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Research Article

Formulation, Sensory, Physical, and Nutritional Evaluation of Sugar-Free Multigrain Cookies: A Comparative Study

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Keywords

Sugar-free multigrain cookies
Sensory evaluation
Nutritional composition
Dietary fiber

Abstract

The present research investigates the formulation, sensory, physical, and nutritional characteristics of sugar-free multigrain cookies produced using a mixture of wheat, oats, bajra, and ragi flours. Four formulations containing different ratios of alternative flours were made: T_1 (100% wheat flour), T_2 (70% wheat flour, 10% oats, 10% bajra, and 10% ragi), T_3 (55% wheat flour, 15% oats, 15% bajra, and 15% ragi), and T_4 (40% wheat flour 20% oats, 20% bajra, and 20% ragi). The physico-chemical properties indicated a significant increase in thickness and volume with the addition of oats, bajra, and ragi, while the spread ratio and diameter was decreased. The nutritional composition indicated that dietary fiber content increased significantly with the inclusion of alternative flours, while protein and fat contents decreased. Sensory evaluation revealed that sample T_3 received the highest ratings for appearance, flavour, crispiness, and overall acceptance. The research establishes that multigrain flour combinations have a beneficial effect on the physical, nutritional, and sensory attributes of sugar-free cookies by improving their texture, flavour, and fiber levels. The research emphasizes the possibilities of multigrain cookies as a healthy, functional snack choice.

1. Introduction

The increasing global prevalence of non-communicable diseases (NCDs), such as obesity, type 2 diabetes, and cardiovascular disorders, has prompted a paradigm shift in consumer food preferences toward healthier dietary options (Cerf, 2021). A major contributing factor to these health concerns is the excessive consumption of added sugars, commonly found in processed foods, including bakery products like cakes and biscuits (Luo et al., 2019). In response, there is a growing consumer demand for sugar-free alternatives that do not compromise taste or texture. Simultaneously, the nutritional benefits of multigrain consumption, as opposed to single-grain products, have gained considerable attention. Multigrain formulations offer a more comprehensive nutritional profile, providing a wider array of essential nutrients, dietary fiber, and phytochemicals (Jing et al., 2018; Dighe et al., 2022).

The adverse effects of high sugar intake are well-documented in scientific literature. Excessive sugar consumption has been linked to increased risk of obesity, insulin resistance, dyslipidemia, and systemic inflammation, all of which are key factors in the pathogenesis of NCDs (Stanhope et al., 2016; Drozdz et al., 2021). Furthermore, high-sugar diets have been associated with cognitive impairments, increased risk of certain cancers, negative neuroplasticity, and emotional disorders such as anxiety and depression. (Jacques et al., 2019). In light of these adverse health outcomes, public health organizations, such as the World Health Organization (WHO), recommend limiting added sugar intake to less than 10% of total energy intake, with further benefits observed at levels below 5% (Moynihan, 2016; Breda et al., 2019; Janzi et al., 2024). This recommendation has led to increased awareness among consumers and a growing market for sugar-reduced or sugar-free products.

Multigrain products offer a distinct advantage over refined grain-based foods due to their enhanced nutritional composition (Dighe et al., 2022). Whole grains, which form the foundation of multigrain formulations, retain the bran, germ, and endosperm, providing a rich source of dietary fiber, vitamins, minerals, and antioxidants (McRae, 2017). Dietary fiber, in particular, crucial in promoting digestive health, regulating blood glucose levels, and reducing the risk of cardiovascular diseases (Alahmari, 2024). Incorporating a variety of grains, such as wheat, ragi (finger millet), bajra (pearl millet), and oats, can further enhance the nutritional profile of baked goods by providing a more diverse range of essential amino acids, vitamins, and minerals (Ashraf et al., 2022). For instance, ragi is known for its high calcium content, while bajra is a good source of iron and protein (Jagati et al., 2021; Ram et al., 2021). Oats contribute soluble fiber, which has been shown to lower cholesterol levels (Grundy et al., 2018).

However, formulating sugar-free multigrain cookies presents several technological challenges. Sugar plays a multifunctional role in cookie production, contributing to sweetness, texture, structure, browning, and moisture retention (Pareyt & Delcour, 2008; Panghal et al., 2018; Boz, 2019). Removing sugar necessitates the use of sugar substitutes that can replicate these functionalities without adding calories or negatively impacting sensory attributes. Common sugar substitutes include artificial sweeteners (e.g., sucralose, aspartame), natural sweeteners (e.g., stevia, erythritol), and bulk sweeteners (e.g., polydextrose, isomalt) (Furlán et al., 2017; Schiatti et al., 2023). The selection of appropriate sugar substitutes and their optimal concentration is crucial for achieving the desired cookie quality (Handa et al., 2012; Lee et al., 2021). Furthermore, the incorporation of multiple grains can affect the dough rheology and final product texture, requiring careful standardization of the recipe and baking process (Ari Akin et al., 2022).

The present research investigates the development of sugar-free multigrain cookies, focusing on the selection of appropriate sugar substitutes and multigrain blends to standardize both nutritional and sensory qualities. The objectives of this study are to create a sugar-free multigrain cookie with a lower glycemic index, enhance its nutritional profile through the incorporation of wheat, ragi, bajra, and oat grains, and ensure consumer acceptability. By addressing these aims, this study contributes to the growing field of healthier baked goods, meeting the needs of a market increasingly focused on health and wellness.

2. Materials and methods

2.1. Raw materials

The present study was conducted at the School of Food Technology, Bhai Gurdas Institute of Engineering and Technology, Sangrur, Punjab. The raw materials and other ingredients used for the sugar-free cookie formulation were procured from various sources. These include Ammonium Bicarbonate (U.P. Chemicals, Ludhiana), Edible Common Salt (Tata Salt Distributors, Sangrur), and emulsifiers such as Diacetyl Tartaric Acid Esters of Mono- and Diglycerides (DATEM) and Soya Lecithin (Shiva Biochem Industries, Punjab). Wheat Flour was purchased from Riyassat Foods Private Limited, Patiala and other grains such as Oats, Bajra, and Ragi were procured from IARI, New Delhi. Refined, Bleached, and Deodorized (RBD) Palm Oil (Loose), were procured from Sundrop Oils Distributors, Chandigarh. Premix Vit-Min CP 12 was sourced from Aakriti Trading Company, Delhi, and dairy-based components such as Skimmed Milk Powder were obtained from Verka Milk Plant, Sangrur. The formulation also included functional ingredients such as sodium bicarbonate (SRL, India) and corn starch, which were purchased from the local market in Sangrur and artificial sweeteners (FOS-Sucralose Liquid Sweetener, Sucralose, and Acesulfame K) were procured from Ensigns Health Care Pvt. Ltd., Pune, Maharashtra. Additional flavoring agents, such as Cardamom Flavor (AOS Products Pvt. Ltd., UP) and Whole Grain Masker (Firmenich Aromatics Production India Pvt. Ltd., Haryana), were also used. All ingredients were selected based on quality, availability, and suitability for creating a healthy, sugar-free cookie.

2.2. Processing of raw material

Oat flour, Ragi flour and Bajra flour were prepared using standardized procedures to ensure consistency and quality. Oats were cleaned to remove impurities and ground into a fine powder using Philips grinder mixer (HL7810003). Ragi flour was prepared by cleaning followed drying (40 °C/4 h) to eliminate excess moisture, and then grounded using Philips grinder mixer (HL7810003). Germination of pearl millet grains was carried out using a method described by Aggarwal et al. (2016) with slight modification. The raw, clean pearl millet grains were soaked in a 2% sodium carbonate solution in a ratio of 1:4 for 10 h at room temperature, with the soak water being changed every 5 h. Following the soak, the grains were thoroughly washed and immersed in a 0.1% formaldehyde solution at a 1:2 ratio for 12 h to prevent mold growth. The treated grains were then placed between 105 folds of muslin cloth in a tray and allowed to germinate at 25°C in an incubator, with continuous spraying of water every few hours to maintain moisture, for a duration of 48 hours. After germination, the seeds were dried at 60°C for 6 h to reduce moisture content to 10% (WB). The rootlets of the germinated seeds were manually removed, and the vegetative parts were separated by winnowing. The millet was subjected to pan roasting at 160°C for 15 min. The germinated and roasted millet grains were then ground into flour using a Philips grinder mixer (HL7810003) and the flours were sieved through a 50-mesh sieve to obtain a fine flour with a particle size of 300 μm or less.

2.3 Preparation of multigrain cookies

The sugar free control and multigrain cookies were prepared using the standardized ingredient levels (Table 1), following the creaming method as outlined by Metwal et al. (2011) with minor modifications (Figure 1). RBD Palm Oil was creamed using a Hobart Mixer at a high speed (300 RPM) until its volume doubled followed by addition of artificial sweeteners, FOS-Sucralose liquid sweetener, Sucralose, and Acesulfame K along with DATEM, soya lecithin, and cardamom flavor. The flour, skimmed milk powder, sodium bicarbonate, premix vitamin-mineral CP 12, corn starch, whole grain masker, and sodium bicarbonate were thoroughly mixed and added to the creamed mixture, resulting in a crumbly texture. The required amount of water was divided into two portions: one to dissolve the common edible salt and the other to dissolve ammonium bicarbonate. Both solutions were added to the mixture to prepare the dough. The dough was mixed until smooth, then portioned into small balls or discs using a dough scoop, with a thickness of 3 mm, and placed on a baking sheet lined with parchment paper. The cookies were baked in a preheated oven at 180°C for 13 min, or until golden brown. After baking, the cookies were cooled at room temperature for 20 min. The cookies were then packed in aluminum foil laminate (0.15 mm thick) and stored at 37°C for further analysis.

Table 1. Standardized ingredients levels of sugar free control and multigrain cookies.

Ingredients	Formulated Samples			
	T_1	**T_2**	**T_3**	**T_4**
Wheat Flour (%)	100	70	55	40
Oats Flour (%)	0	10	15	20
Bajra Flour (%)	0	10	15	20
Ragi Flour (%)	0	10	15	20
FOS-Sucralose Liquid Sweetener (%)	2	2	2	2
Acesulfame k (%)	0.5	0.5	0.5	0.5
Sucralose (%)	0.5	0.5	0.5	0.5
Ammonium Bicarbonate (%)	0.5	0.5	0.5	0.5
Edible Common Salt (%)	0.5	0.5	0.5	0.5
DATEM (%)	1	1	1	1
Soya Lecithin (%)	0.5	0.5	0.5	0.5
RBD PALM OIL (%)	10	9	8	8
Premix Vit-Min CP 12 (%)	0.5	0.5	0.5	0.5
Skimmed Milk Powder (%)	3	3	3	3
Sodium Bicarbonate (%)	0.5	0.5	0.5	0.5
Corn Starch (%)	5	5	5	5
Cardamom Flavor (%)	0.2	0.2	0.2	0.2
Whole Grain Masker (%)	0.3	0.3	0.3	0.3
Water (%)	5-7	5-7	5-7	5-7

Formulations are according to Rajiv and Soumya (2015) with slight modification of ingredients.

T_1 (Control) Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-100:0:0:0), T_2 Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-70:10:10:10), T_3 Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-55:15:15:15), and T_4 Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-40:20:20:20).

2.4 Physical properties

2.4.1 Thickness and diameter

Thickness (mm) and diameter (mm) of control and sugar free multigrain cookie samples were determined by using vernier caliper (LC:0.1 mm).

2.4.2 Spread ratio

The spread ratio of the control and sugar free multigrain cookies was determined by using the equation 1.

$$\text{Spread Ratio} = \frac{\text{Diameter (mm)}}{\text{Thickness (mm)}} \quad (1)$$

2.4.3 Volume (cm³)

The volume of the cookies was determined by the area of cookies multiplied by thickness (Equation 2) as per AOAC (2000).

$$\text{Volume (cm}^3) = \frac{\pi d^2 t}{4} \quad (2)$$

Where, t = Average thickness of cookie (mm) d = Diameter of cookie (mm)

2.4.4 Density (g/cm³)

The density of control and sugar free multigrain cookie samples was obtained by the ratio of mass to the volume of the cookies (Equation 3) as per AOAC (2000).

$$\text{Density } \left(\frac{\text{g}}{\text{cm}^3}\right) = \frac{\text{Mass (g)}}{\text{Volume (cm}^3)} \quad (3)$$

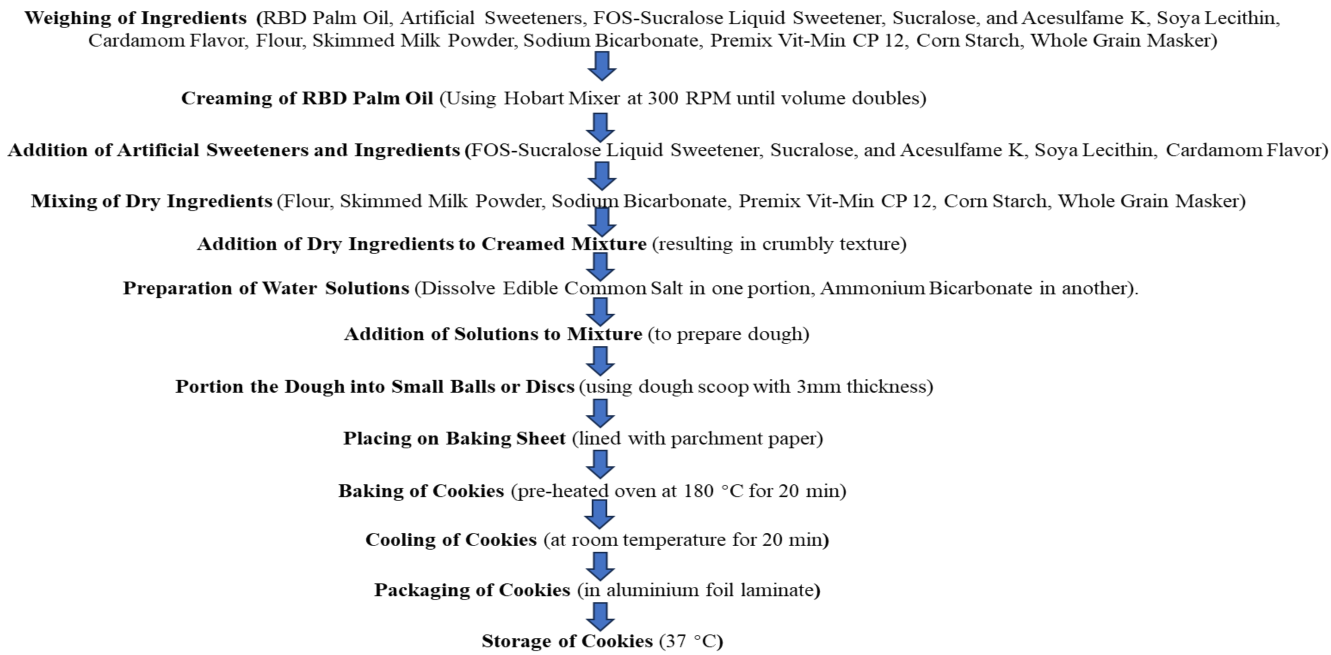

Figure 1. Process flow diagram of preparation of sugar-free multigrain cookies

2.4.5 Color analysis

The change in color of control and multigrain cookie samples was determined by using the procedure described by Kumar & Sudha (2021). A Minolta CR-400 spectrophotocolorimeter (Minolta, Japan) was used to record the lightness/darkness (L*), redness/greenness (a*) and yellowness/blueness (b*) of samples. The sample of cookies were kept in clear square containers and the color values were recorded as mean of two successive readings for every sample.

2.4.6 Textural analysis

The breaking strength of control and multigrain cookies and the hardness of their dough was evaluated using a texture analyzer (Lloyd Instruments Ltd., Hampshire, England) using the 5 kg load cell. The testing conditions were as follows: biscuit dough was shaped into circular discs having a thickness of 10 mm and a diameter of 40 mm. An 80 mm diameter circular probe was employed, and the crosshead speed was set to 50 mm/min. Compression was applied to 50% of the dough's initial height. The breaking strength in cookies was analysed by triple beam snap (three-point break) method, as followed by Kumar et al. (2015). The peak force from the resulting force-displacement curve was taken as the breaking strength of the cookies.

2.4.7 Nutritional composition of cookies

The nutritional composition (moisture, ash, protein, fat, and dietary fiber content) of control cookie and sugar free multigrain cookies were determined according to the standard methods of AOAC (2000).

2.4.8 Sensory analysis

Sugar free control and multigrain cookies was prepared and assigned different codes and then presented to a panel of 12 semi-trained judges (6 males and 6 females). The panelists score was recorded on the 9-point hedonic scale where 9 represented "Liked Very Much" and 1 represented "Disliked Very Much." The score is based on sensory characteristics such as appearance, color, taste, flavour, crispiness, and overall acceptability of the cookies. All the judges were nonsmokers and had avoided eating at least two hours prior to evaluation. The sensory assessment was carried out between 11:00 AM and 12:00 PM (IST) to standardize the evaluation conditions.

2.4.9 Statistical analysis

The data shown are the average of three independent observations unless stated otherwise. The data were subjected to one-way analysis of variance (ANOVA) with a significance level of 5% was done and Duncan's test was applied to determine the differences between the means using the commercial statistical software (SPSS, Inc, Chicago, IL, USA).

3. Results and discussion

3.1 Physical properties

The physical properties (thickness, diameter, spread ratio, volume, and density) of the multigrain cookies showed a significant ($p < 0.05$) effect with the increased incorporation of oats, bajra, and ragi flours in comparison to the control sample (T_1) made with 100% wheat flour (Table 2). In the present study, it was observed that the thickness of the cookies significantly increased ($p < 0.05$) from 5.37 mm (T_1) to 6.07 mm (T_4) with the addition of increasing levels of alternative flours. This increase in thickness could be attributed to the higher fiber content and water absorption capacity in the alternative flours. Studies have indicated that millet and oat flour possess higher water absorption properties compared to traditional wheat flour, which enhances moisture retention in the dough (Ikade et al., 2024; Dauda et al., 2024). This increased moisture retention results in a thicker dough, which, upon baking, yields thicker cookies (Ramashia et al., 2024). Aljobair (2022) also reported similar findings, indicating that the incorporation of millet flour in cookie formulations led to an increase in thickness.

Furthermore, the diameter of the cookies showed a slight decrease from 40.25 mm (T_1) to 39.62 mm (T_4) with the addition of increasing levels of alternative flours (Table 2). This slight reduction in diameter as the concentration of alternative flours increased shows that the cookies spread less during baking (Jukić et al., 2022). Watanabe et al. (2020) and Torra et al. (2021) reported that cookies made with low-gluten flours exhibit decreased dough stability, which directly impacts their spread and final dimensions. Gluten provides elasticity to the dough, allowing it to expand and retain gases produced during baking. A lower gluten content results in reduced gas retention, which leads to smaller cookie diameters (Watanabe et al., 2020). A similar result was observed by Kulkarni et al. (2021), who found that the incorporation of alternative flours, such as pearl millet, reduced cookie diameter.

Table 2. Physical properties of sugar-free control and multigrain cookies.

Samples	Attributes				
	Thickness (mm)	Diameter (mm)	Spread ratio	Volume (cm^3)	Density (g/cm^3)
T_1	5.37 ± 0.01[a]	40.25 ± 0.11[a]	7.49 ± 0.15[d]	17.48 ± 0.04[a]	0.80 ± 0.08[d]
T_2	5.64 ± 0.03[b]	40.31 ± 0.09[ab]	7.14 ± 0.05[c]	17.92 ± 0.20[b]	0.77 ± 0.01[c]
T_3	5.81 ± 0.06[c]	39.87 ± 0.04[b]	6.86 ± 0.03[b]	18.55 ± 0.07[c]	0.73 ± 0.01[b]
T_4	6.07 ± 0.01[d]	39.62 ± 0.15[c]	6.52 ± 0.01[a]	19.34 ± 0.10[d]	0.67 ± 0.03[a]

The results are presented as mean ± SD, n = 3. values in a column with distinct superscripts (a, b, c, d) differ significantly ($p < 0.05$).
T_1 (Control) Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-100:0:0:0), T_2 Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-70:10:10:10), T_3 Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-55:15:15:15), and T_4 Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-40:20:20:20).

The spread ratio is an important indicator of how much the dough spreads during baking. As shown in Table 2, the spread ratio of the cookies decreased from 7.49 (T_1) to 6.52 (T_4) with the increasing concentration of alternative flours. The reduction in spread ratio of the cookies indicates that the presence of oat, bajra, and ragi flours results in less spreading of the dough. Majzoobi et al. (2014) observed that when oat flour incorporated into dough, it exhibits lower viscoelasticity compared to wheat flour, leading to a firmer dough that spreads less during baking. Furthermore, the inclusion of oat flour increases the water absorption, contributing to a thicker dough consistency and further limiting spreading (Popa & Tamba-Berehoiu, 2021). Additionally, bajra and ragi flours disrupt the dough structure, making it more cohesive and less spreadable (Hsieh et al., 2017). A similar finding was also reported by Manchanda et al., (2024), who observed that biscuits made with blends of wheat and millet flours exhibited a lower spread ratio due to reduction in the concentration of gluten proteins within the dough.

The volume of the cookies increased with the incorporation of alternative flours, from 17.48 cm^3 in T_1 (control sample) to 19.34 cm^3 in T_4. This increase in volume could be attributed to the higher water absorption capacity of the ragi, bajra and oat flour. These results are consistent with findings by Raihan & Saini et al. (2017), where cookies prepared with sorghum and oat flour had a higher volume than their wheat flour counterparts due to improved moisture retention and better dough structure. Density values decreased as the proportion of alternative flours increased, with T_1 having the highest density (0.80 g/cm^3) and T_4 the lowest (0.67 g/cm^3). The decrease in density indicates that the cookies became lighter as the proportion of oats, bajra, and ragi flours increased. This could be due to the lower density of the alternative flours compared to wheat flour, as well as the impact of increased fiber content, which can create a more aerated structure in the cookies. Chappalwar et al. (2013) also observed a reduction in density when incorporating oats and millet into baked products due to the higher fiber and air pockets formed within the dough.

3.2 Color analysis

The impact of varying concentrations of flours (wheat, oats, bajra, and ragi) on the surface color of sugar-free control and multigrain cookie samples was evaluated. The color parameters, including L*, a*, and b*, showed a significant ($p < 0.05$) effect with increasing concentrations of oats, bajra, and ragi flours (Fig. 2 and Table 3). In the present study, it was observed that the control sample (T_1), which contained only wheat flour, exhibited the highest lightness and yellowness but the lowest redness compared to samples T_2, T_3, and T_4. As the proportion of oats, bajra, and ragi flours increased in samples T_2, T_3, and T_4 (Table 3), lightness and yellowness decreased, while redness increased significantly ($p < 0.05$). The reduction in lightness and yellowness, along with the increase in redness of cookies made from wheat, oats, bajra, and ragi flour combinations, is attributed to the whole flours of ragi and bajra, which contain bran constituents with darker colors, such as fibers, phenolics, and flavonoids (Torbica et al., 2012; Brites et al., 2018; Paesani et al., 2020; Aljobair, 2022). Additionally, the Maillard reaction during the baking process could also contribute to the color changes of the cookies (Giuberti et al., 2018). The findings align with previous study indicating that the incorporation of alternative flours can affecting color attributes of cookies (Tarannum et al., 2025).

Table 3. Color analysis of sugar free control and multigrain cookies.

Samples	Cookie surface color values		
	L*	a*	b*
T_1	59.73 ± 0.02[a]	8.11 ± 0.04[d]	25.63 ± 0.04[a]
T_2	56.14 ± 0.08[b]	8.41 ± 0.02[c]	25.42 ± 0.02[b]
T_3	55.51 ± 0.07[c]	8.71 ± 0.08[b]	25.12 ± 0.05[c]
T_4	54.23 ± 0.02[d]	9.12 ± 0.02[a]	24.81 ± 0.02[d]

The results are presented as mean ± SD, n = 3. values in a column with distinct superscripts (a, b, c, d) differ significantly ($p < 0.05$). Where, L*-Lightness/darkness, a*-redness/greenness, b*-yellowness/blueness
T_1 (Control) Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-100:0:0:0), T_2 Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-70:10:10:10), T_3 Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-55:15:15:15), and T_4 Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-40:20:20:20).

3.3 Textural analysis

The textural properties of cookies (cookie dough hardness and breaking strength) are shown in Fig 3. Cookie dough hardness showed a significant decrease ($p < 0.05$) as the proportion of non-wheat flours (oats, bajra, and ragi flours) increased. The control sample (T_1) with 100% wheat flour had the highest dough hardness (1532.13 g), indicating a firmer texture compared to the other samples. As more oats, bajra, and ragi flours were added in T_2, T_3, and T_4, the dough became softer, with T_4 showing the lowest hardness (1045.65 g). The decrease in cookie dough hardness with the increased proportion of non-wheat flours (oats, bajra, and ragi) can be attributed to the distinct structural and compositional properties of these flours compared to wheat flour (Baek et al., 2023; Nicolai et al., 2025). Wheat flour is rich in gluten, a protein that provides elasticity and structure, contributing to the firmness of dough, whereas non-wheat flours generally have lower gluten content, resulting in a softer dough texture. Additionally, Dauda et al. (2024) observed that oat flour has a higher water absorption capacity than wheat flour, which can lead to a softer dough texture due to increased moisture content. A similar trend was supported by Sharma et al. (2024), who reported that cookies made with blends of wheat, bajra, and ragi flours demonstrated enhanced nutritional profiles and softer textures, aligning with the observed decrease in dough hardness.

Furthermore, the breaking strength of cookies, measured by a texture analyzer, showed the force required to break the cookies. In Fig 3, it was observed that the breaking strength of cookies increased significantly ($p \le 0.05$) from 1153.09 g (T_1) to 1832.64 g (T_4), with an increased concentration of alternative flours. This increase in the breaking strength of cookies could be due to the binding properties of oats, bajra, and ragi flours, which contain fibers that improve dough cohesion, resulting in a firmer texture post-baking (Rahardjo et al., 2020; Ibrahim et al., 2023).

Additionally, the addition of these flours alters the dough's rheological properties, enhancing stability and reducing the spread ratio, which contributes to a firmer cookie structure (Basri et al., 2020; Gruppi et al., 2024). A similar finding of increased breaking strength in biscuits was also observed by Nirmala et al. (2011), who reported that an increased level of fenugreek seed and flax seed in biscuits increased the breaking strength.

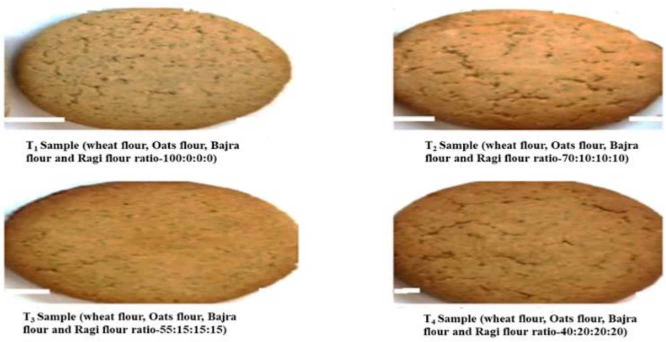

Figure 2. Photographs of sugar-free control and multigrain cookies.

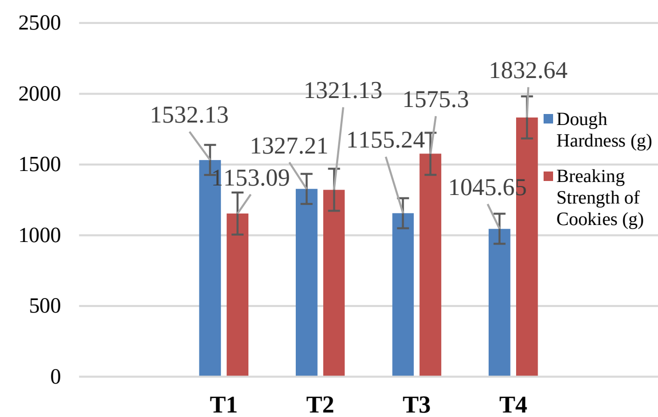

Figure 3. Textural characteristics of dough and prepared sugar-free multigrain cookies.

T_1 (Control) Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-100:0:0:0), T_2 Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-70:10:10:10), T_3 Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-55:15:15:15), and T_4 Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-40:20:20:20).

3.4 Nutritional composition

The nutritional composition of the sugar-free control and multigrain cookies samples were analyzed and presented in table 4. The moisture, ash, protein, fat, and dietary fiber content, significantly varied with the change in the concentration of non-wheat flours (oats, bajra, and ragi). The moisture content significantly ($p < 0.05$) increased from T_1 (5.22%) to T_4 (6.64%), which may be attributed to the higher water retention capacity of the added alternative flours, particularly ragi and bajra. Earlier study of Rathod et al. (2015), showed that the amount of water required for making dough increases with increasing concentration of defatted soy flour and oat flour. Similarly, ash content, indicative of the mineral content in the cookies, control sample (T_1) having the lowest value (1.24%) and T_4 having the highest (3.08%), showed that the additional grains (oats, bajra and ragi) contributed more minerals to the final product. The similar finding of increased ash content of cookies by increasing concentration of defatted soy flour and oat flour compared to wheat flour was reported by Rathod et al. (2015). Furthermore, the protein and fat content decreased with increasing levels of oats, bajra, and ragi. The decrease in fat and protein could be due to the alternative flours have lower protein and fat content compared to wheat flour (Itagi & Singh, 2012). The dietary fiber content showed a significant increase ($p<0.05$) from T_1 (1.65%) to T_4 (4.03%). This is consistent with the well-established fact that oats, bajra, and ragi are excellent sources of dietary fiber (Izydorczyk & Dexter, 2008; Itagi & Singh, 2012). A similar trend of results of fibre content was also observed by Hussain and Kaul, (2018), where higher fibre content in the samples having a higher incorporation of buckwheat and barley flour.

Table 4. Nutritional composition of sugar-free control and multigrain cookies.

Parameters	Samples			
	T_1	**T_2**	**T_3**	**T_4**
Moisture (%)	5.22 ± 0.01^a	5.44 ± 0.05^b	5.96 ± 0.02^c	6.64 ± 0.03^d
Ash (%)	1.24 ± 0.03^a	1.79 ± 0.01^b	2.64 ± 0.05^c	3.08 ± 0.05^d
Protein (%)	10.35 ± 0.05^d	9.97 ± 0.06^c	9.59 ± 0.05^a	8.89 ± 0.01^b
Fat (%)	8.23 ± 0.02^d	8.11 ± 0.06^c	7.99 ± 0.01^b	7.76 ± 0.03^a
Dietary fiber content (%)	1.65 ± 0.07^a	2.32 ± 0.01^b	3.15 ± 0.04^c	4.03 ± 0.02^d

The results are presented as mean ± SD, n = 3. values in a column with distinct superscripts (a, b, c, d) differ significantly ($p < 0.05$).

T_1 (Control) Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-100:0:0:0), T_2 Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-70:10:10:10), T_3 Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-55:15:15:15), and T_4 Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-40:20:20:20).

3.5 Sensory analysis

Sensory evaluation is the one of the most important criteria to assess the quality and acceptability of finished product. Sensory evaluation is of major reflection and is conducted to evaluate the reply of judges/consumers towards the end product (Meilgaard et al., 1999).

Table 5. Sensory analysis of sugar-free control and multigrain cookies.

Attributes	**Cookie samples**			
	T_1	**T_2**	**T_3**	**T_4**
Appearance	7.28 ± 0.02^a	7.54 ± 0.02^{ab}	8.26 ± 0.07^c	7.41 ± 0.01^{abc}
Color	7.27 ± 0.06^a	7.73 ± 0.05^b	7.89 ± 0.03^c	7.62 ± 0.04^d
Flavor	6.82 ± 0.03^d	7.68 ± 0.02^c	8.31 ± 0.02^b	7.65 ± 0.05^a
Taste	6.57 ± 0.01^a	7.69 ± 0.03^b	8.10 ± 0.05^c	7.78 ± 0.05^{bc}
Crispiness	7.30 ± 0.02^a	7.37 ± 0.05^{ab}	8.42 ± 0.01^c	7.62 ± 0.02^d
Overall acceptance	6.89 ± 0.02^a	7.31 ± 0.01^b	8.03 ± 0.05^c	7.74 ± 0.04^d

The results are presented as mean ± SD, n = 12. values in a column with distinct superscripts (a, b, c, d) differ significantly ($p < 0.05$).

T_1 (Control) Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-100:0:0:0), T_2 Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-70:10:10:10), T_3 Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-55:15:15:15), and T_4 Sample-(Wheat flour, Oats flour, Bajra flour and Ragi flour ratio-40:20:20:20).

The sensory evaluation of the sugar free control and multigrain sugar-free cookies was conducted to assess various attributes, including appearance, color, flavor, taste, crispiness, and overall acceptance (Table 5). The cookies were formulated with different ratios of wheat flour, oats flour, bajra flour, and ragi flour in four treatment samples: T_1 (control), T_2, T_3, and T_4. The sample T_5, which had the flour ratio of 55:15:15:15 (wheat flour, oats flour, bajra flour, and ragi flour), consistently received the highest ratings for appearance, color, flavor, taste, crispiness, and overall acceptance, indicating that this formulation produced the most desirable sensory characteristics. The improved attributes in T_3 can be attributed to the balanced combination of flours, particularly oats, bajra, and ragi, which enhanced the texture of cookie, flavor, and crispiness. The other samples, T_2 (70:10:10:10), T_4 (40:20:20:20), and the control T_1 (100:0:0:0), showed lower sensory scores across various attributes, with T_1 had the lowest ratings. These finding shows that incorporating oats, bajra, and ragi flour into the dough increases sensory properties, particularly flavor and texture, which aligns with findings from previous studies (Pal et al., 2018; Anjali et al., 2019).

4. Conclusion

This study highlights the significant impact of incorporating oats, bajra, and ragi flours into sugar-free cookies, improving their physical, nutritional, and sensory properties. The addition of these alternative flours resulted in thicker cookies with increased volume, while the spread ratio and diameter decreased due to reduced gluten content. Nutritionally, the cookies showed a substantial increase in dietary fiber content, beneficial for digestive health, while protein and fat content decreased due to the lower levels in the alternative flours. Sensory evaluation indicated that the formulation with 55% wheat flour and 15% each of oats, bajra, and ragi (T_3) achieved the highest scores for appearance, flavor, crispiness, and overall acceptance. This blend provided an optimal balance of sensory attributes and nutritional benefits, making it a promising option for developing healthier, fiber-enriched sugar-free cookies. These findings support the potential of multigrain cookies as a nutritious snack alternative for consumers seeking reduced sugar and increased fiber intake.

Credit authorship contribution statement

Dinesh Sharma: Writing–original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.
Suhail Ahmad Bhat: Writing–review & editing, Writing–original draft, Methodology, Investigation, Formal analysis, Data curation.
Noopur Khare: Writing–original draft, Methodology, Investigation, Formal analysis, Data curation.
Shafaq Javid: Writing–original draft, Methodology, Investigation, Formal analysis, Data curation
Tanuja Srivastava: Writing–original draft, Methodology, Investigation, Formal analysis, Data curation.
Usman Ahmed: Writing–review & editing, Writing–original draft, Supervision, Project administration, Methodology, Data curation, Conceptualization.

Ethics statement

This study adhered to all applicable ethical guidelines, regulations, and standards. Prior to participation, informed consent was obtained from all panelists and participants involved in the sensory analysis. All procedures were conducted in accordance with ethical research practices to ensure participant rights and confidentiality.

Data availability statement

Data is available on request to corresponding authors.

Conflicts of interest

The authors declare no conflicts of interest.

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Declaration of AI involvement

No artificial intelligence (AI) tools were used in the creation, writing, or development of this manuscript. All content, data analysis, and conclusions presented in this paper were solely produced by the authors.

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