IMPACT OF DIFFERENT FLOURS ON THE TECHNOLOGICAL AND SENSORY QUALITY OF GLUTEN-FREE SPONGE CAKE

A. Ladaniuc*

Technical University of Moldova, Chişinău, Republic of Moldova

Abstract

Gluten-related disorders affect about 5–10% of the global population, while gluten-free products remain limited in the Republic of Moldova. Gluten-free flours differ widely in starch, protein, fiber, and lipid content, which influences their baking performance. This study analyzes the effect of different gluten-free flours on sponge cake quality. Physicochemical parameters (porosity, baking weight loss, color) and sensory acceptability were evaluated. Results showed higher porosity with increased starch and reduced protein, corn starch reaching the highest value (90.7%). High fiber content (buckwheat flour) led to lower baking weight loss (19.2%) compared to corn starch (25.7%). Sensory analysis using a hedonic scale gave the highest acceptability to the rice flour sample. Color parameters were similar between rice flour and wheat flour samples. The results confirm that wheat flour can be replaced in sponge cakes with suitable gluten-free alternatives, depending on their composition.

Key words: *gluten-free, sponge cake, flour composition, porosity, sensory acceptability.*

INTRODUCTION

Gluten is a protein complex found in several cereals, including wheat, barley, and rye, formed from gliadin and glutenin through hydration and mechanical kneading. Due to its unique viscoelastic properties, gluten is present in nearly all pastry products, where it provides structural integrity, gas retention, and dough elasticity.

However, approximately 10% of the global population report gluten-related disorders, including celiac disease (affecting 1–2%) and non-celiac gluten sensitivity [1]. Beyond the commonly recognised gastrointestinal symptoms, such as abdominal pain and diarrhea, gluten intolerance can lead complications due to malabsorption, including iron-deficiency anemia and osteoporosis [2]. Despite growing awareness, access to safe, certified gluten-free products remains limited in many regions.

This is particularly evident in the Republic of Moldova, where no local certified gluten-free pastry products are currently available. Studies of existing local products reveal a concerning picture: 33% of packaged and 100% of unpackaged gluten-free products exceeded the acceptable gluten level, becoming a real risk to sensitive consumers [3].

The aim of this study was to evaluate how the chemical composition of gluten-free flours influences the physicochemical and sensory properties of sponge cake, and to identify future possibilities for gluten-free bakery product development in the Republic of Moldova.

MATERIAL AND METHOD

Six sponge cake samples were prepared under identical conditions, maintaining constant baking temperature, baking time, and preparation technology across all

* Corresponding author: adina.ladaniuc@an.utm.md

The manuscript was received: 24.03.2026
Accepted for publication: 11.05.2026

samples. A standardised 2:1:1 ratio (eggs:sugar:flour) was maintained across all samples, with 28 g of flour per sample. The flour and starch types evaluated were: rice flour, green buckwheat flour, pea flour, golden flaxseed flour, pure cornstarch, and a control sample composed of 80% wheat flour and 20% cornstarch. The mixing procedure was consistent across all samples: eggs and sugar were combined and pre-heated to 45°C, whisked until homogeneous, after which the flour was incorporated and folded gently using a spatula.

The physicochemical analysis included porosity, baking weight loss and colour parameters. Baking weight loss was determined gravimetrically by comparing the total mass of ingredients prior to baking with the mass of the finished sponge cake after cooling. Porosity was measured using the Zhuravlev bread porosity meter. A cylindrical core of 30 mm diameter and 38 mm height (volume: 26.96 cm^3) was extracted from each sample. The porosity was calculated by comparing the volume of the cylindrical core to the volume of the same sample in its compacted state, with porosity expressed as the percentage of air space within the sample [4].

Colour analysis was performed on standardised cross-sectional photographs of each sponge cake crumb. Prior to analysis, images were cropped to include only the crumb area, excluding the crust, to ensure colour uniformity. All samples were photographed simultaneously under consistent mixed lighting conditions (natural daylight combined with artificial indoor lighting) against a white background. The average RGB colour value of each sample was extracted using the online tool Average Colour [5]. RGB values were subsequently converted to the CIE L*a*b* colour space using a Color Converter [6]. Chroma (C*) and Hue angle (h°) were calculated and visualised on a colour wheel using ColorLab [7]. Sensory acceptance was assessed by a panel of 18 participants using a hedonic scale. Participants evaluated each sample across five attributes: appearance, odour, texture, taste, and overall flavour.

RESULTS

The six sponge cake samples prepared in this study are presented in Figure 1, where visible differences in crumb colour and structure can be observed across flour types. The chemical composition of each flour, including carbohydrate, protein, fat, and fiber content, is illustrated in Figure 2. Flour composition directly affected the sponge cake properties, and the correlations between them are presented in the sections below.

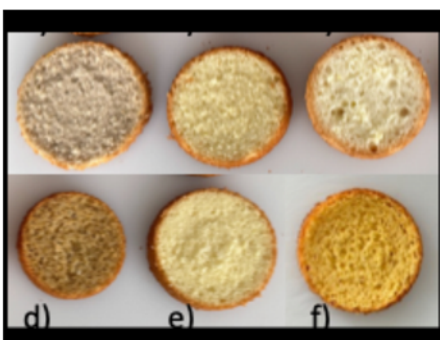

Figure 1 Sponge cake samples: a) buckwheat; b) wheat + cornstarch; c) cornstarch; d) golden flaxseed; e) rice; f) pea.

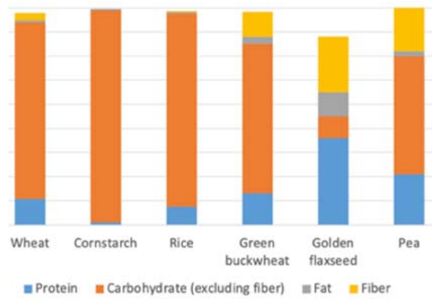

Figure 2 Protein, lipid, carbohydrate (excluding fiber), and dietary fiber content of the flours used.

Baking weight loss and porosity were both highest in the cornstarch sample, suggesting that starch (carbohydrates) may promote greater moisture evaporation during baking, while dietary fiber retains moisture and limits its evaporation. Baking weight loss values for all samples are shown in Table 1.

The correlations between flour chemical composition and baking weight loss were moderate for all four parameters (carbohydrates: $r = 0.80$, fiber: $r = –0.79$, fat: $r = –0.72$, protein: $r = –0.81$), but none reached statistical significance ($p>0.05$), which may be attributed to differences in the initial moisture content of the flours. Porosity values ranged from 61.04% (golden flaxseed) to 90.74% (cornstarch) across the six samples. Protein content was found to inhibit batter expansion, resulting in reduced rise and lower porosity ($r = −0.98$, $p<0.05$). Similarly, fibre ($r = −0.89$) and fat ($r = −0.92$) hindered batter expansion, while carbohydrate content promoted a lighter, more porous crumb structure ($r = 0.96$), all correlations being statistically significant ($p<0.05$). This supports the common recommendation of incorporating 20% cornstarch into wheat flour formulations to improve sponge cake quality. The correlations between flour chemical composition and porosity are presented in Figure 3.

Visible colour differences were observed across sponge cake samples depending on flour type, as shown in Figure 1. Colour parameters are summarised in Table 2 and visualised on a CIELAB polar diagram in Figure 4, where chroma increases from center to the outer edge, representing higher colour saturation. Green buckwheat showed the lowest chroma (C* = 20.33), while cornstarch and rice presented moderate saturation (C* = 25.06 and 33.96, respectively). Pea flour produced the most saturated colour (C* = 58.98), followed by golden flaxseed (C* = 38.75). Regarding lightness, the cornstarch sample was the brightest (L* = 84.0), while golden flaxseed was the darkest (L* = 50.9), consistent with their visible appearance.

Table 1 Baking weight loss of sponge cake samples prepared with different flours and starches.

Flour type	Wheat +20% cornstarch	Cornstarch	Rice	Green buckwheat	Golden flaxseed	Pea
Mass before baking[1], g	105	105	105	106.5	105.5	105
Mass after baking, g	83	78	80	86	86.4	83.3
Baking weight loss, %	20.95	25.71	23.81	19.25	18.1	20.67

Note: *[1]A standardised 2:1:1 ratio (eggs:sugar:flour) was maintained across all samples, with 28 g of flour per sample.*

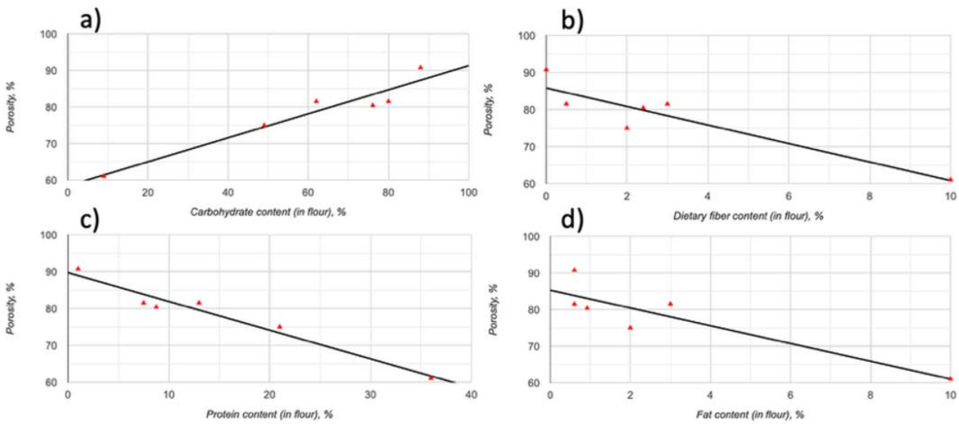

Figure 3 Relationship between baking weight loss and flour composition: a) carbohydrates; b) dietary fiber; c) protein; d) fat.

Table 2 Colour parameters of sponge cake samples[2]

Sample name	L	a*	b*	C*	h [°]	Color
Corn starch	84	0,60	25,05	25,06	88,63	
Golden flaxseed	50,9	11,72	36,94	38,75	72,40	
Green buckwheat	68,9	5,59	19,55	20,33	74,04	
Pea	66,3	11,95	57,76	58,98	78,31	
Rice	78,7	0,87	33,95	33,96	88,53	
Wheat 80% + cornstarch 20%	81,6	0,95	32,72	32,73	88,34	

[2] L - lightness (0 = black, 100 = white); a* - red (+) to green (−) axis; b* - yellow (+) to blue (−) axis; C* - chroma, representing colour saturation; h° - hue angle, measured in degrees on the colour wheel. All parameters were measured in the CIE Lab* colour space.

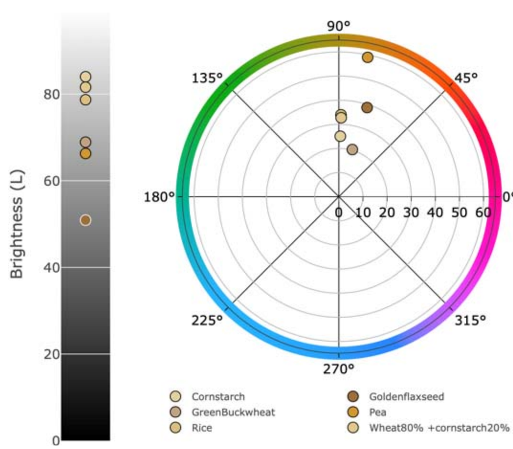

Figure 4 Polar representation of color (hue and chroma) and lightness (L*) for various flours and starches in CIELAB space.

Sensory acceptance was evaluated by 18 panellists using a hedonic scale across five attributes: appearance, texture, odour, taste, and aroma. The golden flaxseed sample was not included in the sensory evaluation.

The highest scores were obtained for the wheat+cornstarch control, followed closely by the rice flour sample, which showed particularly strong acceptance for appearance, taste, and aroma. The cornstarch sample demonstrated good texture acceptance, comparable to the control. The buckwheat sample was appreciated mainly for its odour, likely due to the characteristic flavour familiar to local consumers; however, appearance scores were lower, due to its grayish crumb colour. The pea flour sample received the lowest scores across most attributes, particularly for taste and texture, with consistently low values across panellists indicating a relevant negative perception rather than individual preference. Isolated lower scores were observed for other samples but were attributed to individual panellist variation and were not representative for the group. Overall, wheat+cornstarch, rice, and cornstarch formulations showed the best sensory acceptance. Results are presented in Figure 5:

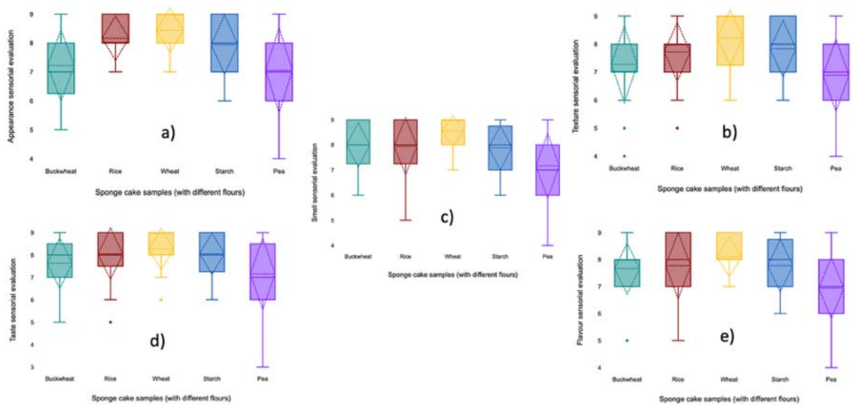

Figure 5. Sensory evaluation of sponge cake samples prepared with different flours: a) appearance, b) texture, c) smell, d) taste, e) aroma.

DISCUSSIONS

The results of this study show that the chemical composition of gluten-free flours has a clear influence on the physicochemical and sensory properties of sponge cake, with porosity being the most strongly affected parameter.

Regarding porosity, flours with higher starch content, such as cornstarch, produced the lightest and most porous sponge cakes, while flours rich in protein, fat, or fiber resulted in denser crumb structures. This can be explained by the increased volume of starch after gelatinization, while protein increases batter stiffness and resistance to rise. Similar results were reported by other authors working with gluten-free cakes, where increasing protein content consistently led to firmer and less porous products [8].

What makes this study original is that it evaluated four composition parameters simultaneously across six different flour types, and found strong and statistically significant correlations for all four, which has not been reported in this specific combination before.

For baking weight loss, the correlations with flour composition were moderate but did not reach statistical significance. This was likely due to differences in the initial moisture content of each flour, which affects how much water is available for evaporation during baking, independently of macronutrient composition. This finding differs from some studies where baking loss was more predictable from flour composition, suggesting that moisture standardisation of flours before baking could be an important variable to control in future research.

The colour differences between samples were mainly related to the natural pigments and chemical composition of each flour. Golden flaxseed produced the darkest crumb, which is consistent with findings reported in similar studies on flaxseed flour in sponge cake [9]. The intense yellow colour of the pea sample (C = 58.98) can be attributed to the naturally occurring carotenoids present in pea flour, including lutein, β-carotene, and zeaxanthin [10].

In terms of sensory acceptance, the wheat+cornstarch and rice flour samples were best received by panellists, which is expected given that their texture and flavour are closest to conventional sponge cake. The pea flour sample scored lowest, likely because its high protein content resulted in a denser texture and a stronger, less familiar flavour. The buckwheat sample was appreciated mostly for its smell, which may reflect the familiarity of local consumers with buckwheat-based products - an aspect that is particularly relevant in the context of the Republic of Moldova, where local consumer preferences have not been previously studied in relation to gluten-free sponge cake.

Future research could explore combinations of gluten-free flours that balance high porosity with better nutritional value, for example by blending cornstarch with small amounts of pea or flaxseed flour. The use of additives such as hydrocolloids could also help improve the texture of high-protein formulations. Additionally, larger consumer studies, shelf-life testing, and steps toward local gluten-free product certification in the Republic of Moldova would be valuable directions to explore.

CONCLUSIONS

This study demonstrated that carbohydrate content is the primary driver of porosity in gluten-free sponge cake, while protein, fat, and fibre have an inhibitory effect. Among the flours evaluated, cornstarch and rice flour showed the best overall physicochemical and sensory performance, supporting their potential for gluten-free bakery development in the Republic of Moldova. Future research should focus on optimised flour blends and steps toward local product certification.

REFERENCES

1. Shiha, MG; Manza, F; Figueroa-Salcido, OG; Ontiveros, N; Caio, G; Jansson-Knodell, C L; Rubio-Tapia, A; Aziz, I; Sanders, DS. Global Prevalence of Self-Reported Non-Coeliac Gluten and Wheat Sensitivity: A Systematic Review and Meta-Analysis. Gut 2026, 75 (3), 502–510. https://doi.org/10.1136/gutjnl-2025-336304.
2. Lebwohl, B; Ludvigsson, JF; Green, PHR. Celiac Disease and Non-Celiac Gluten Sensitivity. BMJ 2015, h4347. https://doi.org/10.1136/bmj.h4347.2
3. Siminiuc, R; Țurcanu, D. Provocări și tendințe în dezvoltarea produselor fără gluten. Echim ART SRL, Chisinau, Republic of Moldova, 2023, 160 p. ISBN 978-9975-3595-3-5.
4. Ciumac, J; Reșitca, V; Chirsanova, A; Capcanari, T. Tehnologia generală a produselor alimentare: Indicații metodice privind efectuarea lucrărilor de laborator. Tehnica-UTM: Chișinău, 2019; pp. 148.
5. Average Colour [Online Tool]. avg-colour.netlify.app (accessed 16.03.2026).
6. ConvertColorCode [Online Tool]. convert colorcode.com (accessed 16.03.2026).
7. ColorLab [Online Tool]. colorlab.dnaphone.it (accessed 16.03.2026).
8. Sahagún, M; Bravo-Núñez, Á; Báscones, G; Gómez, M. Influence of protein source on the characteristics of gluten-free layer cakes. LWT 2018. https://doi.org/10.1016/j.lwt.2018.04.014
9. Ahmadinia, F; Mohtarami, F; Esmaiili, M; Pirsa, S. Investigation of physicochemical and sensory characteristics of low calorie sponge cake made from flaxseed mucilage and flaxseed flour. Sci Rep 2023, 13, 20949. https://doi.org/10.1038/s41598-023-47589-5
10. Wu, DT; Li, WX; Wan, JJ; Hu, YC; Gan, RY; Zou, L. A Comprehensive Review of Pea (Pisum sativum L.): Chemical Composition, Processing, Health Benefits, and Food Applications. Foods 2023, 12(13), 2527. https://doi.org/10.3390/foods12132527