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Characterization of nutritional, antioxidant, and textural properties of corn flakes with Corn Cob, Corn Silk, and Quinoa

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ABSTRACT

Corn cob, produced at approximately 144–164 million tonnes annually, is an underutilized agricultural by-product rich in dietary fiber with strong potential for value-added food applications. This study aimed to develop functional flakes by utilizing sonicated cob, corn grains, silk, and quinoa to enhance the phenolic, functional, and sensory attributes. Four treatments, T_1 - T_4, along with a control (C_2), 100% SCGF, C_1, which was without sonication, were made with different concentrations of sonicated corn grain flour and sonicated cob flour in the range of 10–70%. These were evaluated for their physicochemical (proximate, antioxidant, minerals); textural (hardness, crispiness, gumminess, chewiness, elasticity, water activity), color (Lightness, red, yellowness); functional (bulk density, swelling power, water absorption index, rapid expansion ratio); and sensory properties. Results showed improvement in T_2 and T_3 with increased fat (5.9 ± 0.05) and fiber (6.1 ± 0.01) content. Significant results were recorded for total phenolic content (1120 ± 0.02), DPPH (34.8 ± 0.03), and iron content (60.6 ± 0.01 mg/100 g) in T_2. The level of crispiness was also highest (20–21). While the hardness (242 N), lightness (L* 58.19–63.15) ≤ (L* 64.12–65.1), water absorption index (2.0 ± 0.5) was reduced significantly compared to C_2 and C_1. But it raised the bulk density to (0.29 ± 0.2), and an acceptable RER (5.2–5.3) with improved resilience (>92%) compared to control 1. Sensory analysis demonstrated that T_2 (6.2 ± 0.1) was significantly more acceptable than T1 (5.5 ± 0.3) and C_2. Consequently, results showed that cob, silk, and quinoa have a sustainable contribution in the formulation of specialized food, such as school feeding products, emergency rations, and therapeutic foods.

1. Introduction

The rapid expansion of the global population, alongside accelerating climate change and the depletion of finite natural resources, has intensified the urgency for developing a sustainable and resilient future food system (Anyiam et al., 2025). Within this context, functional foods have emerged as a pivotal strategy to address contemporary nutritional and public health challenges. Functional foods serve as a transformative bridge between nutrition and health, redefining the role of food beyond mere sustenance to a proactive agent in enhancing the quality of life through disease prevention and health promotion. Functional foods are defined as natural or processed foods that contain biologically active compounds capable of delivering clinically substantiated health benefits, validated through specific biomarkers, to promote optimal health, reduce the risk of chronic and viral diseases, and support symptom management (Alu'datt et al., 2025; Javed, Hashmi, Javaid et al., 2025; Martirosyan, 2025).

Corn is one of the world's most essential and widely consumed staple crops and generates substantial quantities of agricultural byproducts, particularly corn cob and corn (Wang et al., 2025). Corn cob (C) is increasingly recognized as a functional, gluten-free ingredient, notable for its enrichment in polyunsaturated fatty acids (PUFAs), accounting for approximately 83.33% of its lipid fraction. Its major fatty acids include palmitic, oleic, and linoleic acids, which are associated with various health-promoting effects (Lee et al., 2018). Global production of corn cob residues reached an estimated 4–6 tons ha^{-1} in 2022, highlighting its abundance and potential for value-added utilization (Cappa et al., 2025). Corn cob contains a high amount of insoluble fiber, which

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may limit its digestibility. Further studies are needed to evaluate the digestibility and bioavailability of nutrients in the developed product (Du et al., 2018).

Similarly, corn silk represents another nutritionally valuable byproduct, with annual production estimated between 3 and 15 million tons (Orellana-Palacios et al., 2025). Corn silk is rich in both flavonoids and phenolic compounds. It is rich in essential minerals such as magnesium, phosphorus, and potassium, as well as fat-soluble vitamins A, D, E, and K. Its compositional profile includes a high moisture content (71.3%), along with 2.9% fat, 12% protein, 68.1% hemicelluloses, and approximately 40% carbohydrates (Ahsan et al., 2025). Owing to their rich bioactive composition, corn byproducts exhibit considerable potential as functional food components (FFCs), offering protective, anti-inflammatory, and anti-obesity properties when recovered through secondary processing streams (Jiao et al., 2022). Phenolic compounds are natural antioxidants present in both free and bound forms in plant materials. Bound phenolics are attached to cell wall components such as cellulose, hemicellulose, and lignin, limiting their extractability. Ultrasonication enhances phenolic release through acoustic cavitation, which disrupts cell walls, increases matrix porosity, and improves solvent penetration. As a result, ultrasound-assisted processing can increase phenolic recovery and antioxidant activity in plant-based foods (Acosta-Estrad et al., 2014).

Dietary fiber-rich ingredients offer nutritional and functional benefits; however, their use in food products may be limited by low bioavailability of bioactive compounds, undesirable sensory changes, and processing challenges. Nevertheless, fibers provide important functional properties such as water-holding and antioxidant capacities. (Ribas-Agustí et al., 2018).

Effective utilization of food byproducts necessitates creative techniques for dealing with the rising output of food waste that can contain valuable nutrients (Javed, Hashmi, Nadeem et al., 2025). Functional food development encompasses a broad spectrum of products, including ready-to-eat cereals formulated from multigrain or composite flours (Martirosyan, 2025).

Likewise, scientists (Demircan B, Velioglu YS & Giuffrè AM, 2023) use the spray-drying process successfully to produce bergamot juice powder with high antioxidant activity, phenolic compounds, and vitamin C content. Optimal conditions (10% maltodextrin, 146.02 °C inlet temperature, and 39.99% pump rate) preserved its bioactive properties, resulting in 62.2% antioxidant activity, 3862.1 ppm total phenolics, and 1385.9 ppm vitamin C. The powder also showed favourable physical properties for further processing. HPLC analysis confirmed the presence of major phenolic compounds in both fresh juice and powder, though at lower concentrations in the powder. Moreover, a study by Ahmed et al. (2025) evaluated the effect of saffron by-products on the oxidative stability of sunflower oil during accelerated storage. Petals, stamens, and leaves were subjected to ultrasound and added at different concentrations (0.2–0.6%) and showed high levels of phenolic and flavonoid compounds, particularly in petals and stamens, resulting in strong antioxidant activity and improved oil stability. Corn bran has a high water-holding capacity and may absorb fecal mutagens in human digestive tracts, shielding the body from the harmful effects of these mutagens, it offers significant functional qualities in reduced-calorie goods (Singh, Liu SX & Vaughn SF, 2012).

Previous studies have reported functional bread formulations incorporating chickpea and oats (Jianpg et al., 2025; Roca-Nasser et al., 2025) as well as muffins enriched with cob flour and soy-based ingredients (Bayona et al., 2025; Dhillon et al., 2025). Despite these advancements, limited research has systematically evaluated the impact of incorporating corn byproducts on the physicochemical properties, antioxidant capacity, micro- and macronutrient composition, and sensory attributes of cereal-based products. Furthermore, corn is inherently deficient in essential amino acids such as lysine and tryptophan, which constrains its protein quality (Illaningtyas et al., 2024). To address these nutritional limitations and enhance overall functional value, the present study was designed to incorporate quinoa—an amino acid–balanced pseudocereal—alongside SC and SS in the development of functional flakes. Moreover, to investigate the combined effects of these ingredients on the functional, physical, nutritional, and sensory properties of the developed flakes, thereby contributing to sustainable, nutrient-dense, and value-added food product innovation.

2. Materials and methods

2.1. Laboratory equipment and chemicals

Laboratory equipment used was a digital weighing balance, Harvest Saver dehydrator (Model R-5A, USA), grinder (WF-9225 West Point), electric blender (WF 929 West Point), gas static oven (SG-5000), muffle furnace (NEY M-525), micro kjeldahl set, furnace, Soxhlet set, spectrophotometer, and glassware for chemical analysis. The chemical reagents used included H2SO4, NaOH, and diethyl ether, and others, which were obtained from chemical laboratories (Mujbaile et al., 2023; Salehi et al., 2024).

2.2. Preparation and processing of raw material

The main ingredients used were whole corn, which was purchased from the local market. These were transferred into polyethylene bags to prevent external contamination during transport to the laboratory. Corn grains, cob, and silk were manually separated from the cob and packed in polythene bags (20 cm × 10 cm). Ingredients were sonicated for 20 min in the ultrasonic bath cleaner (VEVOR 3 L) at frequency of 20 kHz with power intensity of 10 W/cm^2 temperature was continuously monitored and maintained below 35 °C using an ice bath (Niaz et al., 2026), coded corn grain (G20), cob (C20), silk (S20) dried at 52–60 °C for 8–12 h, and ground (150 mesh) until pre-cooked flour was obtained, coded as sonicate corn grain flour (SCGF), sonicated cob flour (SCC), sonicated silk powder (SSP). Additional ingredients used are quinoa flour (QF), sugar, salt, margarine, and water (Oladejo et al., 2022; Shahzad et al., 2022).

2.3. Development of functional flakes (FF)

Four treatments of flakes were developed, along with Control 1 (C_1), with 100% untreated corn grain flour (CGF), and Control 2 (C_2) included 100% SCGF. Treatment (T_1-T_4) made with 10–70% of both SCGF and SCF, having constant SSP and QF (Niaz et al., 2026). These were mixed with other binding ingredients to form a smooth batter by adding water. Then the batter was sheeted (thickness 1–2 mm) on a baking tray and baked at 150–180 °C for 2–3 min in the oven. Finally, cut into flakes and again put in the oven for 2–3 min, as illustrated in Fig. 1 (El-Waseif, 2023) (Dewidar & Hanan, 2020).

2.4. Analysis

2.4.1. Proximate analysis

Proximate analysis of flakes included Ash determined by the gravimetric method, Method No. 08–01.01, moisture by hot air oven Method No. 44–15.02, fiber by Fiber Analyzer Method 32–10.01, fat with Soxhlet extraction Method 30–10.01, and protein with the Kjeldahl digestion method, Method 46–13.01, according to International (2010) protocols.

2.4.2. Mineral determination

The protocol of atomic absorption spectroscopy was used to assess the mineral concentration, including calcium, iron, magnesium, potassium, and zinc in the samples with n = 3 replications, which was measured by Food C and Kjeldahl TMC (2020) official (Method 995.13). To standardize the instrument, standard solutions of varying strengths were prepared (International, 2010) (Libron et al., 2021).

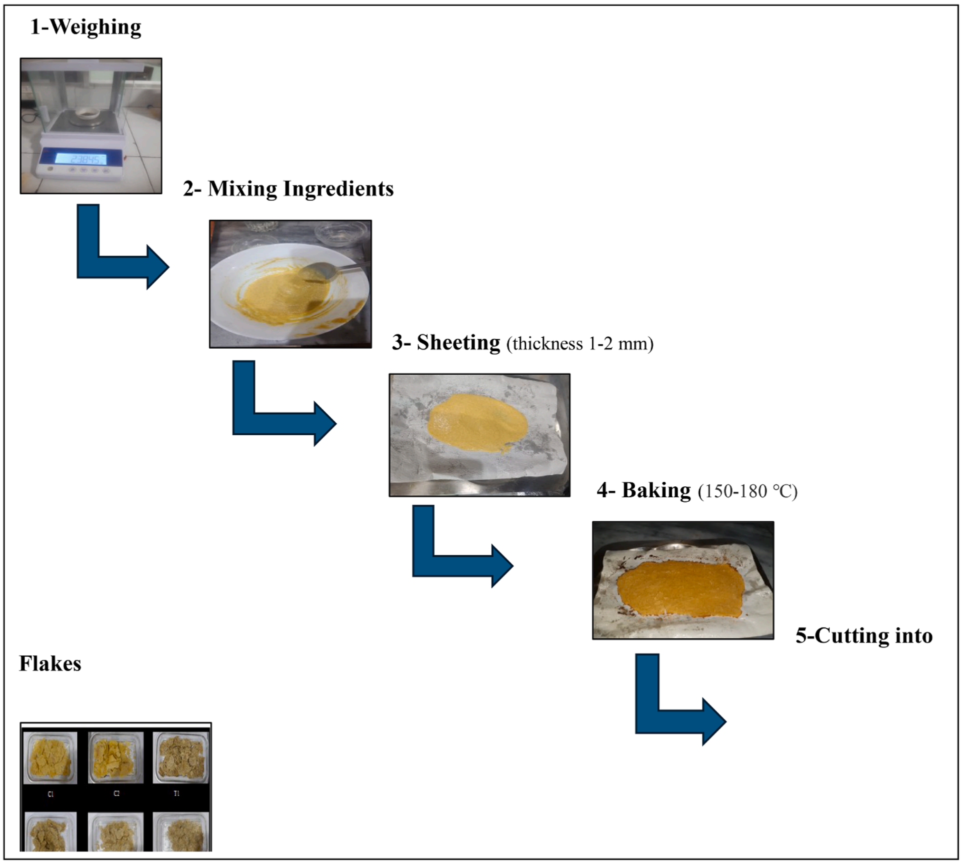

Fig. 1. Procedure for the formulation of Functional Flakes (FF).

2.4.3. Antioxidant analysis

Antioxidant analysis included antioxidant activity (AA), total phenolic contents (TPC), and total flavonoid content (TFC).

2.4.3.1. Antioxidant activity (AA). Specifically, free radical scavenging activity (AA), was measured by using the DPPH (2,2-diphenyl-1-picrylhydrazyl) assay (Lapčík et al., 2023).

2.4.3.2. Total phenolic content (TPC). Folin-Ciocalteu (FC) reagent and gallic acid were used as chemicals in the measurement of the total phenolic content in the flakes. The measurement was made with a spectrophotometer (80–3003–75) at 760 nm (Sharma R, 2024).

2.4.3.3. Total flavonoid content (TFC). Total flavonoid content (TFC) of the flakes samples was measured with a spectrophotometer (Sarepoua et al., 2015).

2.4.4. Texture analysis

The instrumental texture was assessed through TA-XT Plus texture analyser by following the AACC International Method no 74–09.01. The compression level is set to 30%, time 1 s for 1 cycle, and threshold of 0.047 N. The final calculation was done after 4 repetitions. For this analysis, 5–7 flakes of each treatment were overlapped separately to obtain the following parameters: firmness, hardness, cohesiveness, elasticity, gumminess, chewiness, and resilience (Razip et al., 2025).

2.4.5. Colour determination

The colour parameters of the flakes were determined using the methodology described. Firstly, the samples were equally placed in a petri dish and measurements taken with the calibrated calorimeter CM-5 in the form of L*, a*, and b* color space. The total color difference (ΔE*) was calculated using the following equation (Mumtaz et al., 2025).

$$\Delta E = \sqrt{\Delta L * 2 + \Delta a * 2 + \Delta b * 2}$$

Where,
ΔL* = lightness difference
Δa* = redness difference
Δb* = yellowness difference

2.4.6. Sensory analysis

The acceptability of the flakes among consumers was determined by analysing colour, taste, texture, aroma, and overall acceptability using the 5-point hedonic scale described in the supplementary material. Sensory evaluation of flake samples was conducted with 30 members with an age between 25 and 30 years. Panellists were assigned scores ranging from 1 to 5 for appearance, colour, taste, Odor, texture, and overall acceptability. A sensory score of 5 was acceptable, while a score below 5 was regarded as unsatisfactory (Ganguly et al., 2025).

2.4.7. Functional analysis

2.4.7.1. Radial expansion. Radial expansion ratio (RER) was determined by measuring the diameter of the cross-section using a calliper and was calculated from the equation (Mohamed & Essa, 2018).

Radial Expansion Ratio (RER) = D/D_2
Where,
D (cm) = Average diameter of the cross-section of 10 flakes
D2 (cm)= Diameter of die nozzle

2.4.7.2. Water activity (a_w). According to the AACCI method No 44–15.02, the duo hygrometer 4TE was used to measure the water activity at a constant temperature of 25 ± 1 °C (do Nascimento et al., 2024).

2.4.7.3. Bulk density (BD). The flakes' BD was measured by adding 5 g of the sample to a 20 mL graduated cylinder, and the bottom of the cylinder was tapped on the lab bench until the sample's volume did not drop. The sound level was noted, and a formula was used to calculate bulk density (Ojo, 2024).

Bulk Density (BD) = Weight of sample (g) / Volume of sample(ml)

2.4.7.4. Swelling power (SP). The flakes' SP was determined by a calibrated cylinder at room temperature. Around 100 mg of the sample was combined with 10 mL of distilled water. Following 16–18 h of equilibration, the bulk volume was measured, and the swelling capacity was calculated as the volume that the sample occupied per gram of the dry weight of the original sample (Ekpenyobhiele et al., 2025).

Swelling Power (SP %) = Change in volume of sample/ Original weight of sample

2.4.7.5. Water absorption index (WAI). It was assessed after transferring roughly 0.5–1 g of the flake material to a test tube, 10 mL of deionized water was added. After stirring the mixture, it was allowed to hydrate for half an hour. Following a 10-minute centrifugation at 1650 r/min, the mixture was allowed to settle and the supernatant to separate. The sediment was then weighed. A calculation was made to determine the water WAI (Gunasekara et al., 2025).

Water Absorption Index (WAI) = Water absorbed (ml)/ Weight of sample (g)

2.5. Statistical analysis

The averaged data in the form of n = 3, calculated for the mean standard deviation (MSD). Results are presented as mean ± standard deviation with 95% confidence intervals to indicate precision of estimates. All variables satisfied normality assumptions (Shapiro–Wilk, $p > 0.05$), and homogeneity of variance was confirmed using Levene's test ($p > 0.05$), indicating suitability for parametric analysis with statistical software IBM SPSS. Then subjected to an analysis of variance using one-way and two-way ANOVA, with Least Significant Difference applied to determine the significance of differences between treatments. Graphics and a heatmap were drawn by Origin Pro 2021.

3. Result and discussion

3.1. Proximate analysis of functional flakes

Corn cob is an abundant agricultural by-product that is often discarded or underutilized despite being a valuable source of dietary fiber and bioactive compounds. It contains cellulose, hemicellulose, lignin, and bound phenolic compounds that possess antioxidant properties and potential health benefits. The incorporation of corn cob into food products can enhance dietary fiber content, improve nutritional value, and support digestive health. Furthermore, utilizing corn cob as a food ingredient promotes sustainability by reducing agro-industrial waste and contributing to a circular economy (Rose DJ, Inglett GE & Liu SX, 2010). Utilisation of corn (Zea mays) bran and corn fiber in the production of food components. *Journal of the Science of Food and Agriculture, 90*(6), 915–924. The raw data in Table 1 depicted that treatment T_2 with 50% sonicated corn grain flour (x_2) and 30% sonicated cob flour (x_3) was the most effective, exhibiting significantly high ash (y_{ac}), moisture (y_{mc}), fat (y_{fat}), and fibre content (y_{fc}), but a slight decrease in protein content (y_{pc}), in contrast to C_1 and C_2, as illustrated by the comparative contour plot in Fig. 2 (a, b, c, d, e). The applied analysis of variance (ANOVA) results in Table 2 showed the proximate composition of flakes prepared with different combinations of corn, corn cob, corn silk, and quinoa. ANOVA was used to determine whether significant differences existed among the formulations with respect to ash, moisture, fiber, fat, and protein contents.

The results show that the ash content generally increased with increasing corn cob incorporation; however, the response may also be influenced by moisture redistribution and interactions between dietary fiber and other food matrix components. Similar complex interactions have been reported in fiber-enriched food systems. The between-group sum of squares was 5.383 with 5 degrees of freedom, resulting in a mean square value of 1.077. In comparison, the within-group mean square was 0.072. The calculated F-value (15.022) with a significance value of 0.001 ($p < 0.05$) indicates that the ash content of the flakes varied significantly among treatments. This suggests that the incorporation of corn cob, corn silk, and quinoa influenced the mineral content of the developed flakes.

Similarly,

The observed changes in moisture and fiber content are not solely attributable to ingredient concentration. Competition for water between

Table 1
Proximate composition of functional flakes.

	Treatment	x_1	x_2	x_3	x_4	x_5	y_{mc}	y_{ac}	y_{fat}	y_{fc}	y_{pc}
Run		%	%	%	%	%	%	%	%	%	%
1	C_1	100	0	0	0	0	4.9	1	3.7	2.5	3.5
2		100	0	0	0	0	4.8	1	3.6	2	3.4
3		100	0	0	0	0	4.9	1.1	3.5	2.5	3.2
4	C_2	0	100	0	0	0	9.7	1.8	4.3	1.5	4
5		0	100	0	0	0	9.6	1.7	4.2	1.6	3.6
6		0	100	0	0	0	9.6	1.8	4.2	1.4	3.9
7	T_1	0	70	10	10	10	9	2	4.7	2.5	4.3
8		0	70	10	10	10	9	2.5	4.6	2.9	4
9		0	70	10	10	10	10	2	4.7	2.9	4.1
10	T_2	0	50	30	10	10	0.2	2	5.92	6.2	6.5
11		0	50	30	10	10	0.5	3	6	6	6
12		0	50	30	10	10	1	3	6	6.1	7
13	T_3	0	30	50	10	10	2	1.2	4	5.1	4.5
14		0	30	50	10	10	1	1.3	4.1	5	5
15		0	30	50	10	10	2	1.2	3.9	5	4
16	T_4	0	10	70	10	10	1.4	1.5	3	3.4	5.6
17		0	10	70	10	10	1.2	1.5	3	3	5
18		0	10	70	10	10	1.3	1.6	4	3.2	5

x_1 = Corn flour (%), x_2 = Sonicated corn grain flour (%), x_3 = Sonicated cob flour (%),.
x_4 = Sonicated silk powder (%), x_5 = Quinoa flour (%),.
y_{mc} = Moisture content (%); y_{ac} = Ash content (%); y_{fat} = Fat content(%).
y_{fc} = Fiber content (%); y_{pc} = Protein content (%).

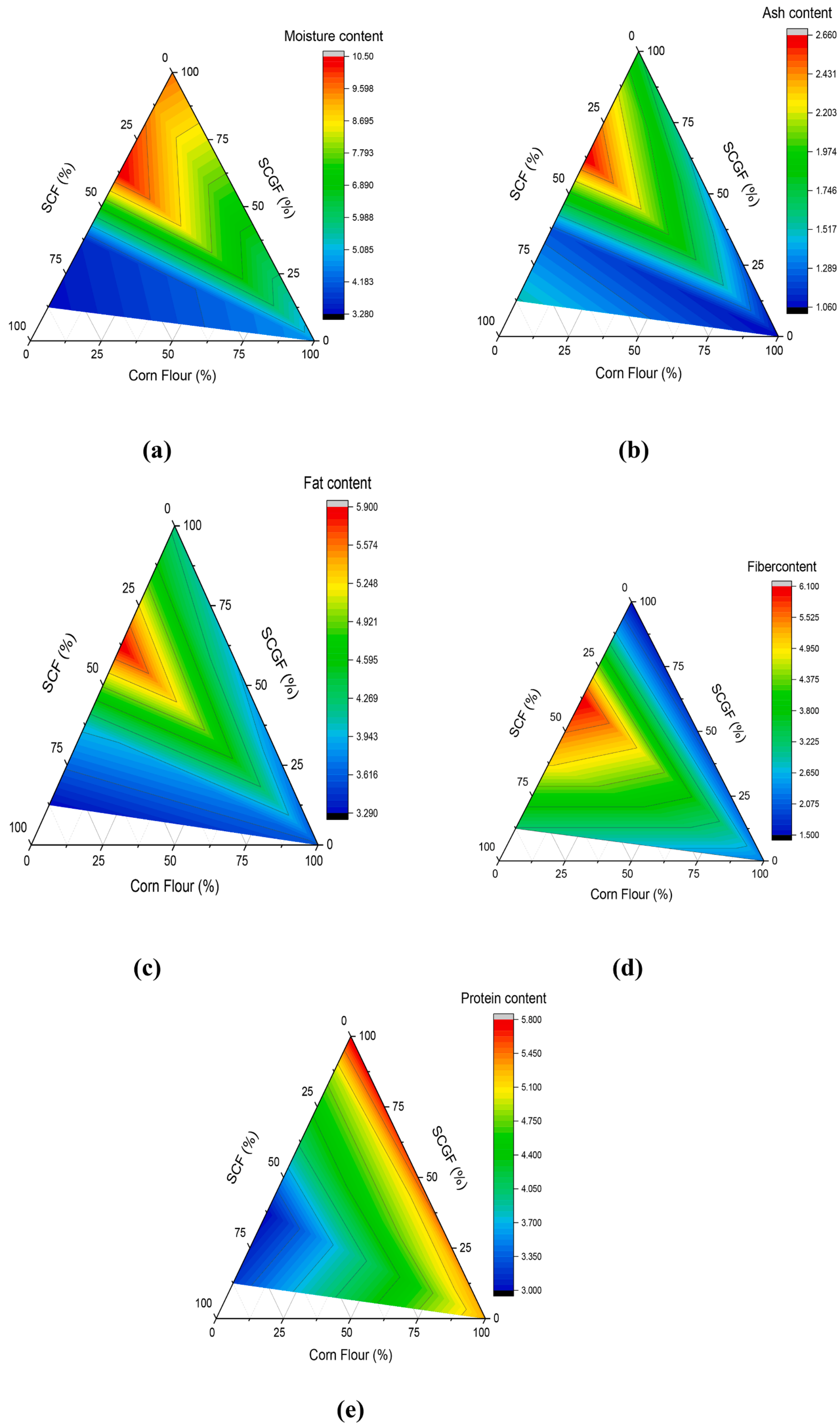

Fig. 2. Comparative contour plots of formulated functional flakes' C_1, C_2, T_1, T_2, T_3, T_4 for their proximate composition (a) Moisture (b) Ash (c) Fat (d) Fiber (e) Protein.

Table 2
ANOVA of the proximate properties of (corn, cob, silk, and quinoa) incorporated functional flakes.

Composition		Sum of Squares	df	Mean Square	F	Sig.	R-squared	Adjusted R-square
Ash content	Between Groups	5.383	5	1.077	15.022	.003		
	Within Groups	.860	12	.072				
	Total	6.243	17				0.54	0.40
Moisture content	Between Groups	250.689	5	50.138	155.308	0.002		
	Within Groups	1.693	12	0.141				
	Total	252.383	17				0.707	0.61
Fiber	Between Groups	45.298	5	9.060	71.787	.005		
	Within Groups	.400	12	.033				
	Total	45.698	17				0.51	0.36
Fat	Between Groups	13.293	5	2.659	43.905	.003		
	Within Groups	.727	12	.061				
	Total	14.020	17				0.51	0.36
Protein	Between Groups	18.918	5	3.784	31.974	.002		
	Within Groups	1.420	12	.118				
	Total	20.338	17				0.45	0.29

SS= Sum of Squares.
df=degrees of freedom.
MS=Mean Square.
F = F-value.
Sig= Significant value.

fiber and starch fractions, along with structural modifications induced by processing, may contribute to the compositional variations observed among treatments. The moisture content also showed highly significant differences among the treatments. The between-group sum of squares was 250.689, producing a mean square of 50.138, while the within-group mean square was 0.141. The F-value of 355.308 with $p = 0.005$ indicates a very big statistical difference between the formulations. This implies that different ingredient combinations significantly affected the moisture level of the flakes, which may influence their shelf stability and texture.

For fiber content, the ANOVA results also revealed a highly significant variation among the treatments. The between-group sum of squares was 45.298 with a mean square of 9.060, whereas the within-group mean square was 0.033. The calculated F-value (271.787) and p-value (0.002) demonstrate that the addition of corn cob, corn silk, and quinoa significantly increased the dietary fiber levels in the flakes. This highlights the effectiveness of utilizing agro-waste components in improving the nutritional quality of the product.

The fat content also showed statistically significant differences among the formulations. The between-group mean square was 2.659, compared with a within-group mean square of 0.061. The F-value of 43.905 with a significance level of 0.001 confirms that fat content varied significantly across the samples. These differences may be attributed to the varying proportions of quinoa and other ingredients used in the flake formulations.

Likewise, the protein content demonstrated significant variation among the treatments. The between-group sum of squares was 18.918 with a mean square of 3.784, while the within-group mean square was 0.118. The calculated F-value (31.974) with $p = 0.002$ indicates a statistically significant difference in protein content among the different formulations. This suggests that the incorporation of quinoa and other ingredients contributed to enhancing the protein content of the flakes.

Overall, the ANOVA results indicate that all proximate parameters (ash, moisture, fiber, fat, and protein) showed highly significant differences ($p < 0.05$) among the flake formulations. These results agreed with the findings; the moisture percentages of the snacks increased after the addition of red corncob powder, in contrast to the control group. This may be because cob contains high fibres, which retain water in the finished product (Mohamed & Essa, 2018).

Fats play a significant role in food and biological systems. The body can synthesize saturated and monounsaturated fatty acids, while polyunsaturated fatty acids (PUFAs) must be obtained through diet or other sources to maintain good health (Javed et al., 2018). The result showed that fat content increased due to the formation of a fiber-lipid composite. However, as the concentration of the corn cob powder increases, the protein content decreases because the cob has a low level of protein (Mohamed & Essa, 2018). These findings correlate with the (Aukkanit et al., 2017) study in which noodles with 20% corn cob fibre showed the highest crude fibre and moisture content. Moreover, the proximate study of putu piring with the addition of 30% corn cob powder (Ahmad et al., 2021) revealed a substantial difference ($p < 0.05$) in crude fibre content between putu piring with oat and corn cob powder. Adding oat and corn cob powder improves the nutritional content of putu piring, making it a high-fiber product. The proximate study of otak-otak made with a combination of 100% corn cob Powder and 0% oat fibre showed that crude fibre and fat considerably differed ($p < 0.05$). Fibre content ranged from 0.49% to 0.86%, while fat content was the highest in this blend compared to other blends (Ahmad & Sapiee, 2024). The researcher examined donuts produced with 5%, 10%, and 15% corncob flour inclusion. The study found that as the number of corn cobs in the donut formulation increased, so did the water content, 26.27%, 27.04%, and 28.35%, ash content 0.70%, 0.09%, and 0.73%, protein 4.88%, 8.25%, and 10.09%, and fat 8.06%, 4.75%, (Khasanah et al., 2025). Corn silk powder (CSP) was utilized to partially replace refined wheat flour at amounts of 10%, 20%, 30% and 40% in muffins. As the amount of CSP grew, the protein and crude fiber content of the muffins gradually climbed to a maximum in CSP 40% (Paick et al., 2024). Considering they may have less of an impact on human nutrition, plant-based proteins are seen as an alternative to animal-based proteins. In culinary applications, ultrasound techniques have been used to alter the chemical and physical properties of plant-based proteins, improving food quality.

The normality of the data was assessed using the Shapiro–Wilk test. As presented in Table X, all variables (B–F) showed non-significant p-values ($p > 0.05$), indicating no significant deviation from a normal distribution. The Shapiro–Wilk statistics ranged from 0.838 to 0.965, confirming that the normality assumption was satisfied for all measured parameters. Therefore, parametric analyses were considered appropriate for subsequent statistical evaluation.

3.2. *Antioxidant profile of functional flakes*

The increase in TPC in T2 may be attributed to synergistic effects between ultrasound-assisted processing and formulation composition, particularly the presence of SCF and quinoa, which contribute additional phenolic compounds and influence their extractability. Antioxidant analysis of the products showed that the T_2 treatment was the most effective, with significant increases in DPPH, TPC, and TFC compared with the control treatments, as shown in Table 3. DPPH activity increased in all supplemented treatments compared with the controls, with T_2 (50:30:10:10) exhibiting the highest scavenging capacity (34.8 ± 0.03), indicating enhanced radical-neutralizing potential due to the higher proportions of cob and quinoa shown in Fig. 3. Total phenolic content (TPC) also increased in T_1 and T_2 (1150±0.01 and 1120±0.02, respectively), suggesting that sonication facilitated greater release of bound phenolics from the by-products. Similarly, total flavonoid content (TFC) was maximized in T_2 (29.0 ± 0.01), significantly surpassing both untreated and treated controls. Overall, T_2 demonstrated the most pronounced improvement in antioxidant attributes, highlighting the synergistic contribution of corn cob, silk, and quinoa under optimized sonication conditions. The addition of corn silk has increased the nutritional quantity. This is supported by the sensory evaluation study of flat Egyptian bread substituted with 4, 6, and 8% corn silk (genotype B), indicating that the 8% substitution was well-liked. Also, a significant increase in the total phenolics and flavonoids, which exceeded three times the value of the control for total phenolics, being 351.7 μg/g in 8% bread and 119.8 μg/g for the control. Meanwhile, the flavonoid content of 8% substituted bread reached a level of 43.25 μg/g, whereas the control recorded zero flavonoids (Aboualfath et al., 2024). A comparative study assessed the quality and shelf stability of tofu produced using microwave and ultrasonic technology compared to traditional boiling methods. Ultrasonication for 20 min has a synergistic impact with significant scavenging activity against free radicals, providing a healthier alternative to microwaves and boiling. For 20 min, ultrasonicated Tofu (UTU) demonstrated the highest (47.40% and 22.2 mg/mL) scavenging activity. Tofu samples ranged in antioxidant activity and total flavonoid content (TFC) from 22.2 to 35.5 mg/mL (Olaniran et al., 2025). Study on the breadsticks made with 100 g kg−1 of corncobs fermented with Ganoderma. The addition of unfermented or fermented corncobs to breadsticks boosted total phenol content (from 0.2 to roughly 3 mg gallic acid equivalent (GAE) g − 1 DW) and antioxidant capacity (from 0.3 to 8 μmol ascorbic acid equivalent g − 1 DW). The breadsticks with the highest free phenol concentration were RR and RR + G (0.40 and 0.32 mg GAE g − 1 DW, respectively) (Cappa et al., 2025). The study by Hallouch et al. (2025) showed that phenolic-rich extracts from argan co-products, obtained by ultrasound-assisted extraction, enhanced the oxidative stability of sunflower oil without affecting its quality. Oils enriched with 200 ppm pulp extract demonstrated the greatest resistance to oxidation, highlighting argan by-products as effective and sustainable natural antioxidants for edible oils.

3.3. Mineral concentration of functional flakes

The values of mineral analysis of the products in Table 4 show that the T_2 treatment was the best among others, showing a significant rise in magnesium, Potassium, Iron, and zinc, while a slight decrease in calcium, in contrast to C_1 and C_2. Calcium content showed a decreasing trend as cob and silk inclusion increased, ranging from 0.8 ± 0.01 mg/kg in the untreated control to 0.1 ± 0.5 mg/kg in T_4 as depicted in Fig. 4. The reduction may be attributed to the dilution effect caused by partial replacement of corn with by-product ingredients. In contrast, magnesium and potassium demonstrated significant enhancement in T_2 (1.9 ± 0.1 to 2.9 ± 0.01 mg/Kg, respectively), indicating that the combined sonication of 50% corn with 30% cob, 10% silk, and 10% quinoa improved the extraction and retention of these minerals. Iron content increased substantially in all supplemented treatments relative to the controls, with T_2 again showing the highest concentration (60.6 ± 0.01 mg/kg). This suggests that corn and cob addition facilitated the iron concentration. Zinc exhibited similar improvement, with T_2 containing the highest level (34±0.02 mg/kg), significantly surpassing both untreated and treated controls. These findings highlight the functional potential of corn by-products and quinoa as mineral-boosting ingredients in ready-to-eat flakes, while also demonstrating the role of sonication in improving mineral measured concenteration. This was agreed by using instrumental and physicochemical methods of analysis. The study on the power ultrasound-assisted method of making tortilla chips has revealed some differences between the raw material masa pH, hue angle (°h), difference between two colors (ΔE), lightness (L), and Calcium, the product intermediate baked chips, and the final product tortilla chips. The texture of the baked chips after ultrasonication was noticeably better ($P < 0.05$). Compared to conventional processing, the texture of fried tortilla chips was significantly ($P < 0.05$) greater in BFG and PFF for ultrasonication (Janve et al., 2015). Few results were aligned with the attempt that was made to develop biscuit from mixing dragon fruit powder (DFP) in the ratio 30%, 40%, 50%, and 60% (w/w) with wheat flour, and they were considered as DFB30 (Dragon Fruit Biscuit 30%), DFB40 (Dragon Fruit Biscuit 40%), DFB50 (Dragon Fruit Biscuits 50%), and DFB60 (Dragon Fruit Biscuits 60%), respectively. As per sensory evaluation, DFB50 is an appropriate formulation of wheat flour for DFP. Biscuit (DFB50) demonstrated higher fiber content by almost five times (7.81 g %), minerals (0.91 g %), and an enhanced spread ratio (8.76) when compared with wheat flour biscuit (B0). Biscuit also reported being supplemented with 0.0092 mg % Gallic acid, with no significant difference noted in protein, fat, calcium, and iron content as compared to wheat biscuit (B0) (Pawde et al., 2020).

According to the dendrogram based on Euclidean distance, the most similar pair is T1 and T4. These two merge at a high similarity level (~90%), meaning they have very similar profiles and form a tight cluster first. Next cluster is (T1–T4), which joins with T3, which merges with the T1–T4 group at around ~75–80% similarity, which is moderately similar. Together they form a T-cluster subgroup. C2 joins the T-cluster group and merges with (T1, T4, T3) at a lower similarity (~35–40%), showed moderately differentiation. It still shares some common traits but is not very close. C1 is more distinct; it joins the rest at a very low similarity level. C1 is clearly separated; it shows the most unique profile among all samples. Most distinct sample: T2 that joins the entire cluster last (at the lowest similarity level, near 0–20%). T2 is the most different product overall. It has the strongest deviation in attributes.

Table 3
Antioxidant Composition of Sonicated-Assisted functional flakes.

Treatment	DPPH%	TPC	TFC
Control 1	29.6 ± 0.05 [a]	1003±0.01[a]	21.3 ± 0.01[a]
Control 2	30.6 ± 0.005 [b]	1009±0.01 [a]	23.0 ± 1[b]
T_1	32.3 ± 0.5[b]	1150±12[a]	25.0 ± 1[b]
T_2	34.8 ± 0.4 [a]	1120±0.02 [a]	29.0 ± 0.01[a]
T_3	32.7 ± 0.6 [b]	1004±1.5 [b]	24.3 ± 0.5 [c]
T_4	29.3 ± 0.05 [a]	995±5 [c]	25.6 ± 0.5 [b]

C1= 100% CGF.
C2= 100% SCGF.
T_1=(70% SCGF+ 10% SCF+10% SSP+10% QF).
T_2= (50% SCGF+ 30% SCF+10% SSP+10% QF).
T_3= (30% SCGF+ 50% SCF+10% SSP+10% QF).
T_4= (10% SCGF+ 70% SCF+10% SSP+10% QF).
Values presented as means± standard error, n = 3.
Values within each row followed by different letters are significantly different at ($p \leq 0.05$).

3.4. Principal component analysis

Principal Component Analysis (PCA) is used as an exploratory multivariate technique to visualize patterns of variation and relationships among variables. PCA does not test hypotheses or infer causality; therefore, interpretations are limited to data structure and variable associations. The PCA biplot explains 89.73% in Fig. 5 (c) of the total variation in the data through two main components (F1 = 67.39% and F2 = 22.34%), in Fig. 5 (a, b), PCA loading plot (correlation circle) showing the contribution of variables to the first two principal components, which together explain 89.73% of total variance. PC1 is mainly

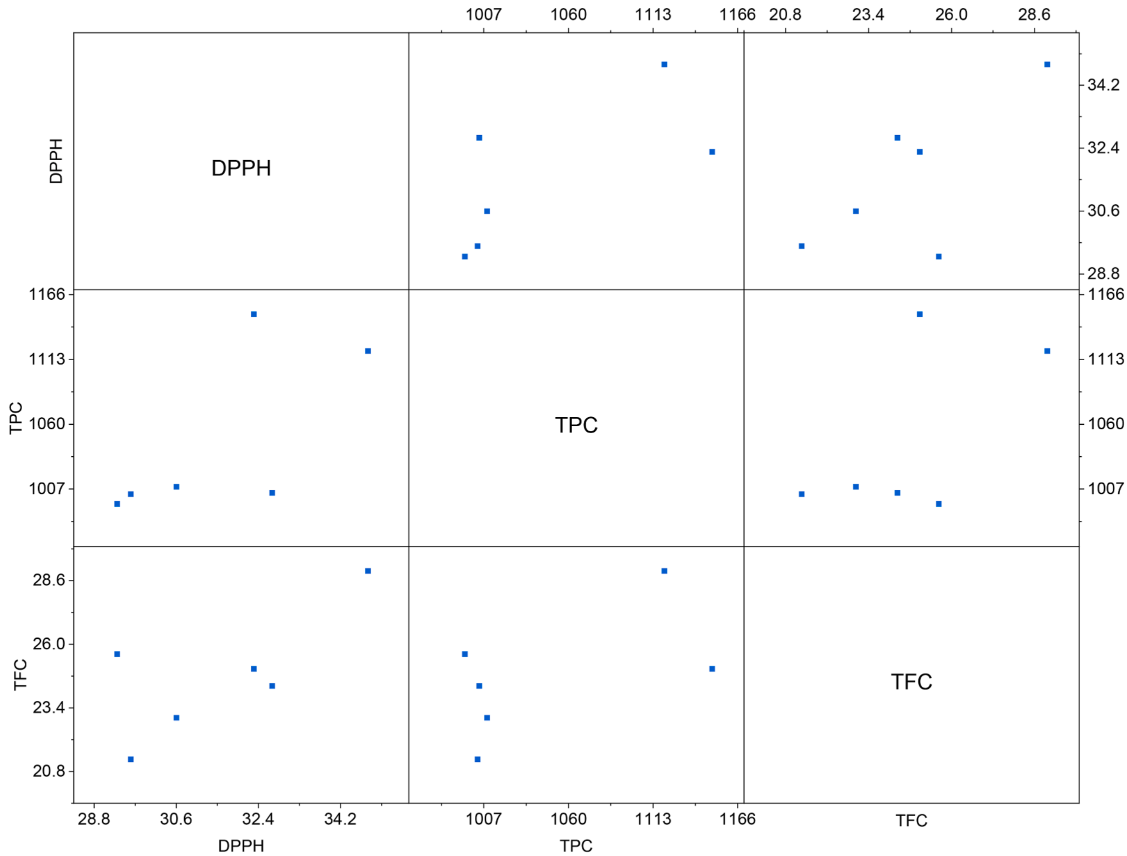

Fig. 3. Scatter matrix of the antioxidant profile of functional flakes.

Table 4
Mineral Content of functional flakes.

Treatment (Corn + Cob+ Silk+ quinoa) %	Calcium	Magnesium	Potassium	Iron	Zinc
Control 1 (Untreated 100% corn)	0.8 ± 0.01[a]	1.2 ± 0.1[b]	2.3 ± 0.1[b]	49.3 ± 0.05[a]	27.6 ± 1.5[b]
Control 2 (Treated 100% corn)	0.6 ± 0.5[b]	1.4 ± 0.01[a]	2.4 ± 0.05[a]	51.6 ± 0.05[a]	30.1 ± 0.7[b]
T_1 (70 + 10+10+10)	0.4 ± 0.5[b]	1.5 ± 0.1[c]	2.5 ± 0.1[b]	56±2[b]	30.6 ± 0.5[b]
T_2 (50 + 30+10+10)	0.3 ± 0.05[a]	1.9 ± 00.1[a]	2.9 ± 0.01[a]	60.6 ± 0.01[a]	34 ±0.02[a]
T_3 (30 + 50+10+10)	0.2 ± 0.5[b]	1.5 ± 0.05[b]	2.3 ± 0.1[c]	53.3 ± 2.8[b]	31±1[c]
T_4 (10 + 70+10+10)	10±0.5 [c]	1.4 ± 0.1 [d]	2.5 ± 0.1[d]	55.3 ± 2.3 [c]	30±1 [d]

C1= 100% CGF.
C2= 100% SCGF.
T_1=(70% SCGF+ 10% SCF+10% SSP+10% QF).
T_2= (50% SCGF+ 30% SCF+10% SSP+10% QF).
T_3= (30% SCGF+ 50% SCF+10% SSP+10% QF).
T_4= (10% SCGF+ 70% SCF+10% SSP+10% QF).
Values presented as means± standard error, n = 3.
Values within each row followed by different letters are significantly different at ($p \leq 0.05$).

associated with antioxidant activity, mineral content, fiber, and phenolic compounds, while PC2 differentiates protein, calcium, and moisture from other quality attributes. Variables located close to each other are positively correlated, whereas those on opposite sides of the origin show negative correlations. Controls, in contrast, contribute the least to the desirable nutritional properties, as illustrated in Fig. 6.

3.5. *Textural analysis of functional flakes*

Hardness, cohesiveness, and elasticity all affect chewability, a textural metric that is correlated with sensory analysis and corresponds to the effort needed to chew. Table 5 summarizes the effects of SCGF, SCF, and QF concentrations on the flakes' hardness/ firmness and chewability properties.

Hardness gradually decreased from Control 1 (255 N) to treated samples; T_2 and T_3 had the lowest values (242 N). Another parameter firmness, dropped from 4.5 N (Control 1) to 3.4–4.0 N, suggesting a weaker interior structure. Treated flakes that are less hard indicate better fracture behaviour, which makes them easier to bite. Likewise, both gumminess and chewiness also decreased markedly in treated flakes. Control samples showed the highest chewiness (3.2–3.5 N), whereas T_3 and T_4 exhibited the lowest values (2.0–2.2 N). This reduction is desirable for breakfast cereals, as it indicates easier mastication and faster breakdown, improving consumer acceptability. These results are aligned with the study in which comparison to the control sample, biscuits significantly boosted dietary fiber, total phenolic content, and antioxidant activity when combined with corn cob powder (CCP). Compared to their untreated counterparts, enzyme-treated goods had increased fracture ability, decreased hardness, and greater overall acceptance (Hoang et al., 2022). Researchers examine the possibility of using ultrasonic and acoustic testing to forecast the physicochemical characteristics of Honey Globe melons. The conclusion that both ultrasonic and acoustic techniques show promise in predicting the firmness characteristics of melon fruits is supported by the analysis results on both metrics taken together. Fruit firmness is predicted using attenuation, age, and density, based on the best evaluation results from the ultrasonic test (Khuriyati et al., 2024).

Fig. 4. Similarity dendrogram of minerals in functional flakes.

Elasticity, which is impacted by the gluten network and starch gelatinization, is the food's capacity to bounce back after deformation. Dilution or absence of gluten may lead to lower elasticity values. Treated samples generally exhibited lower elasticity than controls, indicating reduced recovery after deformation. Resilience and elasticity showed mixed trends. Resilience is a measure of a product's ability to recover from deformation. However, T_2 and T_3 recorded higher resilience values (>92%), suggesting enhanced ability to absorb energy during chewing. This proof from the study shows that when purple corn cob flour (PCF) was partially substituted (5%w/w) for wheat flour (WF) to make bread, it showed an increase in the resilience value (do Nascimento et al., 2024).

Cohesiveness is a measure of the formulation's internal bonding and usually falls within a small range. T_4 had the highest cohesiveness rating (60%), indicating a stronger internally linked matrix. Cohesiveness varied greatly. It was found that the 5% substitute of purple corn had no effect on cohesiveness, a textural parameter linked to crumb strength ($p > 0.05$), whereas the 15% and 25% replacements had a substantial impact on cohesiveness ($p < 0.05$) (Comettant-Rabanal et al., 2025). Similar results by a study in which 100% corn cob powder (CCP): 0% oat fibre was used in otak showed the best cohesion as well as exceptional hardness and chewiness ratings, suggesting a cohesive structure that is resistant to disintegration while chewing (Ahmad & Sapiee, 2024).

In crispiness, with increasing concentration of SCCF, crispiness significantly increased. T_2 and T_3 had significantly greater crispiness scores (20–21), whereas Control 1 had the lowest score (10). Better pore development and cell wall disruption, which encourage brittle fracture during mastication, are associated with this improvement. There is an inverse relationship between the crispiness index and water activity (a_w) for functional flakes. In this study, water activity ranged narrowly from 0.35 to 0.39 across all samples. Treated flakes, particularly T_2 (0.35), exhibited slightly lower a_W values compared to controls, as Pearson correlation in the figure. Following the results of the study, when broken white bean flour was added to the blends for corn flakes and snacks, the WA steadily decreased, ranging from 0.34 to 0.39 and from 0.36 to 0.40, respectively (Dewidar & Hanan, 2020). This ensures crispiness, improved shelf stability, and microbial safety, likely due to enhanced dehydration efficiency or structural compactness induced by treatment. All values remained within the acceptable range for ready-to-eat cereal products.

3.6. Colour parameter of functional flakes

The colour parameters showed a progressive change across formulations. Lightness (L*) decreased from Control 1 (65.19) to T_4 (58.19), indicating darker flakes with increasing treatment intensity or compositional modification. This reduction in L* may be attributed to processing-induced browning reactions., pigment concentration, or structural changes caused by processing. Redness (a*) increased notably in treated samples, with T_2 exhibiting the highest a value (22.98), suggesting greater browning or thermal effects. Conversely, yellowness (b) decreased from 24.99 in Control 1 to 19.63 in T_4, reflecting a shift from yellowish to brownish tones as given in Table 5. Overall, treatments resulted in darker and more intensely coloured flakes, which are commonly associated with novel processing or enrichment, as shown in Fig. 7. The ΔE using the average of your two control samples as reference gives result that T1 ($\Delta E \approx 2.38$) just a noticeable difference, T2 ($\Delta E \approx 3.56$) clearly perceptible, T3 ($\Delta E \approx 5.11$): distinct color change, and T4 ($\Delta E \approx 6.91$) strong visible difference.

A study by researchers proved these findings by the addition of 10% CCP, which showed color and volume characteristics of the loaves were considerably impacted in comparison to the composite bread samples. It was discovered that adding more CCP to the formulation produced firmer, smaller, and darker bread loaves (Lee et al., 2019). Likewise, in another study, the blended dough made of 90% semolina as well as 10% corncob powder was successful. The cooking time, physical quality, and general acceptance of the corncob-incorporated pasta were similar to those of the control pasta (Nguyen et al., 2023).

3.7. Sensory analysis of functional flakes

The sensory evaluation results presented in Table 6 indicate significant variations in appearance, colour, aroma, texture, taste, and overall acceptability among the treatments and controls. In terms of

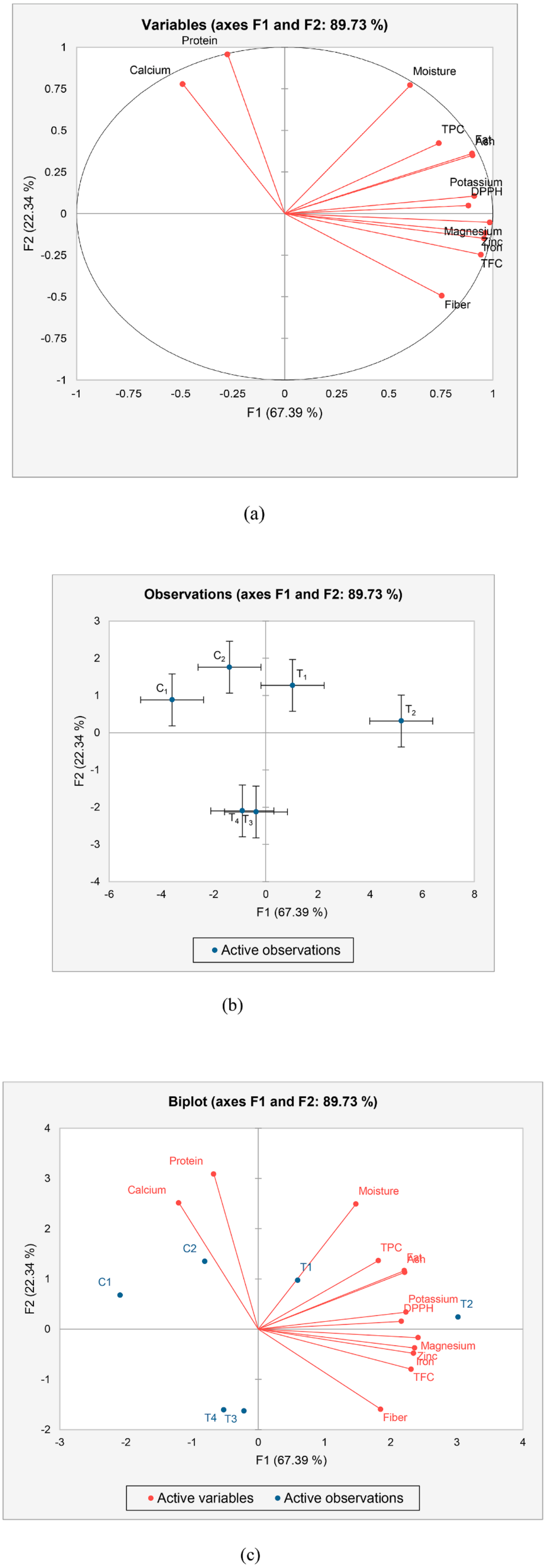

Fig. 5. PCA of all the studied responses of flakes (a) for active variables (b) for active observations (c) collective response.

appearance, T_2 received the highest score (2.2 ± 0.2^{a}), indicating a visually appealing product, while T_4 recorded the lowest score (1.1 ± 0.8^{d}), suggesting reduced visual attractiveness. A similar trend was observed in colour, where T_2 (4.5 ± 0.5^{a}) was most preferred, followed by T_1 (4 ± 0.3^{c}), while T_4 (1.5 ± 0.6^{d}) and T_3 (2 ± 0.3^{d}) were least favoured, possibly due to less desirable pigmentation or product uniformity. These results indicate that treatments T_1 and T_2 positively influenced colour development, possibly due to ingredient interactions or processing conditions, and by the browning response due to high fibre content, because red corncob powder was added according to the study by Mohamed and Essa (2018), while T_3 may have undergone changes that negatively affected its appearance. Regarding flavour, which includes both aroma and taste analysis. Aroma scores showed a moderate variation, with T_2 again leading (3.0 ± 0.2^{a}), reflecting an enhanced and pleasant aroma profile. The control samples recorded lower aroma scores compared to T_1 and T_2, indicating that the treatments contributed positively to flavour perception. In terms of taste evaluation, a similar trend followed, where T_2 (3.2 ± 0.2^{a}) and T_1 (3 ± 0.9^{b}) were significantly preferred, likely due to balanced flavour development. In contrast, T_4 (1 ± 0.5^{d}) and T_3 (1.5 ± 0.3^{d}) received the lowest taste ratings, which may be linked to off-flavours or less appealing sensory notes. This also suggests that the T_2 formulation may have enhanced the retention of volatile compounds, thereby improving aroma perception. After analysing the texture of T2, which illustrates the highest (2.8 ± 0.3^{a}) acceptability. This improvement in texture for T2 could be attributed to better ingredient integration or optimized processing, resulting in a more desirable mouthfeel due to essential fibre, which is freely available in corn cob powder (CCP). But T_3 and T_4 had the lowest liked because it was discovered that adding more CCP to the recipe produced harder, smaller, and darker bread loaves in contrast to the examples of composite bread in a study (Lee et al., 2019). Overall acceptability was highest for T_2 (6.2 ± 0.1^{a}), followed by T_1 (5.5 ± 0.3^{b}), with the lowest rating observed for T_3 and T_4, as shown in Fig. 8. The consistently superior performance of T_2 across all parameters suggests that its formulation and processing were most effective in improving the sensory quality of the product. These findings collectively indicate that treatment T_2 offered the most favourable sensory characteristics, outperforming both control samples and other treatments. The improved scores in appearance, colour, aroma, texture, and taste likely contributed to its higher overall acceptability. Conversely, T_4 consistently received lower ratings, suggesting that its formulation or processing negatively impacted sensory attributes. (Lian et al., 2025) A study investigated how ultrasonic therapy affected the texture and flavor quality of Japonica rice. Hexanal, heptanal, 2-pentylfuran, octanal, nonanal, trans-2-octenal, decanal, undecanal, trans-2-nonanal, trans-2-dodecenal, trans-2-decenal, trans-2,4-decadienal, 2-pentadecanone, and indole were important aroma molecules that affected the aroma of cooked rice both before and after ultrasound treatment. Following ultrasound treatment, the odor activity values (OAVs) of these chemicals increased noticeably and exceeded 1. Moreover, another study found that adding 25% corn cob powder (CCP) and 75% wheat flour greatly improves the kuih kaswi's texture profile, particularly cohesiveness and hardness. Meanwhile, adhesiveness, springiness, and chewiness are significantly lower with increased CCP. According to the overall sensory results, panel members favoured 25% CCP containing kuih kaswi (Kumar & Ahmad, 2024). Results parallel to the study of corn cob powder (CCP), which was used in varying quantities (5, 10, and 20%) to partially substitute bread flour in the formulation. All three bread samples and the control (0% CCP in the formulation) were evaluated, which significantly altered the texture, colour, and volume aspects of the manufactured loaves. Increasing the content of CCP in the formulation was revealed to be responsible for firmer, smaller, and darker bread loaves as compared to the composite bread samples. The bread formulation combined with 10% CCP received the highest mean scores (7.00) of overall acceptances 4 (Lee et al., 2019). A study by researchers indicated that brownies made with 25% cacao shell flour were

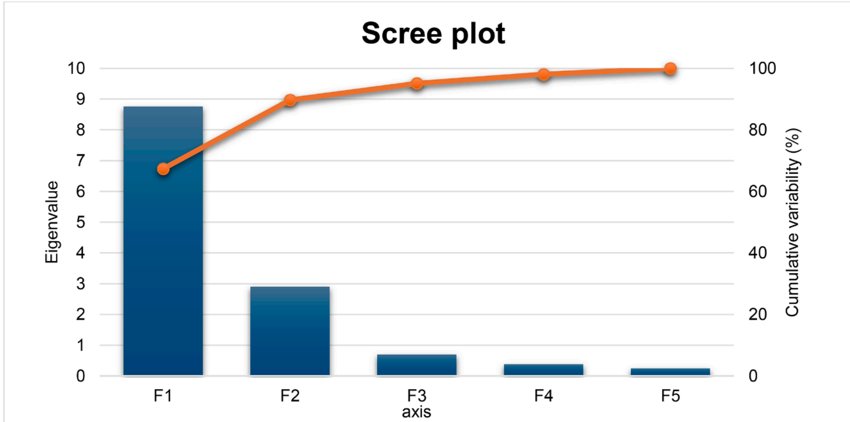

Fig. 6. Eigenvalues for all principal components after PCA of functional flakes.

Table 5
Textural and colour analysis of functional flakes.

Treatments	L*	a*	b*	ΔE	a_w	Hardness	Crispiness	RER	Firmness	Cohesiveness (%)	Resilience (%)	Elasticity (%)	Gumminess	Chewiness
Control 1	65.1	17.4	24.9	-	0.39	255 $\pm 0.2^{a}$	10 ± 0.3^{c}	6.1 $\pm$ 0.1^{b}	4.5 ± 0.4^{b}	50 ± 0.2^{a}	27 ± 0.3^{c}	89.2 ± 0.8^{d}	3 ± 0.3^{c}	3.5 ± 0.4^{b}
Control 2	64.1	18.8	24.0	-	0.39	250 $\pm 0.8^{d}$	12 ± 0.3^{c}	6.3 $\pm$ 0.1^{b}	4.0 ± 0.4^{b}	47 ± 0.8^{d}	24 ± 0.1^{b}	88.4 ± 0.2^{a}	3.5 ± 0.4^{b}	3.2 ± 0.1^{b}
T_1	63.1	19.0	22.4	2.38	0.38	246 $\pm 0.5^{a}$	13 ± 0.4^{b}	5.5 $\pm$ 0.2^{a}	3.9 ± 0.5^{a}	46 ± 0.2^{a}	20 ± 0.2^{a}	90.2 ± 0.3^{c}	2.6 ± 0.1^{b}	2.5 ± 0.3^{c}
T_2	62.0	22.9	23.0	3.56	0.35	242 $\pm 0.5^{a}$	21 ± 0.4^{b}	5.3 $\pm$ 0.2^{a}	3.4 ± 0.8^{d}	40 ± 0.1^{b}	20.5 ± 0.1^{b}	92.3 ± 0.8^{d}	2.5 ± 0.4^{b}	2.1 ± 0.8^{d}
T_3	60.4	20.1	20.4	5.11	0.36	242 $\pm 0.3^{c}$	20 ± 0.2^{b}	5.2 $\pm$ 0.5^{a}	3.5 ± 0.5^{a}	54 ± 0.3^{c}	25 ± 0.4^{b}	92.5 ± 0.1^{b}	2.3 ± 0.1^{b}	2 ± 0.3^{c}
T_4	58.1	19.0	19.6	6.91	0.37	250 $\pm 0.3^{c}$	18 ± 0.2^{b}	4.0 $\pm$ 0.5^{a}	4.0 ± 0.8^{d}	60 ± 0.2^{a}	25 ± 0.1^{b}	91.5 ± 0.1^{b}	2.1 ± 0.1^{b}	2.2 ± 0.8^{d}

C1= 100% CGF.
C2= 100% SCGF.
T_1=(70% SCGF+ 10% SCF+10% SSP+10% QF).
T_2= (50% SCGF+ 30% SCF+10% SSP+10% QF).
T_3= (30% SCGF+ 50% SCF+10% SSP+10% QF).
T_4= (10% SCGF+ 70% SCF+10% SSP+10% QF).
Values presented as means± standard error, n = 3.
Values within each row followed by different letters are significantly different at ($p \leq 0.05$).
L*=lightness.
a*=redness.
b*=yellowness.
a_w=water activity.
RER=Rapid Expansion Ratio.

the most favoured, followed by those with 75%, 50%, and finally 100%, which was the least favoured. Additionally, the dietary fiber content increased with the percentage of cacao shell flour, with 75% being the most acceptable due to its relatively high preference and elevated dietary fiber content (Banaira & Barrion, 2022).

3.8. Functional analysis

3.8.1. Rapid expansion ratio of functional flakes

In treated flakes, the expansion ratio dropped dramatically from 6.3 in C_2 to 4.07 in T_4. Higher solid density or fiber/protein enrichment due to cob incorporation is depicted in Fig. 9. Because dietary fiber content ruptures the cell wall before the gas bubbles expand to their full potential, this may be the reason for the lower rapid expansion ratio (RER) of extruded products illustrated in Table 5. These results are similar to the study, which showed that when the integration ratio of red corncob powder grew from 0 to 10%, the expansion ratio fell by 21.73% (Mohamed & Essa, 2018).

3.8.2. Bulk density

The bulk density of the samples exhibited clear variations across treatments, reflecting the impact of formulation and sonication on the product's physical properties. In terms of bulk density, C_2 recorded the highest value (0.29 ± 0.2^{b}), closely followed by C_1 (0.27 ± 0.2^{a}) and T_1 (0.30 ± 0.1^{b}), indicating relatively compact and dense structures shown in Table S2 in the supplementary file. Interestingly, T_2, which contained 30% sonicated cob and 50% sonicated corn, had the lowest bulk density (0.10 ± 0.3^{a}). Such a reduction in bulk density may occur due to

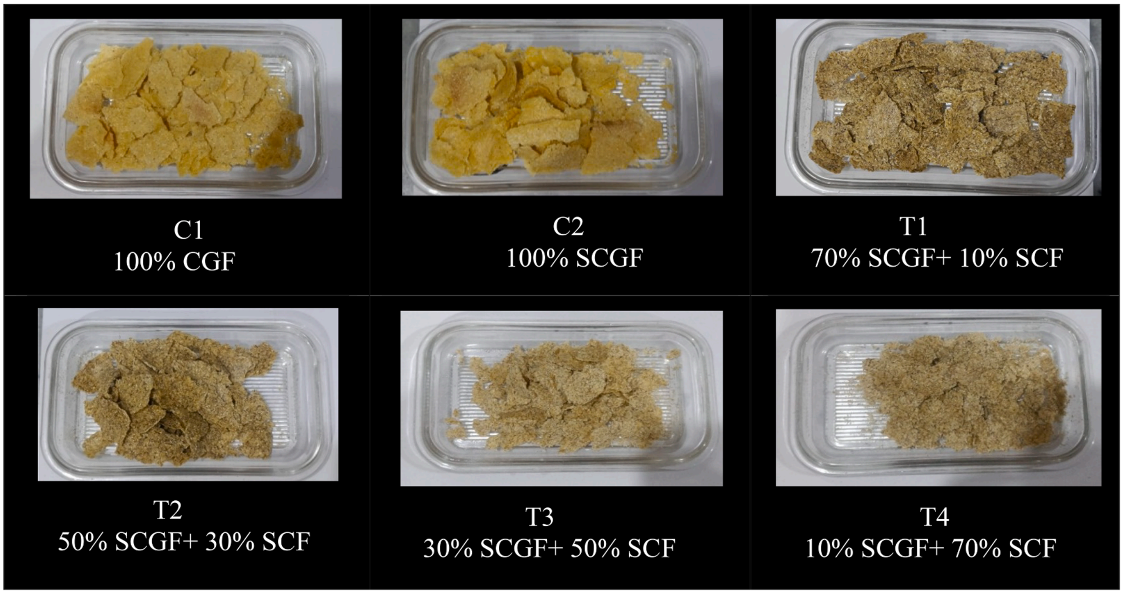

Fig. 7. Treatments of functional flakes (DF).

Table 6
Sensory analysis of sonicated-assisted functional flakes.

Treatments	Appearance	Colour	Aroma	Texture	Taste	Overall acceptability
Control 1	1.2 ± 0.3^a	3 ± 0.2^a	2.2 ± 0.5^a	2.3 ± 0.2^a	2 ± 0.5^a	4.2 ± 0.2^a
Control 2	1.3 ± 0.1^b	3.2 ± 0.1^b	2.3 ± 0.3^b	2.4 ± 0.1^b	2.5 ± 0.6^b	3.1 ± 0.2^b
T_1	2.0 ± 0.1^b	4 ± 0.3^c	2.5 ± 0.4^b	2.6 ± 0.2^b	3 ± 0.9^b	5.5 ± 0.3^b
T_2	2.2 ± 0.2^a	4.5 ± 0.5^a	3.0 ± 0.2^a	2.8 ± 0.3^a	3.2 ± 0.2^a	6.2 ± 0.1^a
T_3	1.5 ± 0.2^c	2 ± 0.3^d	2.4 ± 0.3^c	2.2 ± 0.1^c	1.5 ± 0.3^d	3.0 ± 0.2^d
T_4	1.1 ± 0.8^d	1.5 ± 0.6^d	2.2 ± 0.2^b	2 ± 0.4^c	1 ± 0.5^d	2.5 ± 0.3^d

C1= 100% CGF.
C2= 100% SCGF.
T_1=(70% SCGF+ 10% SCF+10% SSP+10% QF).
T_2= (50% SCGF+ 30% SCF+10% SSP+10% QF).
T_3= (30% SCGF+ 50% SCF+10% SSP+10% QF).
T_4= (10% SCGF+ 70% SCF+10% SSP+10% QF).
Values presented as means± standard error, n = 3.
Values within each row followed by different letters are significantly different at ($p \leq 0.05$).

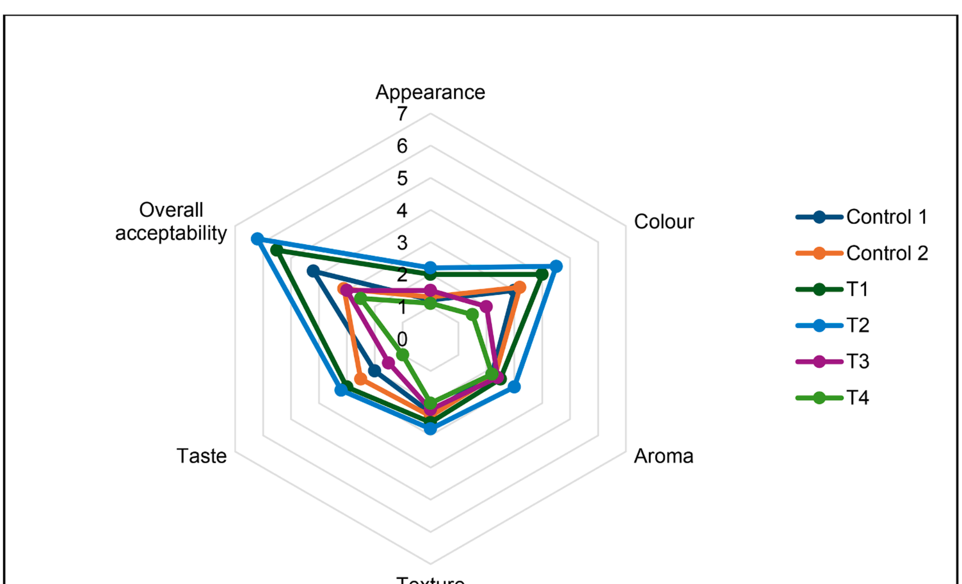

Fig. 8. Sensory characteristics illustration via a spider web.

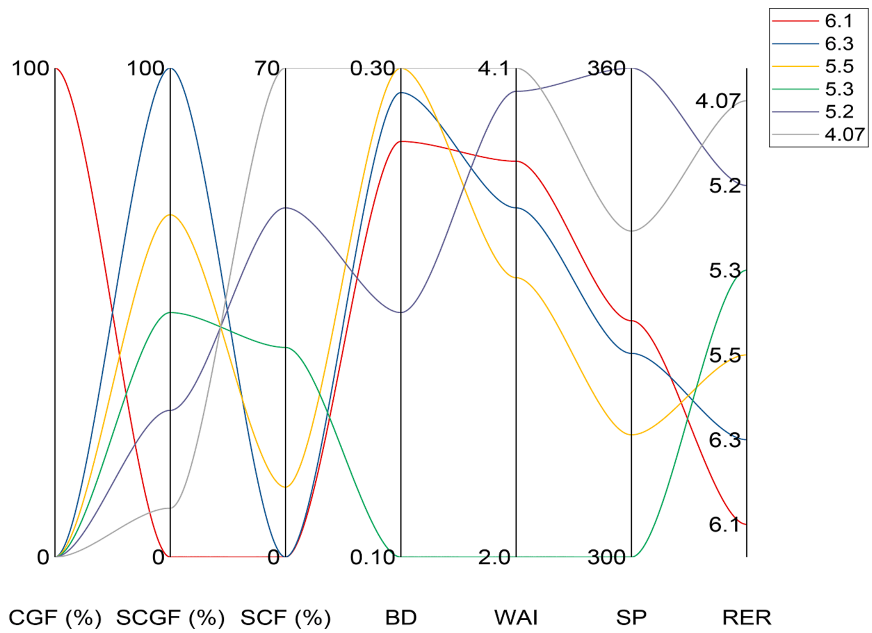

Fig. 9. Parallel set plot of functional analysis of functional flakes.

increased air incorporation or changes in the starch-protein matrix during sonication up to 20 min, as indicated (Zhang et al., 2005). The results shown in Fig. 9 aligned with the research study of both sonicated (OKS) and non-sonicated okaras (UOK) were assayed at two percentages (2% and 3%), resulting in OKS 3% enhanced specific volume (20%), reduced the hardness (30%), raised the cohesion of the crumb, and improved the air inclusion. It revealed the efficacy of the sonication procedure to get a gluten-free bread improver from a bulky by-product of the soybean industry (Moscoso Ospina et al., 2023). Along with that, another study investigation proved that the addition of by-product broken white bean flour (BWBF) in (10, 20, 30, 40, and 50%) in flakes caused a decrease in the water activity as percentages increased in the blends. Therefore, the volume, mass, and density were drastically modified in the produced corn flakes (Dewidar & Hanan, 2020). As a result of the study by dos Santos et al. (2025), specific volume (2.64 L/kg), and stiffness (7.05 N) in a muffin. It was also revealed that muffin batter's pasting and rheological characteristics drop in peak and ultimate viscosity. A considerable drop in specific volume (1.99 to 1.57 cm3 g − 1), weight loss (11.73 to 10.14 *g* 100 *g*−1), and an increase in crumb hardness (633.06 to 2311.5 *g*) of muffins on substitution of refined wheat flour with pomegranate peel powder (PPP) at a rate of 2%, 4%, 6%, 8% and 10% (Giri et al., 2024).

3.8.3. Swelling capacity

The swelling capacity in the flakes analysis results revealed a different trend. T_3 exhibited the highest swelling value (360 ± 0.1^{d}), indicating a strong ability to absorb water and expand, as shown in supplementary Table S2. This could be linked to a more open, hydrated starch structure with minimal restriction from other components. On the other hand, T_2 showed the lowest swelling capacity (300 ± 0.2^{a}), possibly due to structural modifications or reduced starch availability for water uptake. The control samples maintained intermediate swelling values, which may indicate a balanced starch structure with moderate hydration capacity. Results parallel to the study done (Mu et al., 2025) by ultrasonic-assisted nixtamalization wet milling (UNWM) of maize flour, which underwent more effective pasting and displayed the highest viscoelasticity, consistency, and shear stress, exhibiting higher gel strength, water-holding capacity, superior thixotropy, and improved processing adaptability. A study evaluated three varieties of breakfast flakes from germinated maize, millet, and sorghum, and each was substituted with germinated pigeon pea flour at varying levels, 0, 20, 30, 40, and 50%. Water absorption capacity increased in corn (1.06 – 1.73 g/m^2) but declined in millet (1.40 –0.56 g/m^2) and sorghum (1.98 – 0.56 g/m2). The maximum values of swelling capacity were found in maize at 70 °C and 50 °C, and in sorghum at 90 °C. Moisture was highest in corn at 20% level (8.49%), crude fat in corn 40% (14.36%), and protein in corn 40% (13.01%), fiber in sorghum 30% (1.36%), ash in sorghum 0% (0.93%), and carbs in sorghum 30% (87.12%). K, Na, P, and Fe levels grew dramatically as the replacement increased, with the greatest values (Adedokun et al., 2024).

3.8.4. Water absorption index

The highest WAI (4.1 ± 0.6^{d}) was recorded in T_4, closely followed by T_3 (4.0 ± 0.3^{c}), suggesting that these treatments had greater water-binding ability. This could be beneficial for products where moisture retention during preparation or consumption is desirable. Conversely, T_2 again had the lowest WAI (2.0 ± 0.5^{a}), as shown by Fig. 9, reinforcing the idea that its structure was less capable of retaining water, which might result in a drier, crisper final product. A study (Francisco-Ponce et al., 2024) assessed how nixtamalized corn flour (NCF) is affected by ultrasound (US) processing in terms of its physical and powder flow characteristics, as well as how it affects tortilla quality metrics like texture, yield, and the presence of amylose-lipid complexes. Result justified that addition of corn and cob processing increased the cohesiveness index (18.03 N·m·g − 1), the moisture content that corresponded to the minimum integral entropy (MIE) of adsorption and decreased caking (138.77 N), and the speed flow with improved thermal and pasting properties, the most desirable moisture-storage conditions, and flow powder behavior, all of which resulted in a better tortilla product. The addition of corn and cob impacts could be helpful if they are applied to enhance NCF. The higher water absorption observed in treatments T3 and T4 suggests improved hydration capacity, likely associated with structural modification and increased availability of hydrophilic components. Similar trends have been reported in extruded products supplemented with higher levels of red corncob powder, where increased incorporation led to elevated water absorption index, total dietary fiber, and phenolic content. This behavior can be attributed to the higher fiber content, which enhances water-binding sites within the matrix. In contrast, the reduction in expansion observed with increased corncob addition, alongside higher water solubility index, further supports the role of fiber-induced disruption of starch structure and reduced starch–protein network integrity during extrusion (Mohamed & Essa, 2018).

3.8.5. Pearson correlation

Pearson correlation analysis was performed to elucidate the relationships among color attributes, textural parameters, and functional properties of the developed product. The correlation matrix revealed several statistically significant associations ($|r| \geq 0.70$), indicating that processing-induced structural modifications had a substantial influence on both physical ssand sensory-related attributes. Lightness (L*) exhibited a robust positive correlation with yellowness (b*) ($r = 0.96$) and expansion ratio ($r = 0.95$), suggesting that highly expanded samples appeared lighter and more yellow in color. This phenomenon may be attributed to increased air cell formation and reduced bulk density, which enhance light scattering on the product surface. Conversely, L* showed a strong negative correlation with crispiness ($r = -0.76$) and elasticity ($r = -0.74$), indicating that lighter products tended to possess softer and less elastic structures. These findings, as shown in Fig. 10, suggest that excessive expansion, while improving visual appearance, may adversely affect crisp texture.

The redness parameter (a*) demonstrated strong negative correlations with hardness ($r = -0.84$) and firmness ($r = -0.90$), while showing a strong positive correlation with crispiness ($r = 0.83$). This indicates that samples with higher a* values were comparatively crisper and mechanically weaker. Such behavior may be related to surface browning reactions and reduced moisture retention, which favor brittle fracture rather than plastic deformation. Yellowness (b*) was strongly and positively associated with expansion ($r = 0.89$), gumminess ($r = 0.83$), and chewiness ($r = 0.82$), while negatively correlated with crispiness ($r = -0.68$). These results suggest that yellower products were more expanded and exhibited dense, chewy textures, further supporting the observation that expansion promotes chewiness at the expense of crispness. Water activity (a_W) displayed a very strong negative correlation with crispiness ($r = -0.97$) and elasticity ($r = -0.95$), highlighting moisture as a critical determinant of textural degradation. Simultaneously, a_W showed strong positive correlations with chewiness ($r = 0.89$), hardness ($r = 0.84$), and firmness ($r = 0.87$). These relationships indicate that increased moisture plasticized the product matrix, leading to reduced brittle fracture and enhanced dense texture. Similar trends have been widely reported in extruded and flaked cereal products, where moisture disrupts the glassy structure responsible for crispness.

Hardness and firmness were almost perfectly correlated ($r = 0.98$), confirming that both parameters reflect similar mechanical resistance characteristics. Hardness also exhibited strong positive correlations with chewiness ($r = 0.84$) and gumminess ($r = 0.50$), while being strongly negatively correlated with crispiness ($r = -0.81$). Crispiness itself showed very strong positive correlation with elasticity ($r = 0.94$) and strong negative correlations with chewiness ($r = -0.92$) and gumminess ($r = -0.74$). These opposing relationships clearly distinguish crispy products as low-moisture, elastic systems, whereas chewy products are associated with higher density and moisture retention. Expansion ratio was positively correlated with gumminess ($r = 0.89$) and chewiness ($r = 0.75$) but negatively correlated with crispiness ($r = -0.66$), indicating that increased expansion led to softer, more deformable structures.

Bulk density (BD) exhibited a strong positive correlation with water absorption index (WAI) ($r = 0.71$) and a strong negative correlation with crispiness ($r = -0.71$). These results suggest that denser products absorbed more water and exhibited reduced crisp texture. Water absorption index (WAI) showed very strong positive correlations with cohesiveness ($r = 0.90$), resilience ($r = 0.75$), and swelling power (SP) ($r = 0.88$), indicating that products with higher hydration capacity formed more cohesive and structurally stable matrices. Swelling power also demonstrated strong positive associations with cohesiveness ($r = 0.83$) and resilience ($r = 0.69$), reflecting enhanced starch–water interactions and structural integrity upon hydration. Collectively, the correlation

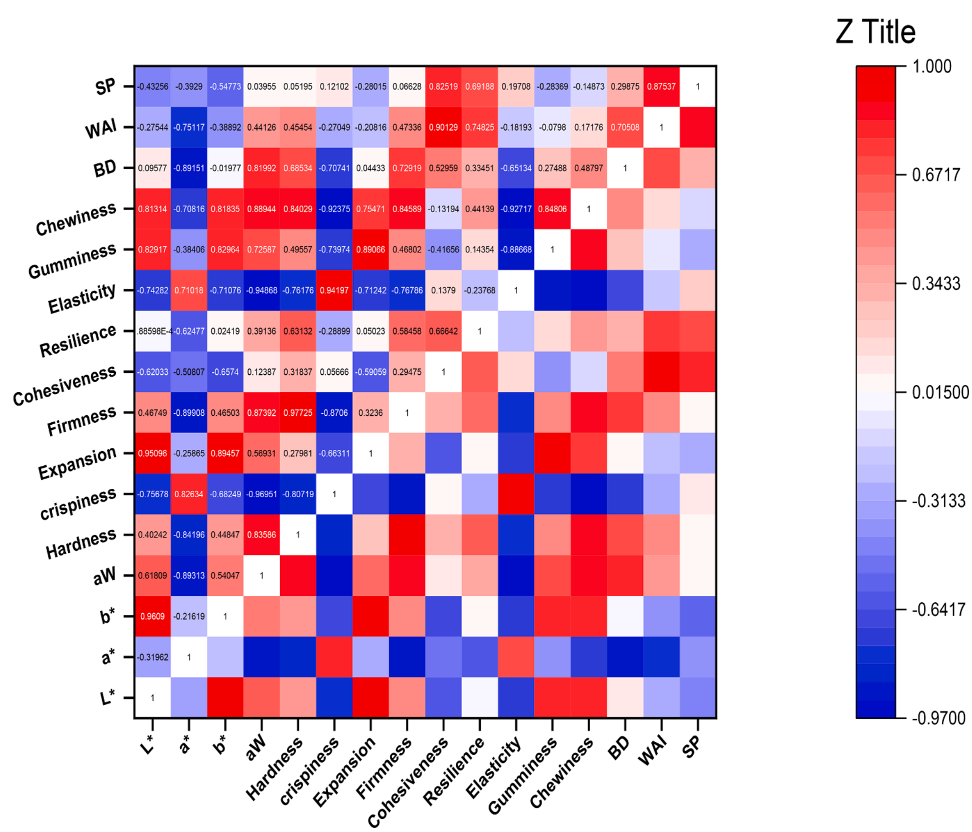

Fig. 10. Pearson correlation heat map of the product's physical properties.

analysis revealed two distinct and opposing quality domains: an expanded, moist, and chewy domain characterized by high L*, b*, a_W, gumminess, and chewiness; and a crispy, elastic, low-moisture domain defined by high crispiness and elasticity. These findings underscore the critical trade-off between expansion-driven softness and crisp textural quality, providing valuable insight for optimizing processing conditions—particularly ultrasonication and moisture control—to achieve targeted functional and sensory attributes.

4. Conclusion

This study demonstrated that the formulations, T_2 and $T_{3,}$ exhibited improved fat, fiber, iron, bioactive components, functional, textural, and sensory attributes of functional flakes. Along with that, optimal physicochemical and textural properties are characterized by improved crispiness, resilience, bulk density, and acceptable expansion behaviour. At the same time, maintaining desirable hardness, gumminess, chewiness, and water activity comparable to the control. Sensory evaluation further confirmed T2′s superior overall acceptability. This indicates consumer preference for balanced incorporation levels, along with its functional and nutritional potential. Overall, the study showed the potential of agro-waste valorisation by transforming corn by-products into high-value functional ingredients suitable for ready-to-eat cereal production. The formulation provides a promising foundation for future product development at an industrial scale, with promising applications in different feeding programs by offering practical solutions to enhance dietary quality.

Table no 7. List of abbreviations

Abbreviations	Definition
C1	Control 1
C2	Control 2
T_1	Treatment 1
T_2	Treatment 2
T_3	Treatment 3
T_4	Treatment 4
BD	Bulk density
WAI	Water absorption index
SP	Swelling power
a_w	Water activity
RER	Rapid expansion ratio
FF	Functional flakes

Ethical review

This study does not involve any human or animal testing.

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CRediT authorship contribution statement

Hina Niaz: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Amna Javed:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Data curation, Conceptualization. **Mohd Redzwan Bin Sabran:** Writing – review & editing, Validation, Supervision, Methodology. **Robert Mugabi:** Visualization, Validation. **Rida Niaz:** Visualization, Validation, Methodology, Investigation, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.afres.2026.102348.

Data availability

Data will be made available on request.

References

Aboualfath, M., Shaltout, O. E., Abou Elyazeed, A. M., Nassar, M. A., & Fathalla, M. A. (2024). Evaluation of chemical and bioactive components of corn silk powder and its application to enhance health and improve the nutritional value of Egyptian flat bread. *Journal of the Advances in Agricultural Researches, 29*(2), 212–223.

Acosta-Estrada, B. A., Gutiérrez-Uribe, J. A., & Serna-Saldívar, S. O. (2014). Bound phenolics in foods, a review. *Food Chemistry, 152*, 46–55.

Adedokun, S., Jimoh, K., Azeez, L., Adeoti, O., Osunrinade, A., & Alabi, A. (2024). Quality Evaluation of Different Flakes Produced From Germinated Maize (Zea May's), Millet (Pennisetum Glaucum) and Sorghum (Sorghum Bicolor L. Moench) Each Substituted with Germinated Pigeon Peas (Cajanus Cajan) Flour.

Ahmad, F., & Sapiee, M. H. (2024). The effect of corn cob powder and oat fibre incorporation in physicochemical properties and sensory acceptance of Otak-Otak. *The Eurasia Proceedings of Health, Environment and Life Sciences, 13*, 32–39.

Ahmad, F., Ismail, N. E., Tuan Chilek, T. Z., Zamri, A. I., Zainol, M. K., Wahab, R. A., & Hamid, M. A. (2021). Effect incorporated of oat and corn cob powder on physicochemical and sensory properties of Putu Piring. *Bulletin of Culinary Art and Hospitality, 1*(1), 2.

Ahmed, M. N., Asbbane, A., Bijla, L., Gagour, J., Hallouch, O., Ibourki, M., … Gharby, S. (2025). Leveraging waste for natural antioxidant production: The effect of direct ultrasound fortification of sunflower oil with saffron by-products to enhance oxidative stability. *International Journal of Food Science and Technology, 60*(1), Article vvaf085.

Ahsan, A., Ahsan, S., Mehmood, T., Khair, K.-U., Farooq, M. A., Chughtai, M. F. J., & Khaliq, A. (2025). Development and optimization of corn silk powder enriched cookies to enhance nutritional composition. *Food Sciences Insights and Trends, 1*(1).

Alu'datt, M. H., Rababah, T., Tranchant, C. C., Al-u'datt, D. A., Gammoh, S., Alrosan, M., Bani-Melhem, K., Aldughpassi, A., Alkandari, D., & AbuJalban, D. (2025). Date palm (Phoenix dactylifera) bioactive constituents and their applications as natural multifunctional ingredients in health-promoting foods and nutraceuticals: A comprehensive review. *Comprehensive Reviews in Food Science and Food Safety, 24*(1), Article e70084.

Anyiam, P., Phongthai, S., Grossmann, L., Jung, Y. H., Sai-Ut, S., Onsaard, E., & Rawdkuen, S. (2025). Potential plant proteins for functional food ingredients: Composition, utilization and its challenges. *NFS Journal, 38*, Article 100216.

Aukkanit, N., Pantong, S., Yeela, J., & Sawatwong, P. (2017). Effects of Corn Cob FIBER addition on noodle properties. *International Journal of Arts & Sciences, 10*(1).

Banaira, D. A., & Barrion, A. S. (2022). *Sensory characteristics, acceptability and dietary fiber of brownies produced from theobroma cacao shell flour*.

Bayona, R. R., Dinahiva, J. K. A., Ellacoria, M. J. M., Escote, R. V., & Rafil, M. E. (2025). Sensory acceptability of Corn (Zea mays L.) cob flour-based muffins. *EPRA International Journal of Multidisciplinary Research (IJMR), 11*(10), 0-0.

Cappa, C., Castorina, G., Fiorillo, G., Casiraghi, M. C., Rollini, M., Consonni, G., Erba, D., Negrini, N., & Marti, A. (2025). Gluten-free breadsticks with Ganoderma-fermented corncobs: Technological and nutritional features. *Journal of the Science of Food and Agriculture, 105*(9), 4916–4926.

Comettant-Rabanal, R., Chávez-Llerena, R. T., Chavéz, D. W. H., Silva, B. A., Rimari-Barzola, R., Encina-Zelada, C. R., Delgado-Soriano, V., & Carvalho, C. W. (2025). Bread composite by wheat and novel Andean purple corn: Dough rheology and physical and bioactive characteristics. *International Journal of Food Science and Technology, 60*(1), Article vvae060.

Demircan, B., Velioglu, Y. S., & Giuffrè, A. M. (2023). Bergamot juice powder with high bioactive properties: Spray-drying for the preservation of antioxidant activity and ultrasound-assisted extraction for enhanced phenolic compound extraction. *Journal of Food Science, 88*(9), 3694–3713.

Dewidar, O. M., & Hanan, M. (2020). Development of extruded snacks and corn flakes using yellow corn and by-product broken beans. *Middle East Journal of Applied Science, 10*(2), 390–406.

Dhillon, P. K., Jayprakash, B. T. R. P., & Singla, P. (2025). Acceptability, protein quality assessment and micronutrient profile of assorted nutraceutical muffins. *Journal of Community Mobilization and Sustainable Development, 20*(3), 916–922.

do Nascimento, G. K. S., dos Santos, T. M., Andressa, I., Benassi, V. M., de Andrade Neves, N., & Schmiele, M. (2024). Exploring the use of purple corn cob flour as a new fiber source in pan bread improved by commercial hemicellulases. *Recent Progress in Nutrition, 4*(3), 1–17.

dos Santos, T. M., Andressa, I., Nascimento, G. K. S., de Andrade Neves, N., & Schmiele, M. (2025). Corncob flour as an alternative ingredient for muffins: Technological and nutritional perspectives. *Revista Principia*, 62.

Du, R., Su, R., Qi, W., & He, Z. (2018). Enhanced enzymatic hydrolysis of corncob by ultrasound-assisted soaking in aqueous ammonia pretreatment. *3 Biotech, 8*(3), 166.

Ekpenyobhiele, E. D., Daniel, O. O., Oluwakemi, B. A., Aderonke, O. M., Olubunmi, A. T., & Adeola, A. A. (2025). Development and evaluation of nutrient-enriched cookies from malted quality protein maize, soybean, and ginger-based composite flours. *Applied Sciences, 1*(1), 1–15.

El-Waseif, M. A. E.-M. (2023). Enhancing the nutritional value of corn flakes by adding quinoa flour. *Egyptian Journal of Chemistry, 66*(13), 1395–1406.

Francisco-Ponce, B. A., Jiménez-Hernández, J., Maldonado-Astudillo, Y. I., Alvarez-Fitz, P., Ramírez, M., Arámbula-Villa, G., Flores-Casamayor, V., Escobar-Puentes, A. A., & Salazar, R. (2024). Effect of ultrasound processing on the physical and powder-flow properties of nixtamalized corn flour and its influence on the quality parameters of tortilla. *Journal of Food Measurement and Characterization, 18*(7), 6050–6061.

Ganguly, S., Bandyopadhyay, K., & Biswas, D. (2025). Formulation and characterization of omega-3 fatty acid enriched mayonnaise containing flax seed oil and chia seed oil. *International Journal of Food Engineering, 21*(8), 599–606.

Giri, N. A., Bhangale, A., Gaikwad, N. N., Manjunatha, N., Raigond, P., & Marathe, R. (2024). Comparative study on effect of pomegranate peel powder as natural preservative and chemical preservatives on quality and shelf life of muffins. *Scientific Reports, 14*(1), Article 10307.

Gunasekara, S., Thennakoon, U., Sandaruwani, M., Ratnayake, K., Herath, K., Malki, M., & Herath, H. (2025). Physicochemical, functional, and nutritional characterization of Cashew (Anacardium occidentale L.) Apple flour and its use in. *Journal of Food and Agriculture, 18*(2), 1–20.

Hallouch, O., Bounasser, B., Asbbane, A., Giuffrè, A. M., Al Abdulmonem, W., Bouyahya, A., … Gharby, S. (2025). Enrichment of refined sunflower oil with phenolic extracts from argan (Argania spinosa L.(Skeels)) co-products using ultrasound-assisted extraction. *Ultrasonics Sonochemistry, 122*, Article 107624.

Hoang, N. H., Do, H. H., Dang, T. H. Y., Ton, N. M. N., Tran, T. T. T., & Le, V. V. M. (2022). Fiber-enriched biscuits prepared with enzyme-treated corncob powder: Nutritional composition, physical properties, and sensory acceptability. *Journal of Food Processing and Preservation, 46*(8), Article e16784.

Illaningtyas, F., Kahfi, J., Maryana, E., Sukarti, I., Wijayanti, S. P., Laily, N., Widodo, W. E., Ikhsan, H. M., & Widjayanti, R. D. E. (2024). Shelf-life determination of soybean hydrolysate flake and its chemical characteristics during storage. *AIP Conference Proceedings*.

International, A. (2010). *Approved methods of analysis*. American Association of Cereal Chemists International.

Janve, B., Yang, W., & Sims, C. (2015). Sensory and quality evaluation of traditional compared with power ultrasound processed corn (*Zea mays*) tortilla chips. *Journal of Food Science, 80*(6), S1368–S1376.

Javed, A., Imran, M., Ahmad, N., & Hussain, A. I. (2018). Fatty acids characterization and oxidative stability of spray dried designer egg powder. *Lipids in Health and Disease, 17*(1), 282.

Javed, A., Hashmi, M. S., Javaid, U., & Amjad, R. (2025a). Classification and therapeutic applications of plant secondary metabolites. *Pharmacognosy and phytochemistry: Principles, techniques, and clinical applications* (pp. 189–206).

Javed, A., Hashmi, M. S., Nadeem, U., Javaid, U., & Rehman, T. (2025b). Valorization of vegetable waste for developing high-value food products: An upcycling approach. *International Journal of Vegetable Science*, 1–57.

Jianpg, R., Lin, Z., Shi, H., Wang, Y., Wang, Y., & Yang, Q. (2025). Chickpea sourdough as a functional ingredient in gluten-free bread: Impact on quality attributes. *Food Hydrocolloids*, Article 112007.

Jiao, Y., Chen, H.-D., Han, H., & Chang, Y. (2022). Development and utilization of corn processing by-products: A review. *Foods, 11*(22), 3709.

Khasanah, S., Nugroho, M., & Astuti, F. Y. (2025). Proximate analysis of donuts substituted with corn cob flour (Zea mays). *G-Tech: Jurnal Teknologi Terapan, 9*(1), 313–319.

Khuriyati, N., Kasih, A. N., Perdana, M. R. A., Izdihar, F. Y., Falah, M. A. F., & Wagiman. (2024). A comparative study of acoustic and ultrasonic nondestructive testing for evaluating melon quality. In *, 1377. IOP Conference Series: Earth and Environmental Science*. IOP Publishing, Article 012006.

Kumar, N. E., & Ahmad, F. (2024). Effect incorporation of corn cob powder on the physicochemical properties and sensory acceptability of Kuih Kaswi. *Journal of Biochemistry, Microbiology and Biotechnology, 12*(SP1), 25–26.

Lapčík, L., Řepka, D., Lapčíková, B., Sumczynski, D., Gautam, S., Li, P., & Valenta, T. (2023). A physicochemical study of the antioxidant activity of corn silk extracts. *Foods, 12*(11), 2159.

Lee, K. Y., Kim, T., Kim, J., Park, A., Noh, H., Kim, S., Ahn, M., & Kim, H. (2018). Assessment of nutritional components, antioxidant contents and physiological activity of purple corn husk and cob extracts. *Journal of Food Hygiene and Safety*, (6), 33.

Lee, C., Gan, Y., Chan, Y., Yap, K., Tang, T., Tan, C., & Lai, O. (2019). Physicochemical and sensory analyses of high fibre bread incorporated with corncob powder. *International Food Research Journal, 26*(5).

Lian, K., Guan, L., Zhang, M., Ye, G., & Li, S. (2025). Effect of ultrasonic treatment on taste and flavor quality of Japonica rice. *Foods, 14*(9), 1627.

Libron, J. A. M. A., Cardona, D. E. M., Mateo, J. M. C., Beltran, A. K. M., Tuaño, A. P. P., & Laude, T. P. (2021). Nutritional properties and phenolic acid profile of selected Philippine pigmented maize with high antioxidant activity. *Journal of Food Composition and Analysis, 101*, Article 103954.

Martirosyan, D. (2025). Functional food science and bioactive compounds. *Bioactive Compounds in Health and Disease-Online ISSN: 2574-0334; Print ISSN: 2769-2426, 8*(6), 218–229.

Mohamed, E. E., & Essa, R. Y. (2018). Quality properties of corn snacks enriched with red corncobs powder. *Journal of Agroalimentary Processes and Technologies, 24*(2), 54–62.

Moscoso Ospina, Y. A., Lionello, M. E., Garófalo, L., Burbano, J. J., Cabezas, D. M., & Correa, M. J. (2023). Effect of ultrasonic treatment on soybean okara to be used as a gluten-free bread improver. *International Journal of Food Science and Technology, 58*(7), 3827–3837.

Mu, Y., Yan, J., Gao, J., Xing, F., Gu, Q., Zhao, C., & Liu, J. (2025). Processing properties of corn flour and quality of fresh wet corn–wheat noodles: Comparison of ultrasonic-assisted nixtamalization wet milling with traditional milling methods. *LWT, 233*, Article 118554.

Mujbaile, V. N., Chandekar, V., Nageshwar, V., Dongarwar, R., & Jamaiwar, O. (2023). *Experimental Optimization of Pulverizer Machine*.

Mumtaz, W., Czarnowska-Kujawska, M., & Klepacka, J. (2025). Effect of Buckwheat husk addition on antioxidant activity, phenolic profile, color, and sensory characteristics of bread. *Molecules, 30*(17), 3625.

Nguyen, T. Q. N., Tran, T. T. T., Mai, V. X. H., Nguyen, T. B., Ton, N. M. N., & Le, V. V. M. (2023). Corncob powder and transglutaminase addition in pasta: Effects on proximate composition, physical and cooking properties, and overall acceptability of the product. *Cereal Chemistry, 100*(2), 346–359.

Niaz, H., Javed, A., & Niaz, R. (2026). Optimization of processing parameters and quality evaluation of breakfast flakes prepared from sonicated corn and its by-products supplemented with quinoa powder. *Food Science & Nutrition, 14*(2), Article e71523. https://doi.org/10.1002/fsn3.71523

Ojo, T. (2024) Functional characteristics and physical properties of cookies produced from wheat, plantain and whole groundnut paste.

Oladejo, A., Nyong, R., & Nkem, O. (2022). Influence of ultrasound pretreatment on the nutritional quality of yellow cassava during convective drying. *World Journal of Applied Science & Technology, 14*(2), 6–11.

Olaniran, A. F., Agaja, F. O., Obayomi, O. V., Ebong, S. I., Malomo, A. A., Olaniran, O. D., Erinle, O. C., & Owa, S. O. (2025). Comparative effect of boiling, microwave and ultrasonication treatment on microstructure, nutritional and microbial quality of Tofu. *Applied Food Research, 5*(1), Article 100750.

Orellana-Palacios, J. C., Garcia, S. R., Rabanal-Ruiz, Y., McClements, D. J., Moreno, A., & Hadidi, M. (2025). Corn silk as an underutilized sustainable source of plant proteins: Extraction, fractionation, structure, and techno-functional properties. *Food Hydrocolloids, 158*, Article 110550.

Paick, S., Das, R., Alam, M., & Sharma, A. (2024). Effect of corn silk powder on the baking and quality dynamics of muffins. *Food Science and Technology International*, Article 10820132241265947.

Pawde, S., Talib, M., & Parate, V. R. (2020). Development of fiber-rich biscuit by incorporating dragon fruit powder. *International Journal of Fruit Science, 20*(sup3), S1620–S1628.

Razip, N. H. M., Firdaus, A., Manikam, R. V. S., & Gandaseca, S. (2025). Physicochemical and sensory characteristics of bread substituted with dragon fruit peels. *Indonesian Food Science and Technology Journal, 9*(1), 1–12.

Ribas-Agustí, A., Martín-Belloso, O., Soliva-Fortuny, R., & Elez-Martínez, P. (2018). Food processing strategies to enhance phenolic compounds bioaccessibility and bioavailability in plant-based foods. *Critical Reviews in Food Science and Nutrition, 58*(15), 2531–2548.

Roca-Nasser, E. A., Medina-García, M., Martínez-Domingo, M. A., Valero, E., Cuadros-Rodríguez, L., & Jiménez-Carvelo, A. M. (2025). Oat flour identification and quantification for multigrain bread–The successful combination of hyperspectral imaging, information theory and chemometrics for conformity assessment. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 343*, Article 126529.

Rose, D. J., Inglett, G. E., & Liu, S. X. (2010). Utilisation of corn (Zea mays) bran and corn fiber in the production of food components. *Journal of the Science of Food and Agriculture, 90*(6), 915–924.

Salehi, F., Amiri, M., & Ghazvineh, S. (2024). Effect of ultrasonic pretreatment on textural properties and sensory attributes of cooked faba beans. *Ultrasonics Sonochemistry, 110*, Article 107040.

Sarepoua, E., Tangwongchai, R., Suriharn, B., & Lertrat, K. (2015). Influence of variety and harvest maturity on phytochemical content in corn silk. *Food Chemistry, 169*, 424–429.

Shahzad, M. K., Shahzad, M. A., Qadeer, U., & Mehmood, A. (2022). Investigation of phytochemical profiling and therapeutic effects of corn silk against diabetes in human male subjects. *Pakistan Journal of Pharmaceutical Sciences*, 35.

Sharma, R. (2024). *Valorization of corn waste for the production of xylitol dr. yashwant singh parmar university of horticulture and forestry]*.

Singh, M., Liu, S. X., & Vaughn, S. F. (2012). Effect of corn bran as dietary fiber addition on baking and sensory quality. *Biocatalysis and Agricultural Biotechnology, 1*(4), 348–352.

Wang, Y., Chen, Y., Feng, L., Wang, F., Liu, T., Gu, F., Wang, F., Huang, Q., & Zheng, J. (2025). Mechanistic study of synergetic stabilization of pickering emulsions by corn glutelin and starch complexes. *Food Chemistry, 463*, Article 141558.

Zhang, Z., Niu, Y., Eckhoff, S. R., & Feng, H. (2005). Sonication enhanced cornstarch separation. *Starch-Stärke, 57*(6), 240–245.

Further reading

AACCI. (2010). Approved methods of AACCI, 11th ed.; methods 46-13.01, 80-51.01, 10-05.01 and 74-09.01. St. Paul, MN, USA: The American Association of Cereal Chemists International.

Golkar, A., Milani, J. M., Motamedzadeghan, A., & Kenari, R. E. (2023). Physicochemical, structural, and rheological characteristics of corn starch after thermal-ultrasound processing. *Food Science and Technology International, 29*(2), 168–180.

Rafique, H., Peng, P., Hu, X., Saeed, K., Khalid, M. Z., Khalid, W., … Nayik, G. A. (2025). Ultrasound-assisted modification of oat protein isolates: Structural and functional enhancements. *Ultrasonics Sonochemistry, 112*, 107204.

Tufail, T., Ain, H. B. U., Ashraf, J., Saeed, F., Basharat, Z., Ahmed, Z., … Mugabi, R. (2025). Effects of germination and ultrasound treatment on the thermodynamics, nutritional and structural quality of highland barley fractions. *Ultrasonics Sonochemistry, 123*, 107652.