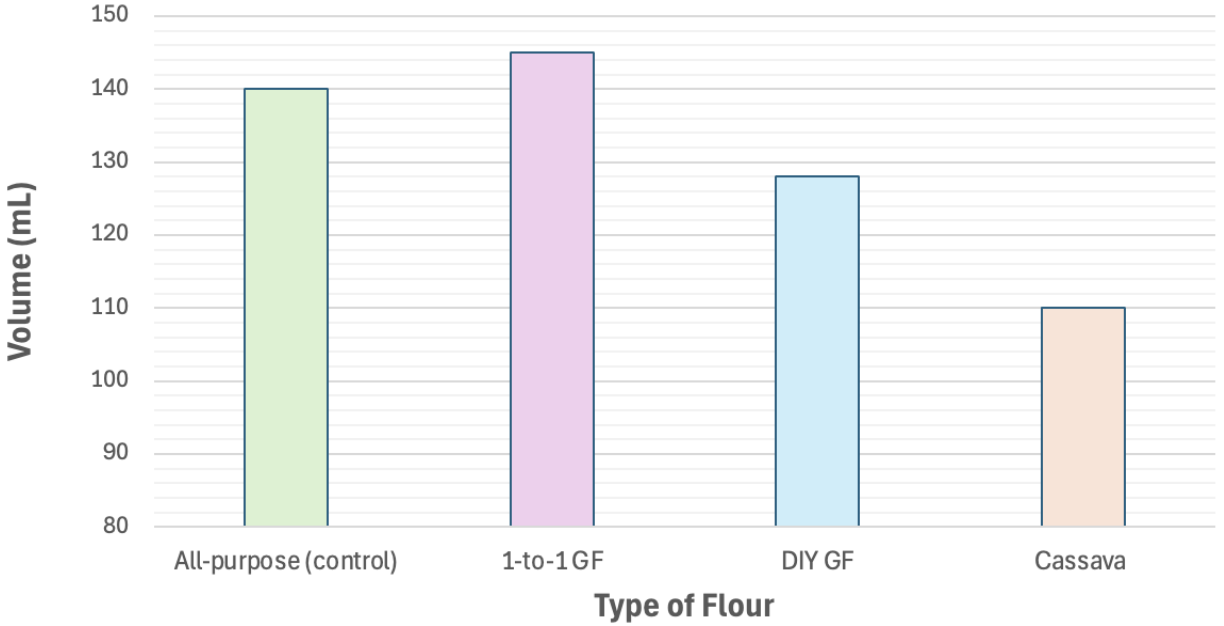


Figure 2: Muffin Volume (mL) vs. Type of Flour. Muffin volume (mL) measured using the rice displacement method for muffins prepared with all-purpose flour (control), 1-to-1 gluten free flour, DIY gluten-free flour, and cassava flour. Values represent mean volume for each formulation. N=1 per formulation. No statistical analysis was conducted; therefore, no p-value was calculated.

Muffin Height

All-purpose: 45 mm

1-to-1 Gluten Free : 40 mm

Cassava: 35 mm

DIY Gluten-Free: 34 mm

Observation:

Gluten removal reduced vertical rise

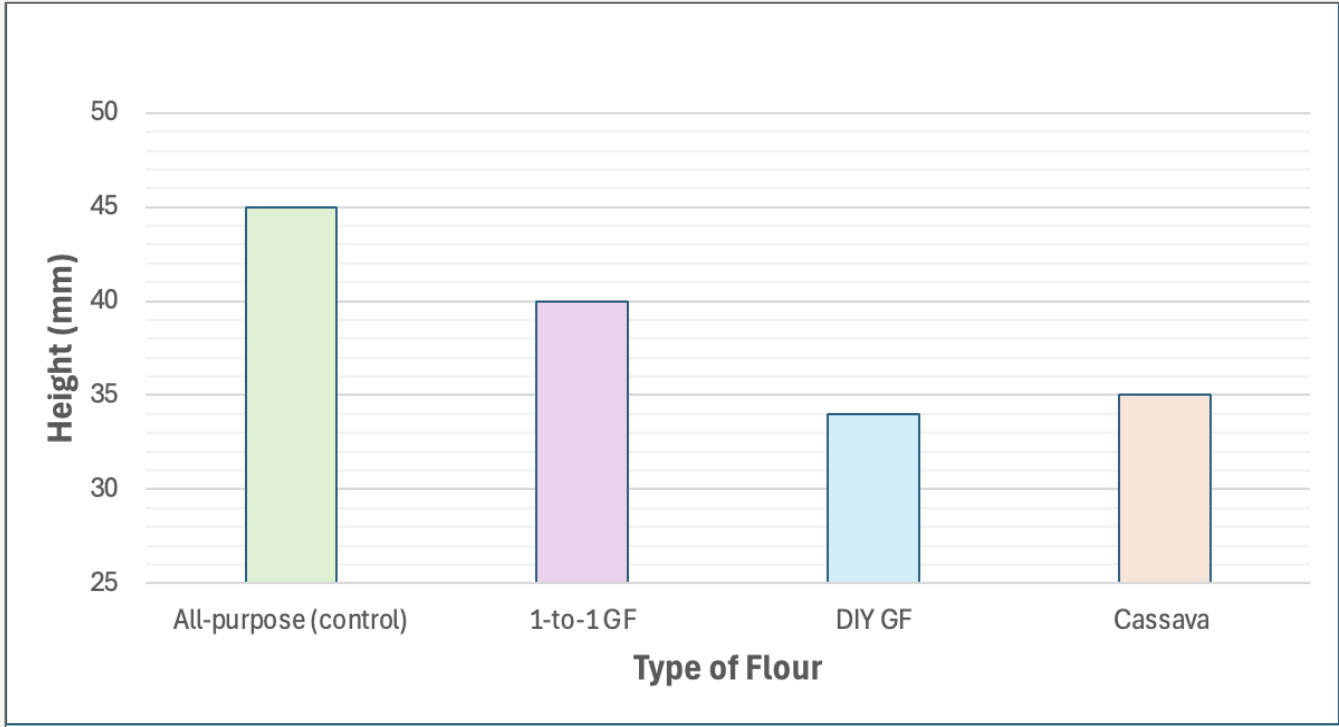


Figure 3: Muffin Height (mm) vs. Type of Flour. Muffin height (mm) measured at the center of each muffin using a ruler. Muffins prepared with all-purpose flour (control) exhibited the greatest height, while gluten-free formulations showed reduced vertical rise. Values represent mean height for each formulation. N-1 per formulation. No statistical analysis was conducted; therefore, no p-value was calculated.

Overall Liking

All-purpose: 5.86 ± 0.90

1-to-1 Gluten Free : 5.14 ± 1.46

DIY Gluten-Free : 4.57 ± 1.81

Cassava: 3.29 ± 1.50

Cassava significantly lower than control and 1-to 1 Gluten Free Flour ($p < 0.05$)

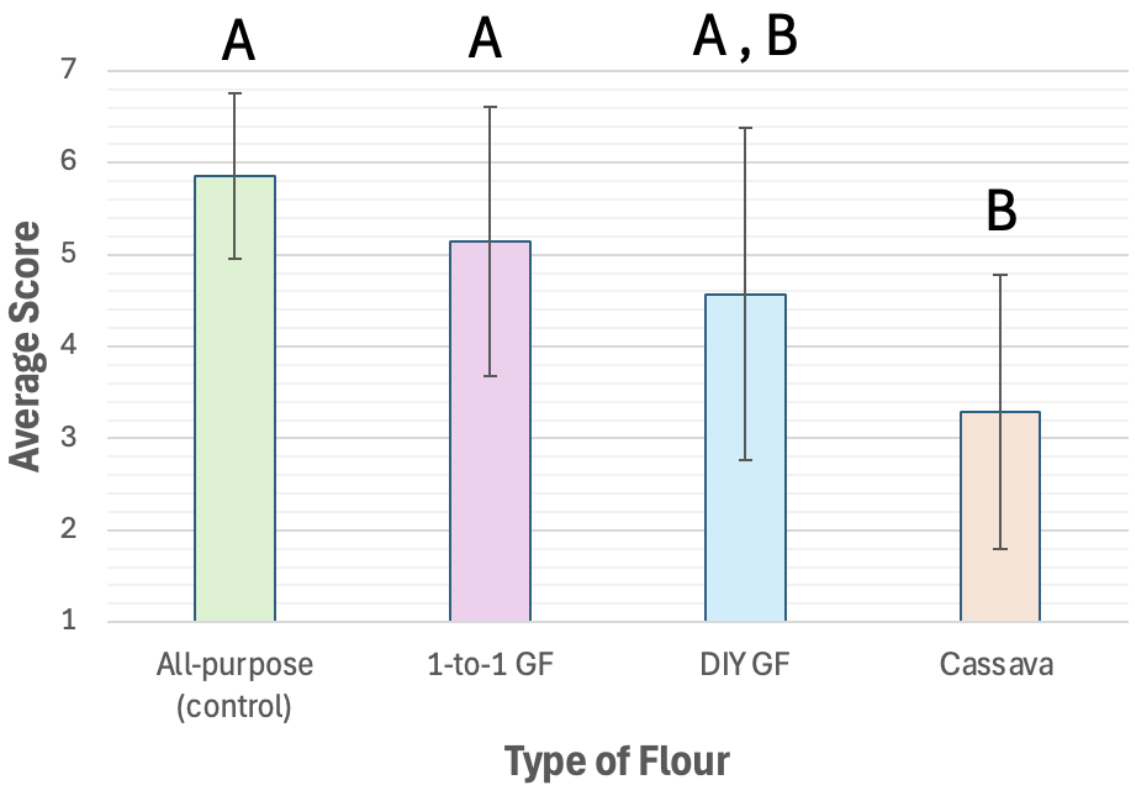


Figure 4: Overall Liking vs. Type of Flour. Mean overall liking scores (1 = least, 7 = greatest) for muffins prepared with all-purpose flour (control), 1-to-1 gluten free flour, DIY gluten-free flour, and cassava flour. Values represent mean ± SD (n = 7 panelists). Statistical significance was assessed using paired, two-tailed t-tests with $\alpha = 0.05$.

Sweetness

- No significant differences ($p > 0.05$)
- Similar sweetness perceptions despite different flours

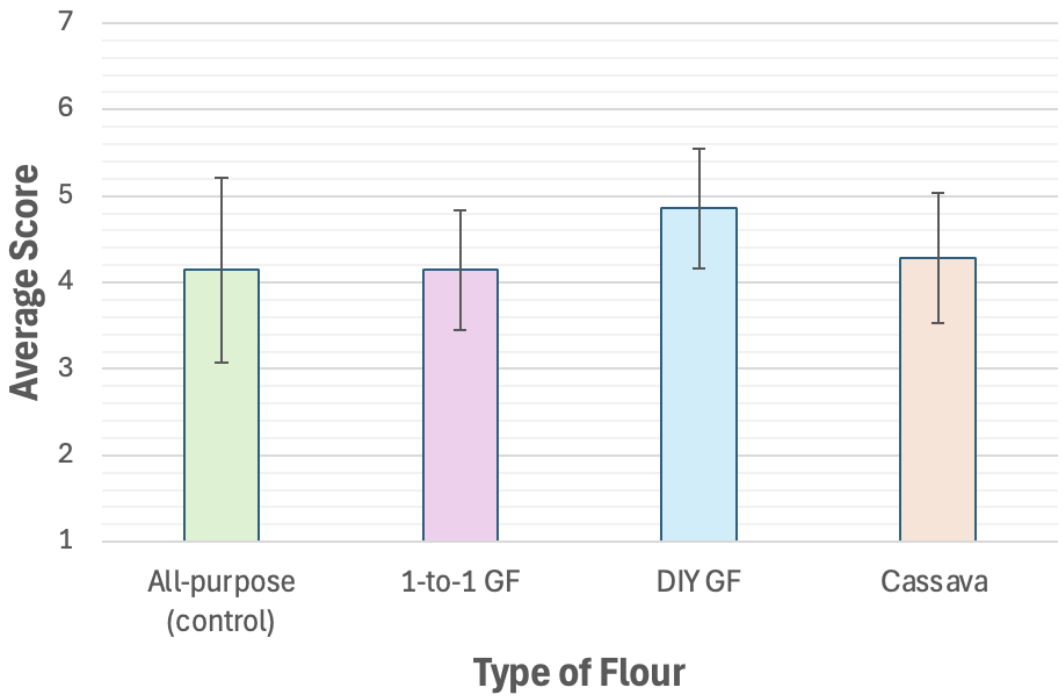


Figure 5: Perceived Sweetness vs. Type of Flour. Mean percieved sweetness scores (1 = least, 7 = greatest) for muffins prepared with all purpose flour (control), 1-to-1 gluten-free flour, DIY gluten-free flour, and cassava flour. Values represent mean ± SD (n = 7 panelists). Statistical significance was assessed using paired, two-tailed t-tests with $\alpha = 0.05$.

Moistness

- DIY Gluten-Free was numerically the highest
- No statistically significant differences ($p > 0.05$)

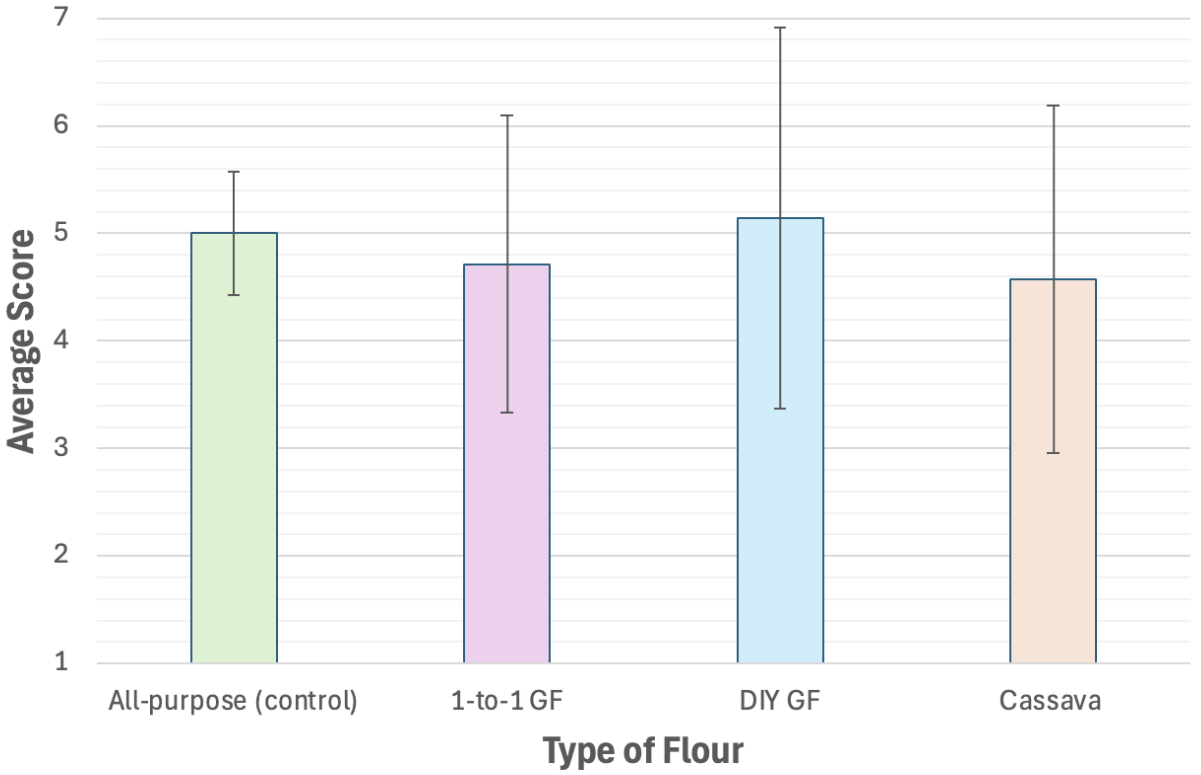


Figure 6: Perceived Moistness vs. Type of Flour. Mean perceived moistness scores (1 = least , 7 = greatest) for muffins prepared with all-purpose flour (control), 1-to-1- gluten-free flour, DIY gluten-free flour, and cassava flour. Values represent mean ± SD (n = 7 panelists). Statistical sigificance was assessed using paired, two-tailed t-tests with $\alpha = 0.05$

Crumb Density

- Gluten-free muffins were perceived as more dense
- No statistically significant differences ($p > 0.05$)

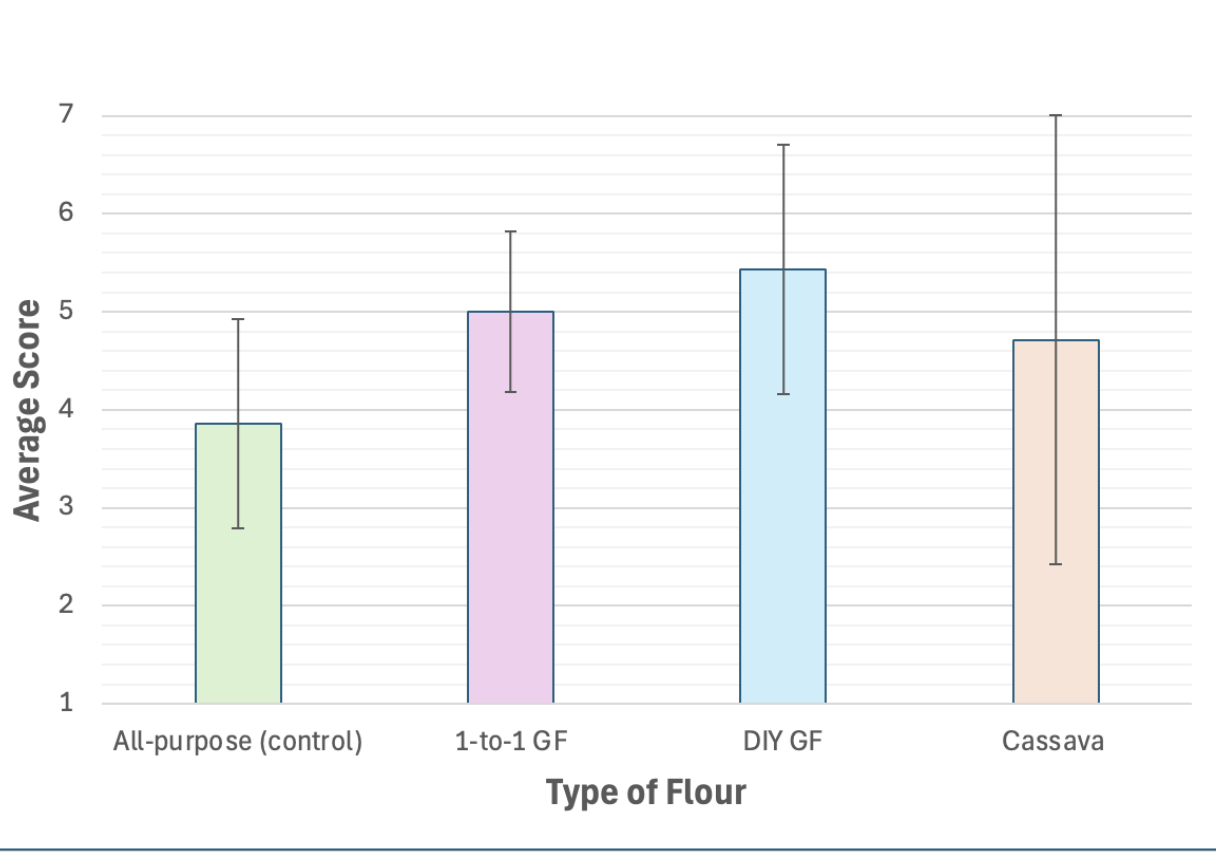


Figure 7: Perceived Crumb Density vs. Type of Flour. Mean perceived crumb density scores (1 = least dense, 7 = most dense) for muffins prepared with all-purpose flour (control), 1-to-1 gluten-free flour, DIY gluten-free flour, and cassava flour. Values represent mean ± SD (n = 7 panelists). Statistical significance was assessed using paired, two-tailed t-tests with α = 0.05.

General Comments

- All-purpose → fluffy and airy, good interior, good volume
- Cassava → tasted earthy, more savory
- 1-to-1 Gluten-Free → chewy
- DIY Gluten-Free → gummy interior, chewy texture, stuck to paper, fell apart in mouth

Nutrition Facts Comparison

(Cronometer, n.d.)

Muffin: All-Purpose 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 %

* 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.

Full Info at cronometer.com </>

Muffin: 1-to-1 Gluten-Free Flour

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 %

* 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.

Full Info at cronometer.com </>

Muffin: DIY Gluten-Free Flour

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 %

* 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.

Full Info at cronometer.com </>

Muffin: Cassava Flour

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 %

* 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.

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.

Discussion : Hypotheses

- Muffins made with gluten-free flours generally had reduced height compared to the all-purpose flour control, supporting the height hypothesis.
- The hypothesis that gluten-free muffins would have lower volume was only partially supported, because the commercial 1-to-1 gluten-free flour achieved a volume similarly to the control.
- Overall liking differed by flour formulation, with cassava flour muffins rated significantly lower than the control, while other gluten-free formulations were not significantly different.
- Flour type did not significantly affect perceived sweetness or moistness, most likely due to the identical sugar and fat content across all formulations.

Functional Properties

- All-purpose flour produced taller, less dense muffins because gluten forms an elastic protein network that traps air during baking.
- Gluten-free flours lack this protein network and rely primarily on starch for structure, resulting in reduced vertical rise and denser crumb texture.
- The commercial 1-to-1 gluten free flour performed most similarly to the all-purpose flour most likely due to the formulation strategies designed to mimic gluten functionality.
- Cassava flour increased dietary fiber but negatively affected texture and overall acceptability, demonstrating a trade-off between nutritional value and sensory quality.
- Gluten-free flour baking success depends on flour formulation, not necessarily just the removal of gluten.

(Ho et al., 2019; Park & Kim, 2023; Chisenga et al., 2019)

Study Limitations & Future Directions

Limitations

- Sensory evaluation conducted with a small, untrained panel
  - Increased variability, reduced ability to detect difference
- Individual preferences for texture and flavor may have influenced sensory ratings.
- Minor variation in mixing, portioning, or baking conditions may have affected final product characteristics despite standardized procedures.

Future Studies:

- Increase number of sensory panelists, incorporating trained evaluators
- Repeat baking trials to strengthen statistical power.
- Use instrumental texture analysis to objectively measure crumb density and elasticity.
- Explore binders or thickeners in homemade (DIY) gluten-free formulations to improve structure and sensory quality.

Summary

- Flour choice strongly impacts structure and acceptability.
- Commercial 1-to-1 gluten free flour performed most similarly to the control.
- Cassava flour muffins resulted in improved fiber but reduced overall liking.
- This study highlights the difficulty and importance in trying to achieve balance between nutrition and sensory quality of gluten-free goods.

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