

DEVELOPMENT AND CHARACTERIZATION OF NUTRIENT-DENSE OAT-BASED ENERGY CRACKERS FOR COMBATING MALNUTRITION

Hafiz Danish Butt¹, Poonam Gill², Khadija Tul Kubra³, Baila Ahmad⁴, Anum Urooj^{*5},
Muhammad Rehan Arif^{*6,7}

¹Department of Food Engineering, University of Agriculture, Faisalabad, Pakistan

^{2,3,*5}National Institute of Food Science and Technology, University of Agriculture, Faisalabad, Pakistan

⁴Department of Food Science and Technology, The Islamia University of Bahawalpur, Pakistan

^{*6}Key Laboratory of Green Prevention and Control of Tropical Agriculture and Forestry Disasters, School of Tropical Agriculture and Forestry, Hainan University, DanZhou 571737, China

⁷College of Food and Biological Engineering, Qiqihar University, Qiqihar, 161006, China

^{*5}anumurooj.uaf@gmail.com, ^{*6,7}rehanarif5272@gmail.com

DOI: <https://doi.org/10.5281/zenodo.19730779>

Keywords

crackers, Groundnut powder, Functional foods, Nutritional composition, Antioxidant activity, Mineral profile, Malnutrition

Article History

Received: 24 February 2026

Accepted: 04 April 2026

Published: 24 April 2026

Copyright @Author

Corresponding Author: *

Anum Urooj,

Muhammad Rehan Arif

Abstract

Malnutrition and food insecurity remain major global health challenges, particularly in low- and middle-income countries, driven by increased consumption of energy-dense, nutrient-poor foods. This study aimed to develop oat-based energy crackers enriched with almonds and varying levels of groundnut powder (0–40%) and evaluate their physicochemical, nutritional, phytochemical, mineral, antioxidant, and sensory properties. Roasted groundnut powder exhibited high fat (48.38%) and protein (26.95%) contents, along with essential minerals and notable phenolic (67.66 mg GAE/g) and flavonoid (14.16 mg QE/g) contents. Increasing groundnut incorporation significantly improved protein (17.31–21.17%) and fat (28.99–36.74%) levels in crackers. Enhanced phytochemical content and antioxidant activity were also observed. Mineral analysis showed increased potassium and magnesium, with slight reductions in calcium and phosphorus. Sensory evaluation indicated high acceptability (7.4–8.8/9). Overall, these crackers represent a nutrient-dense, functional food with potential to improve dietary quality and address malnutrition.

1. INTRODUCTION

Malnutrition persists one of the most serious global public health issues, affecting millions of individuals across all age groups and regions (Munarro et al., 2026). In 2022, approximately 390 million adults worldwide were underweight. Among children under five years of age, an estimated 149 million were stunted, while 45 million were wasted. According to the Global

Report on Food Crises (2024), approximately 37.7 million children aged 6-59 months across 26 countries were affected by acute malnutrition, with the most severe conditions reported in Sudan, Yemen, Mali, and the Gaza Strip. Global acute malnutrition cases increased from 26.9 million in 2023 to 30.4 million in 2024, showing the escalating severity.

Global dietary patterns are shifting due to urbanization, globalization, and lifestyle changes. Traditional meal structures are increasingly being replaced by frequent snacking and reliance on ready-to-eat (RTE) foods, a trend often described as “snackification” (Statistics Market Research Consulting, 2025; Iqbal et al., 2026). The global RTE and snack food market has expanded significantly which is projected to grow from USD 11.25 billion in 2026 to USD 15.51 billion by 2035, driven by urbanization, rising incomes, and demand for convenience. Globally, convenience foods are preferred by approximately 72% of consumers, with 58% actively seeking time-saving meal options (Sisay et al., 2026).

Large-scale food to food fortification has also been explored as a cost-effective strategy in vulnerable populations to address micronutrient deficiencies which are currently adopted in more than 140 countries (Olson et al., 2021; Shabbir et al., 2026). Alongside increasing attention beyond basic nutrition food market is projected to reach USD 586 billion by 2030, show growing consumer awareness of health and wellness (Costlow et al., 2025; Coomson et al., 2025). Despite their convenience and widespread consumption, conventional snack foods present notable nutritional concerns for sensory appeal and shelf stability rather than nutritional quality (Asghari et al., 2016; Gregory, 2024). Evidence from the National Health and Nutrition Examination Survey (NHANES) among university students, high intake of energy-dense snacks has been associated with such as chocolate, potato chips, and biscuits have been associated with high fat and sugar intake, contributing to impaired metabolic health (Aljefree et al., 2022; Mirmiran et al., 2014).

To growing health awareness, the food industry has shifted toward the modern formulations of healthier snack alternatives that increasingly incorporate functional ingredients. Market analyses indicate rising consumer demand for snacks with more than 68% of urban consumers preferring health-oriented snack options (AlJaloudi et al., 2024; Polaris Market Research, 2025). Manufacturers are Energy-dense snack products, particularly protein bars, granola-based

snacks, fortified cereals, and functional snack mixes, and energy crackers, have gained commercial interest due to their convenience and functional applications (NielsenIQ, 2024; Barakat et al., 2025). Energy bars or crackers are RTE formulations composed of nutrient-dense ingredients, typically providing 200-300 kcal per serving with balanced macronutrient composition. These products are widely consumed as between-meal snacks and therapeutic interventions for malnutrition (Bright et al., 2025; Argessa, 2025).

Oats (*Avena sativa* L.), belonging to the Poaceae family, are a widely cultivated cereal grain which are grown under both irrigated and rain-fed conditions (Kaur et al., 2022; Olas, 2024;). Adaptability to marginal soils, making them an agronomically resilient crop that is recognized for their nutritional and functional value in food systems (Leszczyńska et al., 2023; Prasanthi et al., 2025). Oats have a nutrient-dense composition, containing approximately 11–18% protein, 5–9% lipids, and 60–70% carbohydrates soluble globulins, and β -glucan (2.3–8.5%), which is bioactive component (50–80%) (Tan et al., 2021; Cortijo-Alfonso et al., 2024). Oat flakes, bran, and flour are incorporated into breakfast cereals, cookies, biscuits, and crackers to improve dietary fiber content and enhance texture and moisture retention (Ma et al., 2026; Alemayehu et al., 2023).

Almonds (*Prunus dulcis*) are nutrient-dense tree nuts widely recognized for their functional and health-promoting properties (Tahiri & Gilbert, 2025). It contains 20–25% protein due to their nutritional properties, almonds are widely incorporated into granola bars, energy bars, cereals, bakery products, and confectionery items. (Poznyak et al., 2022). More than 500 phytochemicals have been identified, with the majority concentrated in the almond skin, including catechin, epicatechin, chlorogenic acid, and proanthocyanidins (Redondo-Puente et al., 2021). Regular almond consumption promote satiety, supporting body weight management, and contribute to gut health through increased short-chain fatty acid production and improved intestinal barrier function (Kolahi et al., 2025). Almond flour is particularly important in gluten-

free formulations, providing a nutrient-rich alternative to refined flours (Wang et al., 2025). Groundnuts (*Arachis hypogaea*), also known as peanuts, are widely consumed botanically leguminous oilseeds (Xiang et al., 2025; Zhang et al., 2026). It belongs to the Fabaceae family later spreading globally through trade and agricultural expansion. Due to rich profile of 25–30% proteins, 36–54% lipids, 10.5–20% carbohydrates, and 1.4–3.9% dietary fiber, cultivated in more than 100 countries, with China, India, Nigeria, the United States, and Sudan among the major producers (Bonku & Yu, 2020; Farooqui et al., 2019). Their adaptability to diverse agroecological conditions and high yield potential make them a key crop for food security (Rasane et al., 2015; Nunes et al., 2024). Due to their high caloric density, affordability, and nutrient composition, peanuts are widely used in both staple diets and therapeutic nutrition (RUTF) targeting malnutrition (Bodoira et al., 2022). The present study aims to develop oat-based energy crackers enriched with almonds and groundnuts. Subsequently, proximate minerals, phytochemical characterization, and sensorial attributes of crackers was assessed.

Materials and Methods

Procurement of raw materials

All raw materials required for the formulation of oat-based energy crackers, including oats,

almonds, groundnuts, sugar, fat, and other baking ingredients, were procured from local markets of Faisalabad, Pakistan. The materials were shifted to the laboratory under hygienic conditions and stored in airtight containers at room temperature until further use. All chemicals and reagents used for analyses were purchased of analytical grade (Merck, Germany).

Preparation of groundnut powder

Groundnut seed powder was prepared following a standardized procedure mentioned by Urooj *et al.*, (2026a) for plant-based seeds with slight modification. Raw peanuts were cleaned and sorted to remove immature or damaged seeds and foreign materials. The cleaned groundnuts were roasted at 150 °C for 10-15 min to enhance flavor and promote the removal of the seed coat. After roasting, the groundnuts were cooled at room temperature, and the skins were manually removed. The roasted groundnuts were then ground using a laboratory grinder (Panasonic MX-AC400, Malaysia). Grinding was carried out intermittently to minimize heat generation and oil prevent separation. The resulting powder was passed through a 60-mesh sieve (250 µm) to obtain a uniform particle size. The standardized groundnut powder was packed in airtight polythene bags and stored at 4 °C until further analyses and product development.



Figure 1. Processing steps involved in the preparation of groundnut seeds (*Arachis hypogaea*) powder

Development of oat-based energy crackers

Oat-based energy crackers formulation was carried out using modified methods described by Iqbal et al. (2026), with slight modifications. The base formulation consisted of a mixture of oats and almonds, while groundnut powder was incorporated at varying levels, control treatment (T₀) consisted 100% oat and almond mixture without groundnut powder while experimental treatments, replacing the oat and almond mixture at levels of 10%, 20%, 30%, and 40%, respectively shown in Table 3.2. All dry ingredients were

accurately weighed using an electronic analytical balance and mixed thoroughly to obtain a homogenous blend. Dough was prepared by adding appropriate amounts of fat and water, followed by mixing until uniform consistency was achieved then sheeted to a consistent thickness, cut into desired shapes, and baked in a preheated oven at 180 °C for 15-20 min until golden brown. After baking, the crackers were cooled to room temperature and packed in airtight containers for further analysis.

Table 1: Formulation plan for oat-based energy crackers enriched with groundnut powder

Treatments	Oat: Almond Mixture (%)	Groundnut Powder (%)
T ₀ (control)	50:50	0
T ₁	45:45	10
T ₂	40:40	20
T ₃	35:35	30
T ₄	30:30	40

Characterization of roasted groundnut powder and oat-based energy crackers

Proximate analysis

The proximate composition of roasted groundnut powder and developed crackers, including moisture content, crude fat, crude protein, crude fiber, total ash, and carbohydrate contents, was determined according to the standard method of method AOAC (2019).

Phytochemical analysis

Sample preparation

2 grams of finely ground nut powder and crackers were separately mixed with 20 mL of diluted methanol and extracted at room temperature for two hours. The mixture was then filtered through Whatman No.1 filter paper, and collected in sample vials for further phytochemical analysis,

following the procedures mentioned by Arioglu-Tuncil and Çelik (2026).

Total phenolic contents (TPC)

Total phenolic contents of the extracts were determined using the Folin-Ciocalteu (FC) colorimetric method as presented by Chatziharalambous et al. (2023). In this method, 200 µL of the extract was mixed with 1 mL of freshly diluted FC-reagent (10-fold). After incubated for 5 min, 1.5 mL of sodium carbonate solution (60 g/L) was added. The mixture was then left at room temperature for 90 min. Absorbance was measured at 750 nm using a UV-Vis spectrophotometer. A standard calibration curve of gallic acid was used to quantify the phenolic contents, and the results were expressed as mg GAE/100 g of sample.

$$TPC \text{ (mg/g of GAE)} = c \times \frac{V}{M}$$

Where,

c = Gallic acid concentration (mg/mL)

V = Volume of extract

M = Weight of ethanolic extract (g)

Total flavonoid contents (TFC)

Total flavonoid contents were determined using a colorimetric method determined by Ahmed and Abozed (2015) and Hamed et al. (2021). In this procedure, 0.5 mL of the extract was placed into test tube, followed by the addition of 0.3 mL of 5% NaNO₂, 4 mL of distilled water, and 0.5 mL of methanol. The mixture was allowed to stand for 5 min, after which 0.3 mL of 10% AlCl₃ solution was added and stirred thoroughly. After 6 min of incubation 10 mL of distilled water was 2 mL of 1 M NaOH solution was added to the mixture. The solution was mixed well and allowed to stand for 10 min. The absorbance was then measured at 510 nm using a UV-Vis spectrophotometer. The flavonoid contents were quantified using a standard calibration curve of quercetin, and the results were expressed as mg QE/100 g of sample.

Anti-oxidative potential (DPPH)

The antioxidant activity of the samples was determined using the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay following the method described by Chatziharalambous et al. (2023) with slight modifications. Briefly, 1 mL of the sample extract was mixed with 2 mL of 0.5 mM DPPH solution prepared in methanol. The reaction mixture was incubated in the dark at room temperature for 30 min to permit the reaction to proceed. After incubation, the absorbance of the mixture was measured at 517 nm using a UV-Visible spectrophotometer. A standard calibration curve was prepared using different concentrations of α -tocopherol. The antioxidant activity of the samples was calculated from the standard curve and expressed as micrograms of α -tocopherol equivalents per gram of sample ($\mu\text{g } \alpha\text{-tocopherol eq./g}$). The radical scavenging activity was calculated using the following equation:

$$\text{Antioxidant activity } (\mu\text{g } \alpha\text{-tocopherol eq./g}) = \frac{C \times V}{W}$$

Where:

C = concentration obtained from α -tocopherol standard curve ($\mu\text{g/mL}$)

V = volume of extract (mL)

W = weight of sample used for extraction (g)

Mineral analysis

Mineral analysis roasted groundnut powder and developed crackers was performed following methods similar to those used in functional cracker formulations as outlined by Molina et al. (2025). Wet digestion was implemented to determine the mineral content, and quantification was carried out using colorimetric, spectrophotometric, and titrimetric techniques. 5 g of each cracker sample was initially heated over a Bunsen burner and then incinerated in a muffle furnace at 550-600 °C until white ash was obtained. The resulting ash was dissolved in diluted acid and filtered, after which the volume was adjusted to 250 mL with distilled water. Mineral elements, such as calcium (Ca), iron (Fe), zinc (Zn), were quantified using atomic absorption spectrophotometry (Agilent AA240, Varian, USA). Standard calibration curves were used to

determine mineral concentrations, and the results were expressed as mg/100 g dry weight (DW).

Sensory evaluation of crackers

Sensory evaluation of energy crackers was conducted using a 9-point hedonic scale to determine consumer acceptability and quality attributes, following procedures previously reported by Rahman & R (2024) on crackers supplemented with edible insects and nutribite crackers formulated with lotus root (insect) powder supplementation as described by Ivanišová et al. (2023). A semi-trained panel consisting of five postgraduate students from the National Institute of Food Science and Technology (NIFSAT) participated in the sensory analysis following the procedure described by Urooj et al. (2026b). Before the evaluation, the panelists were briefed on the use of the 9-point hedonic scale, where 1 = dislike extremely and 9 = like extremely.

The crackers were assessed for sensory qualities such as color, aroma, taste, and overall acceptability. To minimum bias, the composition of crackers samples was not disclosed to the panalists. Each small portion of samples was labeled with random 3-digit codes before being presented to the panelist in a randomized order. Water was provided to rinse their mouths between samples in order to minimize carry-over effects during the evaluation.

Statistical analysis

All experiments were performed in triplicate, and the results were expressed as mean \pm standard deviation (SD). The obtained data were statistically analyzed using Statistix 8.1 following the procedure described by Urooj et al. (2026c). Significant differences were observed among treatments; Tukey's Honest Significant Difference (HSD) test was used for multiple comparisons at a significance level of $p < 0.05$.

Results and Discussions

Proximate composition of groundnut powder

The proximate composition of roasted groundnut powder was determined and the results are presented in Table 2. The moisture content of sample was $4.73 \pm 0.02\%$, which indicates a relatively low level of residual water can be attributed to the roasting process, where heat treatment promotes evaporation of water from the groundnuts. The value is consistent with Meng et al. (2019) reported that raw peanuts contained approximately 4.95% moisture, while roasted powder showed moisture values around 4.73%. Fat content of roasted powder was $48.38 \pm 0.02\%$, indicating that peanuts naturally contain a high proportion of oil as reported by Meng et al. (2019), who found lipid content of 47.82% in raw peanuts and values ranging from 41–49% after different thermal processing methods. Similarly, Alhassan et al. (2017) reported crude fat values ranging from 31–46% in different groundnut accessions processed into powder.

Protein content was $26.95 \pm 0.04\%$, demonstrating level falls within the typical range reported for Meng et al. (2019) 26.63% in raw peanuts and a range of 24–27% after various

thermal treatments, indicating that heat processing has minimal impact on protein levels. Similarly, Abdullahi et al. (2021) reported crude protein values up to 30.6% in different groundnut genotypes, highlighting peanuts as a protein-rich food. Crude fiber content recorded $2.50 \pm 0.04\%$ which is within the range of Alhassan et al. (2017) from 1.4–3.9% in powdered groundnut samples. Ash content of roasted groundnut powder was $1.99 \pm 0.01\%$, comparable to reported findings by Meng et al. (2019) 2.92% in raw peanuts, while thermal processing produced values generally ranging between 1–5%. Similarly, Alhassan et al. (2017) reported ash contents ranging from 1.2–2.3%, which fall within the typical mineral content. Carbohydrate content was $15.46 \pm 0.05\%$ which is slightly lower than some previously reported results by Meng et al. (2019) reported carbohydrate content of 22.63% in raw peanuts, with processed samples showing values ranging from 21–31% depending on the processing method. Similarly, Alhassan et al. (2017) reported carbohydrate values between 21–37% in powdered groundnut samples.

Phytochemical composition

The antioxidant potential of roasted groundnut powder analyzed in this study is presented in Table 2, in which Total phenolic content ranged of 67.66 ± 1.24 mg GAE/g, which is higher than 28.64 ± 0.19 to 62.79 ± 1.18 mg GAE/g as documented by Lakhlifi El Idrissi et al. (2024). The total flavonoid content (TFC) ranged 14.16 ± 2.00 mg QE/g are also consistent with the findings of Lakhlifi El Idrissi et al. (2024), who reported TFC values between 4.20 ± 0.07 and 18.35 ± 0.06 mg QE/g. The antioxidant activity of roasted groundnut powder was further evaluated using the DPPH radical scavenging assay, which showed ranging of 430 ± 4.08 μ g α -tocopherol E/g. Thermal processing, such as roasting, is known to influence the phenolic profile and antioxidant potential of peanuts. Salve et al. (2021) reported that roasting significantly alters the polyphenol composition and improves the antioxidant properties of peanuts due to structural changes and release of bound phenolic compounds during processing. Similarly, Hassan et al. (2021)

demonstrated that roasting treatments significantly increased the total phenolic and flavonoid contents and enhanced antioxidant activity in peanut pod shells. Likewise, Hamed et al. (2021) mentioned strong antioxidant

properties in peanut skin extracts due to their high phenolic content, highlighting the role of peanut-derived phytochemicals as natural antioxidants in food systems.

Table 2: Proximate composition and antioxidant properties of roasted groundnut powder

Moisture (%)	Fat (%)	Protein (%)	Fiber (%)	Ash (%)	Carbohydrate (%)	TPC (mg GAE/g)	TFC (mg QE/g)	DPPH (µg α-tocopherol E/g)
4.73±0.02	48.38±0.02	26.95±0.04	2.50±0.04	1.99±0.01	15.46±0.05	67.67±1.25	14.17±2.00	430±4.08

Mineral content of groundnut powder

Mineral composition analyzed in this study is presented in Table 3. Calcium content (57.4 ± 0.86 mg/100 g) was comparable to previous reports for roasted peanuts (Zhao & Yang, 2022), indicating a moderate level of this essential mineral important for bone health. Iron content (1.57 ± 0.02 mg/100 g) is also within the reported range for roasted groundnuts, contributing to the dietary requirement for hemoglobin synthesis and oxygen transport. Magnesium (178 ± 0.82 mg/100 g) and phosphorus (361.7 ± 1.25 mg/100 g) were present in relatively high amounts, consistent with the values reported by Zhao & Yang (2022). Potassium (633 ± 2.45 mg/100 g) levels were also substantial, supporting the role of peanuts in electrolyte balance and cardiovascular health. Sodium was low (5.9 ± 0.16 mg/100 g), making peanuts suitable for low-sodium diets.

Trace minerals such as zinc (2.77 ± 0.008 mg/100 g), copper (0.42 ± 0.008 mg/100 g), and manganese (1.78 ± 0.016 mg/100 g) were present in appreciable amounts. Zinc plays a key role in

immune function and enzymatic reactions, while copper and manganese are essential cofactors in antioxidant defense and metabolic processes. These findings align with Zhao & Yang (2022), and Sanni et al. (2024), confirming the stability of trace mineral composition in roasted peanuts. Thermal processing, particularly roasting can lead to marginal increases in potassium and magnesium due to moisture loss and concentration effects, whereas calcium, phosphorus, iron, copper, and zinc may decrease slightly due to heat-sensitive reactions or interactions with the food matrix (Eker & Kadiroglu, 2025). Comparative studies by Zhao & Yang (2022) reported similar trends for peanuts grown in different regions of China, where macro- and trace mineral concentrations were influenced mainly by sub-regional soil conditions rather than processing methods. Similarly, Sanni et al. (2024) reported that roasted peanuts maintained stable levels of K, Mg, Ca, Mn, and Zn, while Cu varied slightly due to variation in variety

Table 3: Mineral Composition (mg/100g) of roasted groundnut

Calcium	Iron	Magnesium	Phosphorus	Potassium	Sodium	Zinc	Copper	Manganese
57.4±0.86	1.57±0.02	178.0±0.82	361.6±1.25	633.0±2.45	5.90±0.16	2.77±0.01	0.42±0.01	1.78±0.02

Proximate composition of oat-based energy crackers

Proximate composition of oat-based energy crackers as presented in Table 4. A gradual decrease in moisture content (6.96% to 6.07%) was observed across formulations. Similar reductions in moisture with formulation modifications have been reported in multigrain and composite snack systems, where moisture ranged from 11.27% to 13.06% in composite flours and 24.88% to 30.38% in protein bars, depending on ingredient composition and processing conditions (Amin et al., 2024; Mosikyan et al., 2024). The reduction may be attributed to increased dry matter content and reduced water-binding capacity of oat-based blends, which is technologically advantageous for improving shelf stability and reducing microbial susceptibility. Fat content increased markedly from 28.99% in T₀ to 36.74% in T₄, indicating enhanced lipid incorporation at higher substitution levels. A similar increasing trend in fat content has been reported in energy bar formulations, reaching up to 11.86% in flaxseed-based bars and increasing further with seed or nut enrichment (Verma et al., 2022; Alfheaid et al., 2023).

Protein content also increased from 17.31% to 21.17%, showing improved nutritional quality of the formulated crackers. Comparable increases in protein content have been widely reported in

cereal- and legume-based functional products, where protein ranged from 8.02% to 13.13% in multigrain composite flours and from 18.70% to 22.40% in protein bar formulations depending on enrichment level (Mitra et al., 2022; AlJaloudi et al., 2024). Fiber content showed a decreasing trend from 6.84% to 5.10%, which is partially consistent with findings in processed bakery and energy bar systems, increases up to 10.48% in enriched formulations (AlJaloudi et al., 2024), others have demonstrated variability depending on ingredient ratio, refinement level, and processing losses (Amin et al., 2024). Ash content remained relatively stable (2.16% to 2.09%), indicating minimal variation in total mineral composition across treatments. Similar stability in ash content has been reported in date-based and protein bar systems (1.77%–2.28%), where mineral content was primarily dependent on base ingredients rather than formulation ratio (Alfheaid et al., 2023). This suggests that substitution levels in the current study did not significantly alter mineral density. Carbohydrate content decreased significantly from 42.25% to 31.53%, which is consistent with a proportional increase in fat and protein fractions. Comparable reductions have been reported in fruit- and protein-enriched bars, where nitrogen-free extract (carbohydrates) decreased from 27.42% to 17.49% as functional ingredient concentration increased (Alfheaid et al., 2023).

Table 4: Proximate composition (%) of cracker-enriched with varying concentration of groundnut

Treatments	Moisture	Fat	Protein	Fiber	Ash	Carbohydrates
T ₀	6.96 ± 0.03	28.99 ± 0.03	17.31± 0.03	6.83 ± 0.01	2.16 ± 0.01	42.25 ± 0.02
T ₁	6.73 ± 0.02	30.93 ± 0.03	18.27± 0.03	6.41 ± 0.05	2.14 ± 0.01	39.57 ± 0.02
T ₂	6.51 ± 0.03	32.87 ± 0.03	19.24± 0.03	5.97 ± 0.04	2.12 ± 0.01	36.89 ± 0.02
T ₃	6.29 ± 0.03	34.80 ± 0.03	20.20± 0.03	5.56 ± 0.05	2.11 ± 0.01	34.21 ± 0.02
T ₄	6.07 ± 0.02	36.74 ± 0.04	21.17± 0.03	5.12 ± 0.06	2.09 ± 0.01	31.53 ± 0.02

Antioxidant activity of oat-based energy crackers

The total phenolic content (TPC), total flavonoid content (TFC), and antioxidant activity (DPPH assay) of oat-based energy crackers are presented in Figure 2. TPC increased from 150.7 mg GAE/100 g in T₀ to 160 mg GAE/100 g in T₄, showing that higher substitution levels improved the

concentration of phenolic compounds. This increase may be attributed to the incorporation of oat-based and plant-derived ingredients rich in naturally occurring polyphenols. A similar trend was reported by AlJaloudi et al. (2024), where increased inclusion of lupine seeds and wheat germ significantly enhanced total phenolic

content in formulated protein bars due to their inherent bioactive compounds. Similarly, TFC increased steadily from 69.28 mg QE/100 g to 76.6 mg QE/100 g, indicating improved flavonoid concentration with formulation enrichment. This trend aligns with findings of AlJaloudi et al. (2024), who reported higher flavonoid levels in functional protein bars formulated with plant-based ingredients such as lupine seeds and dried fruits, which are naturally rich sources of flavonoids and other antioxidant compounds. The

antioxidant activity, measured by DPPH assay, increased from 48.19 to 64.91 μg α -tocopherol equivalent/g, indicating a strong enhancement in free radical scavenging potential across treatments. Comparable results were reported by AlJaloudi et al. (2024), where higher inclusion of functional ingredients significantly improved antioxidant activity in protein bars, confirming a strong positive correlation between phenolic content and radical scavenging capacity.

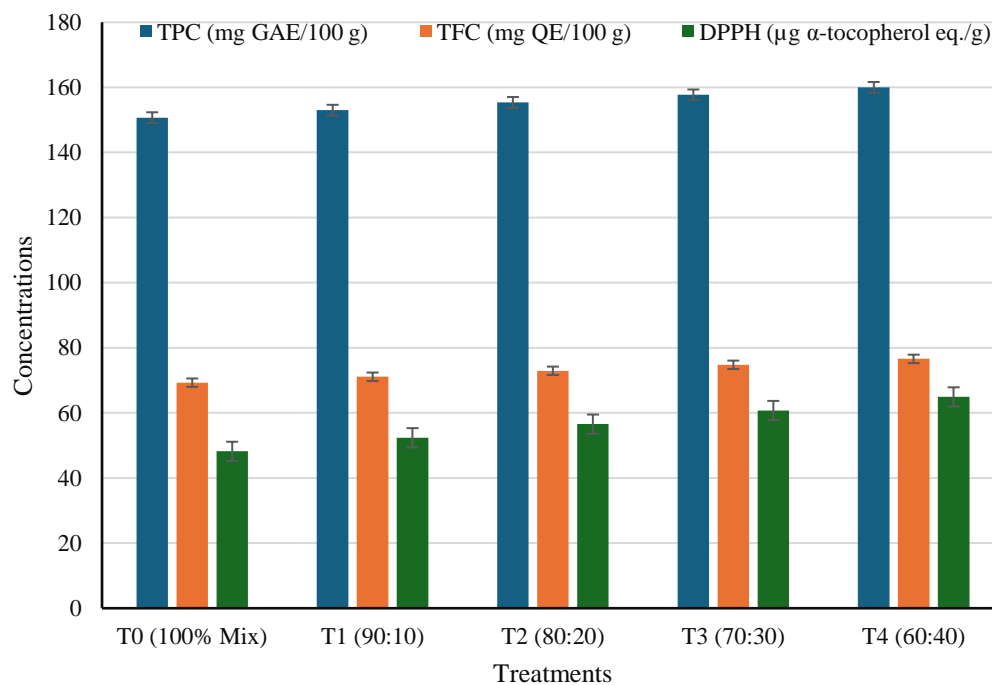


Figure 2. Phytochemical characterization of oat-based energy crackers

Mineral content of oat-based energy crackers

Mineral composition of oat-based energy crackers is presented in Table 5. Calcium content ranged from 164.25 mg in T₀ to 121.51 mg in T₄, showing a gradual decline with increasing concentration levels. This reduction may be attributed to dilution of calcium-rich ingredients present in the base formulation. AlJaloudi et al. (2024) investigated protein bars formulated with lupine seeds and wheat germ that calcium levels were influenced by the composition of raw materials, as whey protein concentrate and oat flakes used in the control bars contained substantially higher calcium levels (548

and 270 mg/100 g, respectively) compared with lupine seeds and wheat germ, which contributed lower calcium contents. Iron content decreased from 3.25 mg to 2.58 mg across treatments. Similar variability has been reported in cereal-based snack and protein bar products, where the mineral profile strongly depends on the proportion of cereal, legume, and plant-based ingredients used in the formulation (AlJaloudi et al., 2024).

Magnesium content ranged from 173.2 mg to 175.12 mg, showing a slight but consistent increase across treatments. In the study by

AlJaloudi et al. (2024), protein bar formulations were also reported to contain high magnesium levels (290 and 198 mg/100 g, respectively). Phosphorus levels decreased from 426.5 mg in T₀ to 400.57 mg in T₄, suggesting a dilution effect caused by increasing substitution of ingredients with relatively lower phosphorus content. Similar patterns were noted in the protein bar formulations developed by AlJaloudi et al. (2024), where wheat germ and lupine seeds provided high phosphorus concentrations (approximately 700 and 440 mg/100 g, respectively), significantly influencing the final mineral composition of the product. Potassium content showed a notable increase from 490.65 mg in T₀ to 547.59 mg in T₄, indicating that substituted ingredients contributed higher potassium levels to the formulation. Protein bars developed by AlJaloudi et al. (2024), where wheat germ and lupine seeds contained substantial potassium concentrations (3000 and 1010 mg/100 g, respectively), leading to enhanced potassium levels in the final products.

Sodium levels in the developed crackers remained relatively low, increasing slightly from 4.85 mg to 5.27 mg across treatments. Such low sodium values are nutritionally desirable, as reduced sodium intake is associated with improved cardiovascular health. The protein bar formulations reported by AlJaloudi et al. (2024) also demonstrated variations in sodium content depending on ingredient composition, with the control bars exhibiting relatively higher sodium levels due to the use of whey protein concentrate. Zinc content showed a slight increase from 2.49 mg to 2.60 mg, indicating a modest improvement in micronutrient density with increasing substitution levels. Copper and manganese contents, however, decreased gradually from 0.65 mg to 0.56 mg and 2.35 mg to 2.12 mg, respectively. These reductions may be associated with lower concentrations of these minerals in substituted ingredients or formulation dilution effects.

Table 5: Mineral Composition (mg/100g) of treatments with varying concentrations of groundnut flour

Treatment	Calcium	Iron	Magnesium	Phosphorus	Potassium	Sodium	Zinc	Copper	Manganese
T ₀	164.25±0.12	3.25±0.03	173.20±0.15	426.50±0.20	490.65±0.22	4.85±0.02	2.49±0.02	0.65±0.01	2.35±0.03
T ₁	153.56±0.10	3.08±0.02	173.68±0.14	420.02±0.18	504.89±0.24	4.96±0.03	2.52±0.02	0.63±0.02	2.29±0.02
T ₂	142.88±0.11	2.91±0.03	174.16±0.13	413.53±0.17	519.12±0.23	5.06±0.02	2.55±0.02	0.60±0.01	2.24±0.03
T ₃	132.20±0.09	2.75±0.02	174.64±0.14	407.05±0.19	533.35±0.25	5.17±0.03	2.57±0.03	0.58±0.02	2.18±0.02
T ₄	121.51±0.10	2.58±0.03	175.12±0.12	400.57±0.18	547.59±0.24	5.27±0.02	2.60±0.02	0.56±0.01	2.10±0.01

Sensory evaluation of oat-based energy crackers

Sensory evaluation results demonstrate that ingredient modification not only enhanced nutritional and functional attributes but also

improved sensory quality, which is critical for consumer acceptance of functional snack products. Color scores increased from 7.4 (T₀) to a maximum of 8.8 (T₂), followed by minor variation

in T₃ (8.4) and T₄ (8.7). The improvement in color acceptability with substitution suggests enhanced visual appeal due to the incorporation of plant-based ingredients, which likely promoted Maillard browning and caramelization during baking. Aroma scores showed a consistent improvement from 7.3 in T₀ to 8.3 in T₄, indicating that substitution positively influenced volatile flavor development.

Taste scores increased from 7.8 in T₀ to a peak of 8.8 in T₃, followed by a slight decline in T₄ (8.6). The improvement in taste up to T₃ can be attributed to the synergistic interaction between oats and functional ingredients, which enhances sweetness perception and overall flavor complexity. However, similar studies (Shabbir et al., 2026) have reported that high levels of plant-based fortification may slightly reduce palatability due to stronger inherent flavors of bioactive compounds. Overall acceptability increased markedly from 7.4 in T₀ to 8.8 in T₁, with consistently high values observed across all

substituted formulations T₂ (8.4), T₃ (8.5), T₄ (8.7). The highest acceptability at T₁ suggests that a low-to-moderate substitution level provided the most balanced sensory profile, combining improved flavor, aroma, and appearance without compromising consumer preference. Importantly, the sustained high acceptability across T₂ to T₄ indicates that even higher substitution levels remained organoleptically acceptable, demonstrating strong formulation stability and consumer tolerance for functional enrichment. Aljaloudi et al. (2024) reported that incorporation of lupine seeds, wheat germ, and dried fruits in protein bars improved sensory attributes such as taste and aroma due to enhanced flavor complexity and natural sweetness. Similarly, Hossain et al. (2025) observed that oat- and flaxseed-enriched bars achieved higher sensory acceptance at moderate substitution levels, while excessive inclusion slightly reduced taste scores due to intensified seed-derived flavor notes.

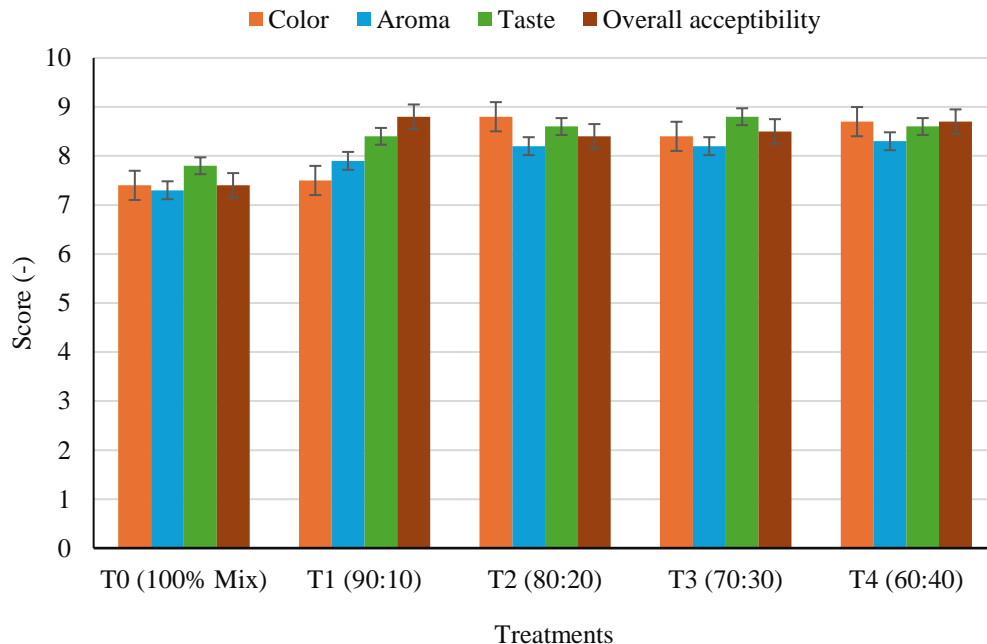


Figure 3: Sensory acceptability scores of oat-based energy crackers across different formulations

Conclusion

This study confirms that roasted groundnut powder is an effective fortifying ingredient for oat-

based energy crackers, significantly enhancing their protein content, bioactive profile, and antioxidant capacity. The roasting process not only

preserved essential nutrients but also improved the availability of phenolic compounds, contributing to the functional value of the final product. While minor reductions in moisture, fiber, and certain minerals were observed at higher substitution levels, the crackers maintained a well-balanced nutritional composition with appreciable levels of key minerals. Sensory evaluation further demonstrated that product acceptability was highest at low-to-moderate inclusion levels, indicating an optimal range for formulation. Overall, the developed crackers represent a promising functional snack with potential for health-oriented food applications. Future research should address shelf-life stability, nutrient bioavailability, and clinical validation to support large-scale commercialization.

5. REFERENCES

- Abdullahi, Y. M., M., A. A., Baba, I., Garba, H., Salihu, M. N., Lawal, M. M., Umar, M. D., & Muhammad, F. (2021). Study on proximate composition of four genotypes of *Arachis hypogaea* L. (groundnut). *International Journal of Scientific Reports*, 7(8), 369–373. <https://doi.org/10.18203/issn.2454-2156.IntJSciRep20212831>
- Adhikari, B., Dhungana, S. K., Ali, M. W., Adhikari, A., Kim, I. D., & Shin, D. H. (2018). Resveratrol, total phenolic and flavonoid contents, and antioxidant potential of seeds and sprouts of Korean peanuts. *Food Science and Biotechnology*, 27(5), 1275–1284. <https://doi.org/10.1007/s10068-018-0364-7>
- Ahmed, Z. S., & Abozed, S. S. (2015). Functional and antioxidant properties of novel snack crackers incorporated with Hibiscus sabdariffa by-product. *Journal of Advanced Research*, 6(1), 79–87. <https://doi.org/10.1016/j.jare.2014.07.002>
- Alhassan, K., Agbenorhevi, J. K., Asibuo, J. Y., & Sampson, G. O. (2017). Proximate composition and functional properties of some new groundnut accessions. *Journal of Food Security*, 5(1), 9–12. <https://doi.org/10.12691/jfs-5-1-2>
- Aljaloudi, R., Al-Dabbas, M. M., Hamad, H. J., Amara, R. A., Al-Bashabsheh, Z., Abughoush, M., Choudhury, I. H., Al-Nawasrah, B. A., & Iqbal, S. (2024). Development and characterization of high-energy protein bars with enhanced antioxidant, chemical, nutritional, physical, and sensory properties. *Foods*, 13(2), 259. <https://doi.org/10.3390/foods13020259>
- Alfheaid, H. A., Barakat, H., Althwab, S. A., Musa, K. H., & Malkova, D. (2023). Nutritional and physicochemical characteristics of innovative high-energy and protein fruit- and date-based bars. *Foods*, 12(14), 2777. <https://doi.org/10.3390/foods12142777>
- Aljefree, N. M., Shatwan, I. M., & Almoraie, N. M. (2022). Impact of the intake of snacks and lifestyle behaviors on obesity among university students living in Jeddah, Saudi Arabia. *Healthcare*, 10(2), 400. <https://doi.org/10.3390/healthcare10020400>
- Alemayehu, G. F., Forsido, S. F., Tola, Y. B., & Amare, E. (2023). Nutritional and phytochemical composition and associated health benefits of oat (*Avena sativa*) grains and oat-based fermented food products. *The Scientific World Journal*, 2023, 2730175. <https://doi.org/10.1155/2023/2730175>
- Amin, S., Pasha, I., Amin, A., Ahmed, F., & Aadil, R. M. (2024). Characterisation of wholegrain composite for pretzels: A comprehensive nutritional and functional analysis. *International Journal of Food Science & Technology*, 59(7), 4841–4850. <https://doi.org/10.1111/ijfs.17213>
- AOAC. (2019). *Official methods of analysis* (20th ed.). Association of Official Analytical Chemists.

- Argessa, G. D. (2025). Development and nutritional optimization of a healthy snack bar for children using locally available ingredients. *Science Frontiers*, 6(3), 34–56. <https://doi.org/10.11648/j.sf.20250603.11>
- Arioglu-Tuncil, S., & Çelik, Ö. F. (2026). Enrichment of gluten-containing and gluten-free crackers with red cabbage powder: Evaluation of antioxidant, physical, and textural properties. *Turkish Journal of Agriculture - Food Science and Technology*, 14(2). <https://doi.org/10.24925/turjaf.v14i2.466-475.8490>
- Barakat, H., Alpheaid, H. A., Aljutaily, T., Alayouni, R., Alharbi, H. F., & Alsanei, W. A. (2025). Elucidating the nutritional profile and biochemical characterization of high-energy nutritional bar formulated with Sukkari date paste and mixed nuts. *Foods*, 14(21), 3661. <https://doi.org/10.3390/foods14213661>
- Bodoira, R., Cittadini, M. C., Velez, A., Rossi, Y., Montenegro, M., Martínez, M., & Maestri, D. (2022). An overview on extraction, composition, bioactivity and food applications of peanut phenolics. *Food Chemistry*, 381, 132250. <https://doi.org/10.1016/j.foodchem.2022.132250>
- Bonku, R., & Yu, J. (2020). Health aspects of peanuts as an outcome of its chemical composition. *Food Science and Human Wellness*, 9(1), 21–30. <https://doi.org/10.1016/j.fshw.2019.12.005>
- Bright, J., Emanuel, G., & Silver, M. (2025, April 25). Where's Plumpy'Nut? A lifesaving food for malnourished kids is caught up in U.S. cuts. US National Public Radio.
- Chatziharalambous, D., Kaloteraki, C., Potsaki, P., Papagianni, O., Giannoutsos, K., Koukoumaki, D. I., Sarris, D., Gkatzionis, K., & Koutelidakis, A. E. (2023). Study of the total phenolic content, total antioxidant activity and in vitro digestibility of novel wheat crackers enriched with cereal, legume and agricultural by-product flours. *Oxygen*, 3(2), 256–273. <https://doi.org/10.3390/oxygen3020017>
- Coomson, J. B., Smith, N. W., & McNabb, W. (2025). Impacts of food fortification on micronutrient intake and nutritional status of women of reproductive age in Africa. *Advances in Nutrition*, 16(7), 100463. <https://doi.org/10.1007/s13668-024-00543-x>
- Cortijo-Alfonso, M. E., Romero, M. P., Macià, A., Reguant, J., Moreno, J., & Motilva, M. J. (2024). Effect of barley and oat consumption on immune system, inflammation and gut microbiota: A systematic review of randomized controlled trials. *Current Nutrition Reports*, 13, 582–597. <https://doi.org/10.1007/s13668-024-00543-x>
- Costlow, L., Bai, Y., Adams, K. P., et al. (2025). Impacts of large-scale food fortification on the cost of nutrient-adequate diets: A modeling study in 89 countries. arXiv.
- Düşkün, B., Kutlu, G., Akman, P. K., et al. (2025). Formulation of fiber-enriched crackers with oleaster powder: Effect on functional, textural, and sensory attributes. *Plant Foods for Human Nutrition*, 80, 82. <https://doi.org/10.1007/s11130-025-01323-w>
- Eker, T., & Kadiroglu, P. (2025). Comparative analysis of raw and roasted peanut skins: General composition, fatty acids, and minerals. *Journal of Raw Materials to Processed Foods*, 6(1), 61–67. <https://doi.org/10.57251/jrpfods.2025.5>
- Emergen Research. (2026). Processed snack market: Industry analysis, size, share, growth, and forecast (2024–2034) (Report ID: EMER-16809).

- Farooqui, R., Aarthi, E., & Ashlesha, P. (2019). Sensory and nutrient analysis of oats biscuits enriched with nuts. *International Journal of Current Research*.
- Gregory, A. (2024, February 28). Ultra-processed food linked to 32 harmful effects to health, review finds. *The Guardian*. <https://www.theguardian.com/society/2024/feb/28/ultra-processed-food-32-harmful-effects-health-review>
- Hamed, A. M., Taha, S. H., Darwish, A. A., et al. (2021). Antioxidant activity and some quality characteristics of buffalo yoghurt fortified with peanut skin extract powder. *Journal of Food Science and Technology*, 58, 2431-2440. <https://doi.org/10.1007/s13197-020-04835-2>
- Hassan, A. B., Al Maiman, S. A., Alshammari, G. M., Mohammed, M. A., Alhuthayli, H. F., Ahmed, I. A. M., Alfawaz, M. A., Yagoub, A. E. A., Fickak, A., & Osman, M. A. (2021). Effects of boiling and roasting treatments on the content of total phenolics and flavonoids and the antioxidant activity of peanut (*Arachis hypogaea* L.) pod shells. *Processes*, 9(9), 1542. <https://doi.org/10.3390/pr9091542>
- Hossain, M. S., Wazed, M. A., Shuvo, S. D., et al. (2025). Fortified and functional foods: Trends, innovations, and their public health impact for future nutrient enrichment. *Journal of Agriculture and Food Research*, 23, 102275. <https://doi.org/10.1016/j.jafr.2025.102275>
- Hossain, S., Momee, M. F., Trisa, A. H., Rahman, A., & Mazumder, M. A. R. (2025). Physico-chemical, textural and sensory properties of bars enriched with oats and flaxseed flour. *Food and Humanity*, 5, 100766. <https://doi.org/10.1016/j.foohum.2025.100766>
- Iqbal, S., Urooj, A., Afzal, M., Bashir, A., Rasheed, M. M., Khan, M., Asif, M., Arshad, N., & Fatima, A. (2026). Nutritional, phytochemical, and sensory characterization of gluten-free cookies developed from rice, chickpea, and banana peel composite flour. *Policy Research Journal*, 4(3), 502-516. <https://doi.org/10.5281/zenodo.19061728>
- Ivanović, S., Avramović, N., Dojčinović, B., Trifunović, S., Novaković, M., Tešević, V., & Mandić, B. (2020). Chemical composition, total phenols and flavonoids contents and antioxidant activity as nutritive potential of roasted hazelnut skins (*Corylus avellana* L.). *Foods*, 9(4), 430. <https://doi.org/10.3390/foods9040430>
- Ivanišová, E., Rajnoha, M., Harangozo, L., Kunecová, D., Čech, M., Gabríny, L., Gálik, B., Banach, J. K., Kowalczewski, P. Ł., & Pietrzak-Fiećko, R. (2023). Physicochemical, nutritional, antioxidant, and sensory properties of crackers supplemented with edible insects. *Applied Sciences*, 13(21), 11911. <https://doi.org/10.3390/app132111911>
- Kaur, N., Agarwal, A., & Sabharwal, M. (2022). Food fortification strategies to deliver nutrients for the management of iron deficiency anaemia. *Current Research in Food Science*, 5, 2094-2107. <https://doi.org/10.1016/j.crfs.2022.10.005>
- Kolahi, A., Movahed, S., Tejareh, F., et al. (2025). Impact of almond supplementation on oxidative stress biomarkers. *Scientific Reports*, 15, 29632.

- Lakhlifi El Idrissi, Z., Oubihi, A., Ibourki, M., El Youssfi, M., Gharby, S., El Guezane, C., Ullah, R., Iqbal, Z., Goh, K. W., Gallo, M., Bouyahya, A., Harhar, H., & Tabyaoui, M. (2024). Peanut (*Arachis hypogaea* L.) flour and oilcake flour: Exploring the influence of roasting and varietal differences on proximal composition, elemental profiling, antimicrobial and antioxidant properties. *Food Chemistry X*, 24, 101791. <https://doi.org/10.1016/j.fochx.2024.101791>
- Leszczyńska, D., Wirkijowska, A., Gasiński, A., Średnicka-Tober, D., Trafiałek, J., & Kazmierczak, R. (2023). Oat and oat processed products—Technology, composition, nutritional value, and health. *Applied Sciences*, 13(20), 11267.
- Ma, Z. F., Liu, S., Fu, C., Zhou, S., & Lee, Y. Y. (2026). Functional foods in health promotion and disease prevention: Innovations, evidence and challenges. *Foods*, 15(4), 764. <https://doi.org/10.3390/foods15040764>
- Meng, S., Li, J., Chang, S., & Maleki, S. J. (2019). Quantitative and kinetic analyses of peanut allergens as affected by food processing. *Food Chemistry X*, 1, 100004. <https://doi.org/10.1016/j.fochx.2019.100004>
- Mirmiran, P., Bahadoran, Z., Delshad, H., & Azizi, F. (2014). Effects of energy-dense nutrient-poor snacks on the incidence of metabolic syndrome. *Nutrition*, 30(5), 538-543. <https://doi.org/10.1016/j.nut.2013.09.014>
- Molina, C. N., Gasparre, N., Mañes, J., & Scanlon, M. G. (2025). Development of high-protein functional crackers enriched with adaptogenic compounds. *LWT*, 230, 118257. <https://doi.org/10.1016/j.lwt.2025.118257>
- Mosikyan, S., Dolan, R., Corsi, A. M., & Bastian, S. (2024). A systematic literature review and future research agenda to study consumer acceptance of novel foods and beverages. *Appetite*, 203, 107655. <https://doi.org/10.1016/j.appet.2024.107655>
- Munarso, S. J., Elmatsani, H. M., Djafar, M. J., et al. (2026). Global trends and innovations in anti-inflammatory functional beverages: A bibliometric and consumer insights analysis (2006–2025). *Beverages*, 12(1), 7. <https://doi.org/10.3390/beverages1201007>
- NielsenIQ. (2024, May 30). State of snacking: What the data shows.
- Nunes, Y. C., de Oliveira Santos, G., Mendes Machado, N., et al. (2024). Peanut seeds and by-products in metabolic syndrome and cardiovascular disorders. *Phytomedicine*, 123, 155170. <https://doi.org/10.1016/j.phymed.2023.155170>
- Olas, B. (2024). Nuts and cereals as functional foods: Nutritional composition and health-promoting properties. *Nutrients*, 16(2), 310. <https://doi.org/10.3390/nu16020310>
- Olson, R., Gavin-Smith, B., Ferraboschi, C., & Kraemer, K. (2021). Food fortification: The advantages, disadvantages and lessons from Sight and Life programs. *Nutrients*, 13(4), 1118. <https://doi.org/10.3390/nu13041118>
- Polaris Market Research. (2025). Healthy snacks market size, share, trends, industry analysis report by product, claim, distribution channel, packaging, and regional forecast (2025–2034) (Report ID: PM1039).
- Poznyak, A. V., Litvinova, L., Poggio, P., Sukhorukov, V. N., & Orekhov, A. N. (2022). Effect of glucose levels on cardiovascular risk. *Cells*, 11, 3034.
- Prasanthi, K. D., Dhar, R., Rana, K. P., & Kumar, P. (2025). Oats as a functional food. *Journal of Scientific Research and Reports*, 31(5), 574–588.

- Rahman, S. I., & R, N. (2024). Development and evaluation of Nutribite crackers using lotus root (*Nelumbium nelumbo*). *Journal of Food and Dietetics Research*, 4(1), 1–9. <https://doi.org/10.48165/jfdr.2024.4.11>
- Rasane, P., Jha, A., Sabikhi, L., Kumar, A., & Unnikrishnan, V. S. (2015). Nutritional advantages of oats and opportunities for its processing as value-added foods. *Journal of Food Science and Technology*, 52(2), 662–675. <https://doi.org/10.1007/s13197-013-1072-1>
- Redondo-Puente, M., Mateos, R., Seguido, M. A., et al. (2021). Appetite and satiety effects of oat β -glucan. *Foods*, 10, 2511.
- Salve, A. R., LeBlanc, J. G., & Arya, S. S. (2021). Effect of processing on polyphenol profile, aflatoxin concentration and allergenicity of peanuts. *Journal of Food Science and Technology*, 58(7), 2714–2724. <https://doi.org/10.1007/s13197-020-04779-7>
- Sanni, J. A., Sanni, G. O., Awoniyi, R. R., Osanyinlusi, R., Richards, Y. E., Adesina, G. I., Adenuga, O. O., Apata, S. A., & Ekun, O. E. (2024). Effects of processing on the proximate composition, mineral content and phytochemical analysis of groundnut seeds (*Arachis hypogaea*). *Biology, Medicine, & Natural Product Chemistry*, 13(1), 63–71. <https://doi.org/10.14421/biomedich.2024.131.63-71>
- Shabbir, A., Asif, H., Shakoor, S., Hussain, M., Fatima, A., Fatima, I., Urooj, A., & Asif, M. (2026). Development and characterization of flat bread incorporated with Moringa powder for nutritional, biofunctional, and sensory evaluation. *Policy Research Journal*, 4(4), 233–246. <https://doi.org/10.5281/zenodo.19606314>
- Sisay, B. G., Lacy, K. E., McNaughton, S. A., & Leech, R. M. (2026). Associations of snack frequency, energy density and nutritional quality with diet quality and cardiometabolic risks in adolescents: NHANES 2009–2016. *British Journal of Nutrition*, 135(1), 98–107. <https://doi.org/10.1017/S0007114525105746>
- Statistics Market Research Consulting. (2025). Snackification of traditional meals market forecasts to 2032: Global analysis by product type, distribution channel, and consumer demographics (Report No. SMR20610730). MarketResearch.com.
- Tahiri, M., & Gilbert, J. A. (2025). Potential prebiotic effect of almonds. *Journal of Applied Microbiology*, 136(4), 1xaf078.
- Tan, Z. H. N., Tee, S. N., Tan, E. E., & Oni, Y. (2021). Formulation of functional crackers enriched with fermented soybean (tempeh) paste: Rheological and microstructural properties. *Future Foods*, 4, 100050. <https://doi.org/10.1016/j.fufo.2021.100050>
- Urooj, A., Mumtaz, F., Shabbir, A., Sultan, M., Tirmazi, S. M., Sarwar, M. S., Iqbal, S., & Asif, M. (2026a). Exploring the ameliorative effects of *Anethum graveolens* and *Foeniculum vulgare* seeds on dyslipidemia: A comparative efficacy in high fat diet-induced model. *Policy Research Journal*, 4, 506–527. <https://doi.org/10.5281/zenodo.18831840>
- Urooj, A., Shabbir, A., Hafeez, R., Rasheed, M. M., Asif, M., Aslam, I., Fatima, T., Shakoor, A., Zaman, K., & Faryad, A. (2026b). Physicochemical, phytochemical, and sensory evaluation of cookies fortified with jujube powder. *Policy Research Journal*, 4(3), 273–286. <https://doi.org/10.5281/zenodo.18976208>

- Urooj, A., Shabbir, A., Shahbaz, A., Ahmed, S., Ul Hassan, H. N., Asif, M., Usman, A., Tofique, M., Abbas, S., & Safdar, A. (2026c). Synergistic effects of *Cinnamomum zeylanicum* and inositol on metabolic and hormonal parameters in women with polycystic ovary syndrome. *Journal of Physical Education, Health and Social Sciences*, 4(1), 637-648. <https://doi.org/10.63163/jpehss.v4i1.1176>
- Wang, S., Bloszies, C., Lee, K., et al. (2025). Phytonutrients and health benefits of almonds. *Food Chemistry*, 494, 145120.
- Xiang, F., Qin, J., Ding, C., et al. (2025). Application of foodomics technologies in the study of peanut quality. *Trends in Food Science & Technology*, 155, 104793. <https://doi.org/10.1016/j.tifs.2024.104793>
- Zhang, T., Wang, Y., Chen, P., Jiang, M., & Zhu, W. (2026). Post-harvest drying, storage and processing of peanuts. *Food Reviews International*, 42(2), 487-513.
- Zhang, Y., Li, Y., Ren, X., Gao, J., Wang, Y., & Zhu, D. (2024). Comparative study on the nutritional quality of peanut in saline and non-saline land. *Foods*, 13(23), 3751. <https://doi.org/10.3390/foods13233751>
- Zhao, H., & Yang, Q. (2022). Study on influence factors and sources of mineral elements in peanut kernels for authenticity. *Food Chemistry*, 382, 132385. <https://doi.org/10.1016/j.foodchem.2022.132385>

