

Original Article

Development of Protein-Enriched Cookies with Wheat, Oat, and Hemp Flour

Umber Gul¹, Shahzad Muzammil², Muhammad Naveed Babur³

¹ Faculty of Allied Health Sciences, The Superior University, Lahore, Pakistan
² Faculty of Allied Health Sciences, The Superior University, Lahore, Pakistan
³ Professor, Faculty of Allied Health Sciences, The Superior University, Lahore, Pakistan

✉ **Correspondence:** Shahzad Muzammil, shahzad.muzammil@superior.edu.pk

Received: 12/21/2025		Accepted: 1/25/2026	Published: 1/31/2026
HOW TO CITE			
Umber Gul et al. 2026. Development of Protein-Enriched Cookies with Wheat, Oat, and Hemp Flour. Journal of Health, Wellness and Community Research. 4(2). DOI: https://doi.org/10.61919/mmyfs625			
ARTICLE INFORMATION			
Author Contributions	Concept: UG, MNB; Design: UG, SM, MNB; Data Collection: UG, SM; Analysis: UG, SM, MNB; Drafting: UG, SM, MNB.		
Ethical Approval	The study was approved by research ethical board of The Superior University, Lahore, Pakistan		
Informed Consent	Written informed consent was obtained from all participants		
Conflict of Interest	The authors declare no conflict of interest.		
Funding	No external funding.		
Data Availability	Available from the corresponding author on reasonable request.		
AI Declaration	No generative AI was used for conceptualization, analysis, or content generation. AI use was limited to language refinement, and the authors remain fully responsible for the accuracy, originality, validity, and integrity of the manuscript's content.		

ABSTRACT

Background: Plant-based protein enrichment of commonly consumed bakery products may improve their nutritional profile while supporting the development of more diverse and sustainable food products. Hemp seed flour provides protein, dietary fiber, lipid, and mineral constituents, whereas oat flour contributes fiber and other functional components. **Objective:** To develop protein-enriched cookies containing wheat, oat, and hemp flour and evaluate their proximate composition, physicochemical properties, instrumental texture, and sensory acceptability. **Methods:** A laboratory-scale product-development study produced four cookie formulations containing nominal hemp-flour substitution levels of 0% (T0), 5% (T1), 10% (T2), and 15% (T3). Proximate composition, water activity, pH, instrumental texture, and sensory properties were evaluated. Twenty-two untrained panelists assessed sensory attributes using a 9-point hedonic scale. One-way ANOVA with post-hoc comparison was used at $p \leq 0.05$. **Results:** Protein increased from 14.20% in T0 to 17.25% in T3, fiber from 6.50% to 10.08%, and ash from 1.36% to 2.30%. Carbohydrate-by-difference was 50.14%, 45.94%, 47.17%, and 40.05% for T0–T3, respectively. T3 had the lowest water activity (0.3593 ± 0.0030), highest hardness (60.9 ± 0.36 N), highest fracturability (69.0 ± 0.50 N), and highest overall acceptability score (7.8 ± 0.09). **Conclusion:** Incorporation of hemp flour up to the 15% treatment level increased protein, fiber, and ash and produced a firmer cookie while maintaining favorable sensory acceptance. Long-term shelf life and microbiological safety were not evaluated. **Keywords:** Cookies; Dietary Fiber; Hemp Flour; Protein Enrichment; Composite Flour; Sensory Evaluation.

INTRODUCTION

Growing global food demand and increasing interest in dietary diversification have stimulated research into alternative and complementary sources of plant protein. Hemp seed and other plant-derived proteins are increasingly being investigated for incorporation into conventional foods because they can increase protein density while providing technologically useful constituents. Bakery products are particularly suitable for this approach because cookies and biscuits are widely consumed, convenient, shelf-stable products that can accommodate partial substitution of cereal flour with protein-rich ingredients (1–3).

Industrial hemp (*Cannabis sativa* L.) seed and its food derivatives have attracted particular attention because hemp seed contains substantial quantities of protein, lipid, dietary fiber, minerals, and other bioactive constituents (1,4,5). The major hemp storage proteins include edestin and albumin, while the lipid fraction contains substantial amounts of polyunsaturated fatty acids (4,5). Contemporary reviews of hempseed protein also emphasize its nutritional potential together with technological challenges related to functionality, color, flavor, and incorporation into formulated foods (2). These characteristics make hemp flour and hemp-protein preparations potentially useful ingredients for nutritional enrichment of cereal-based products.

Protein quantity alone, however, does not establish protein quality. House et al. evaluated hemp-seed products using the protein digestibility-corrected amino-acid score and demonstrated that processing and product form influence digestibility and overall protein quality (6). More recent characterization of hempseed protein extracts has likewise demonstrated that physicochemical properties and digestibility depend on the source and processing of the protein fraction (7). Consequently, an increase in crude protein concentration in a bakery product provides useful compositional information but cannot independently establish improved amino-acid adequacy, digestibility, or biological value.

Oat flour provides a complementary cereal ingredient. Oats contain protein, lipid, minerals, phytochemicals, and substantial dietary fiber, including mixed-linkage β -glucan (8,9). Processing conditions and the physicochemical characteristics of β -glucan influence its functional behavior in foods, while oat flour and oat-derived ingredients have been incorporated into bakery products to modify nutritional composition, water interactions, texture, and sensory characteristics (8–10). The combination of oat and hemp ingredients may therefore provide a useful composite-flour approach in products intended to contain greater amounts of plant protein and fiber.

Wheat flour remains central to conventional cookie manufacture because its gluten-forming proteins contribute to dough structure and handling. Cookies generally require less gluten development than bread, however, allowing partial replacement of wheat flour by non-wheat ingredients. Studies using protein blends and cereal fibers have shown that flour substitution can modify dough hydration, rheology, dimensional characteristics, texture, and final-product quality (11,12).

Substitution with high-protein or high-fiber plant ingredients can change water absorption, dough consistency, spread during baking, color, hardness, fracturability, and sensory acceptance. Protein-enriched cookie studies have demonstrated that these responses depend on the type and proportion of protein incorporated (3). Related work with hemp protein in wheat-based bakery systems has also shown changes in dough water absorption, rheological characteristics, extensibility, firmness, color, and bread quality, emphasizing that the technological effects of enrichment are formulation dependent (13).

Cereal- and plant-flour studies similarly indicate that incorporation of oat, bran, seed flour, and other fiber-rich ingredients may increase selected nutritional components while changing rheological and physical characteristics of baked products (10,12). These changes can arise from interactions among dietary fiber, protein, starch, lipid, and water as well as dilution or modification of the gluten-containing flour fraction.

Hemp inclusion may be particularly influential because hemp flour contains both protein and insoluble structural material. Mikulec et al. demonstrated that hemp flour altered the protein content, texture, color, physicochemical characteristics, and antioxidant properties of wheat bread (14). Incorporation of whole hempseed flour into wheat-based flatbread has likewise been associated with changes in rheological characteristics and increases in protein and fiber content (15). More recent work on composite wheat-hemp bread confirms that inclusion level is an important determinant of physicochemical quality and textural behavior during storage (16).

Sensory performance is equally important in enriched bakery products. Nutritional improvement has limited practical value when formulation changes produce excessive hardness, bitterness, dryness,

dense structure, undesirable color, or unfamiliar flavor. Plant-protein cookie studies demonstrate that sensory responses depend on protein source and inclusion level and that technological improvement does not necessarily correspond to improved consumer liking (3,17). Sweeteners, fat, chocolate, nuts, flavoring ingredients, baking conditions, and the extent of flour substitution may all influence the acceptable incorporation level.

Recent cookie research using hemp and other plant-protein preparations further demonstrates that protein enrichment can modify hardness, color, geometry, crumbliness, flavor, and overall sensory properties (3,17). These observations support direct physicochemical, mechanical, and sensory testing rather than assuming that greater protein incorporation will automatically produce a technologically or sensorially superior product.

The present study therefore developed composite cookies containing wheat and oat flour with increasing nominal levels of hemp flour. The objective was to evaluate differences in proximate composition, water activity, pH, instrumental texture, and sensory acceptability and to identify a formulation that combined improved nutritional composition with acceptable product quality.

MATERIALS AND METHODS

A laboratory-scale product-development study was conducted over six months in the Culinary Laboratory of The Superior University, Lahore, Pakistan.

Hemp seed and other raw materials were procured from local markets in Lahore. Ingredients included wheat flour, oat flour, hemp flour, sugar, butter, eggs, baking powder, vanilla extract, salt, water, chocolate chips, mixed nuts, and cinnamon. Ingredients were stored in airtight containers before use.

The base formulation contained 120 g wheat flour, 70 g oat flour, 80 g butter, 70 g sugar, two large eggs, 5 g vanilla extract, 5 g baking powder, 4 g salt, 50 mL water, 80 g chocolate chips, 50 g mixed nuts, and 2 g cinnamon.

Four formulations were evaluated according to their nominal experimental hemp-flour levels:

T0: 0% hemp flour;

T1: 5% hemp flour;

T2: 10% hemp flour;

T3: 15% hemp flour.

Dry ingredients were mixed separately. Butter and sugar were creamed until light and fluffy, followed by gradual incorporation of eggs and vanilla. The dry ingredients were then combined with the wet mixture, after which chocolate chips and nuts were incorporated into the dough.

The dough was chilled for at least 30 minutes. The oven was preheated to approximately 175°C. Cookies were formed to a consistent size and baked for approximately 10–12 minutes until golden brown. After brief cooling on the baking tray, the cookies were transferred to a wire rack, cooled completely, and stored in airtight containers.

Proximate analyses were performed in triplicate using established food-analysis procedures (18). Dry matter was calculated from measured moisture according to the following equation:

Dry matter (%) = 100 – moisture (%).

Crude protein was determined using Kjeldahl digestion and distillation. Total nitrogen was converted to crude protein using a conversion factor of 6.25. Crude fat was determined using continuous Soxhlet extraction with petroleum ether. Crude fiber was measured using sequential 1.25% sulfuric-acid and 1.25% sodium-hydroxide digestion followed by ignition. Ash was determined by incineration at approximately 550°C.

Carbohydrate was calculated by difference:

Carbohydrate (%) = 100 – [moisture (%) + protein (%) + fat (%) + fiber (%) + ash (%)].

Because dry matter equals 100 minus moisture, carbohydrate could equivalently be calculated as dry matter minus protein, fat, fiber, and ash.

Water activity was measured at 25°C using a calibrated digital water-activity meter. For pH determination, ground cookie was prepared as a 10% w/v suspension in distilled water, homogenized for approximately 30 minutes, and measured using a calibrated digital pH meter.

Mechanical properties were assessed using a TA-XT2 Texture Analyzer. Force-displacement measurements were used to determine maximum breaking force or hardness, fracturability, deformation distance before initial fracture, and break distance.

Sensory evaluation was performed by 22 untrained panelists. Color, taste, texture, flavor/aroma, and overall acceptability were assessed using a 9-point hedonic scale, a widely established approach for measurement of food liking and acceptance (19,20).

Results were expressed as mean $\pm$ SD. One-way analysis of variance was used to compare treatment formulations, and post-hoc treatment comparisons were interpreted at a significance threshold of $p\leq 0.05$.

Ethical approval was obtained from the Institutional Review Board of Superior University, Lahore, Pakistan.

RESULTS

Proximate Composition

Hemp-flour incorporation produced clear changes in protein, fiber, ash, and carbohydrate composition. Protein increased progressively from 14.20 $\pm$ 0.03% in T0 to 17.25 $\pm$ 0.04% in T3, representing an approximately 21.5% relative increase. Fiber increased from 6.50 $\pm$ 0.13% to 10.08 $\pm$ 0.05%, corresponding to an approximately 55.1% relative increase. Ash increased from 1.36 $\pm$ 0.07% in the control to 2.30 $\pm$ 0.05% in T3.

Dry matter decreased from 98.10 $\pm$ 0.20% in T0 to 96.88 $\pm$ 0.30% in T3. Accordingly, derived moisture increased from 1.90% to 3.12%. Fat varied among treatments, with the lowest value in T2 at 22.70 $\pm$ 0.30% and the highest value in T3 at 27.20 $\pm$ 0.40%.

Carbohydrate calculated from the stated difference equation was 50.14% for T0, 45.94% for T1, 47.17% for T2, and 40.05% for T3.

Table 1. Proximate Composition of Wheat–Oat–Hemp Cookies

Treatment	Dry Matter, %	Protein, %	Fiber, %	Fat, %	Ash, %	Carbohydrate, %
T0	98.10 $\pm$ 0.20	14.20 $\pm$ 0.03	6.50 $\pm$ 0.13	25.90 $\pm$ 0.50	1.36 $\pm$ 0.07	50.14
T1	98.02 $\pm$ 0.45	15.80 $\pm$ 0.10	7.65 $\pm$ 0.15	27.00 $\pm$ 0.10	1.63 $\pm$ 0.08	45.94
T2	97.92 $\pm$ 0.10	16.90 $\pm$ 0.02	9.15 $\pm$ 0.18	22.70 $\pm$ 0.30	2.00 $\pm$ 0.10	47.17
T3	96.88 $\pm$ 0.30	17.25 $\pm$ 0.04	10.08 $\pm$ 0.05	27.20 $\pm$ 0.40	2.30 $\pm$ 0.05	40.05

Carbohydrate means were calculated from the stated difference equation. Variability and post-hoc significance groupings for calculated carbohydrate were not determined because replicate-level covariance data were unavailable.

Water Activity and pH

Water activity differed among treatments but did not decline monotonically with each increment of hemp flour. The control had a water activity of 0.3987 $\pm$ 0.0080. T1 decreased to 0.3689 $\pm$ 0.0074, T2 increased slightly to 0.3860 $\pm$ 0.0040, and T3 had the lowest value at 0.3593 $\pm$ 0.0030.

The pH increased from 6.59 $\pm$ 0.02 in T0 to 6.82 $\pm$ 0.15 in T3.

Table 2. Water Activity and pH

Treatment	Water Activity	pH
T0	0.3987 $\pm$ 0.0080 ^a	6.59 $\pm$ 0.02 ^a
T1	0.3689 $\pm$ 0.0074 ^b	6.61 $\pm$ 0.10 ^{ab}
T2	0.3860 $\pm$ 0.0040 ^c	6.64 $\pm$ 0.05 ^{bc}
T3	0.3593 $\pm$ 0.0030 ^d	6.82 $\pm$ 0.15 ^d

Different superscript letters indicate the reported post-hoc treatment groupings.

Instrumental Texture

Hardness increased progressively from 45.2 $\pm$ 0.20 N in T0 to 60.9 $\pm$ 0.36 N in T3. Fracturability similarly increased from 55.2 $\pm$ 0.25 N to 69.0 $\pm$ 0.50 N.

Deformation distance before fracture decreased substantially, from 4.83 $\pm$ 0.21 mm in the control to 1.60 $\pm$ 0.10 mm in T3. Break distance remained close to 4.9 mm in T0–T2 but decreased to 3.53 $\pm$ 0.35 mm in T3.

Overall acceptability increased from 7.0 $\pm$ 0.07 in T0 to 7.8 $\pm$ 0.09 in T3. T1 and T2 had intermediate overall acceptability scores of 7.4 $\pm$ 0.04 and 7.6 $\pm$ 0.12, respectively.

Available sensory measurements also showed an increase in color score from 6.8 $\pm$ 0.10 in T0 to 7.6 $\pm$ 0.07 in T3 and in taste from 6.9 $\pm$ 0.09 to 7.8 $\pm$ 0.05. T3 recorded texture and flavor scores of 7.8 $\pm$ 0.06 and 7.7 $\pm$ 0.05, respectively.

Table 3. Instrumental Textural Properties

Treatment	Hardness, N	Deformation Distance, mm	Fracturability, N	Break Distance, mm
T0	45.2±0.20 ^d	4.83±0.21 ^a	55.2±0.25 ^d	4.97±0.15 ^a
T1	48.2±0.17 ^c	3.37±0.15 ^b	58.7±0.20 ^c	4.90±0.20 ^a
T2	52.2±0.24 ^b	1.80±0.17 ^c	66.6±0.40 ^b	4.93±0.25 ^a
T3	60.9±0.36 ^a	1.60±0.10 ^d	69.0±0.50 ^a	3.53±0.35 ^b

Sensory Evaluation

Table 4. Overall Sensory Acceptability

Treatment	Overall Acceptability, 9-Point Scale
T0	7.0±0.07 ^c
T1	7.4±0.04 ^b
T2	7.6±0.12 ^{ab}
T3	7.8±0.09 ^a

T3 therefore combined the highest measured protein, fiber, and ash concentrations with the highest overall sensory acceptability score, although it also exhibited the greatest instrumental hardness and the lowest deformation distance.

DISCUSSION

The present study demonstrated that incorporation of hemp flour into wheat-oat cookies altered nutritional composition, water activity, texture, and sensory acceptance. Increasing the nominal hemp level was accompanied by progressive increases in protein, fiber, and ash. The highest hemp formulation also had the lowest calculated carbohydrate concentration and lowest measured water activity. Instrumentally, increasing hemp was associated with greater hardness and fracturability and reduced deformation before fracture, whereas the highest overall sensory acceptance was recorded for T3.

The clearest nutritional effect was the increase in crude protein from 14.20% in the control to 17.25% at the 15% hemp treatment level, corresponding to an approximately 21.5% relative increase. This direction is consistent with the recognized protein content of hemp seed and hemp-derived food ingredients (1,2,4,5). Hempseed protein is characterized principally by edestin and albumin fractions, and contemporary reviews support its potential as an ingredient for protein-enriched food formulation while also emphasizing the importance of processing and functional performance (2,4).

House et al. demonstrated that hemp products can provide nutritionally useful protein, although protein digestibility and overall quality vary with processing and product characteristics (6). Subsequent work has likewise demonstrated variation in the physicochemical and digestibility characteristics of hempseed protein preparations (7). The present study measured crude protein rather than amino-acid composition, digestibility, or protein-quality indices. The findings therefore establish protein enrichment of the cookie formulation but do not demonstrate improved protein bioavailability or a specific nutritional or clinical benefit.

Fiber increased from 6.50% to 10.08%, representing an approximately 55% relative increase. This finding is compatible with the fiber-containing composition of hemp-derived ingredients and the contribution of oat flour to the composite formulation (4,5,8,9). Previous cookie and biscuit studies have similarly shown that incorporation of cereal bran, oat flour, or other plant ingredients can increase dietary-fiber-related components while altering water absorption, dough behavior, breaking strength, and other product characteristics (10,12).

Ash increased from 1.36% in the control to 2.30% in T3. Hemp seed contains nutritionally relevant mineral constituents, and increased ash has been observed in products enriched with plant materials (1,4,5). Nevertheless, ash represents the total inorganic residue following incineration and cannot establish changes in particular micronutrients. The present results therefore should not be interpreted as evidence of increased iron, magnesium, zinc, calcium, or other individual minerals without direct mineral analysis.

Carbohydrate calculated by difference was 50.14% in T0, 45.94% in T1, 47.17% in T2, and 40.05% in T3. The reduction was therefore not linear across every treatment increment, because T2 contained slightly more calculated carbohydrate than T1. Nevertheless, the highest-hemp formulation had the lowest calculated carbohydrate fraction. Similar formulation studies have demonstrated that substitution of wheat flour with protein-rich ingredients can alter the relative carbohydrate contribution of cookies

because the percentages of protein, lipid, fiber, ash, and moisture contribute directly to the compositional balance (3,11).

An important distinction was observed between moisture and water activity. Dry matter decreased from 98.10% in T0 to 96.88% in T3, indicating that calculated moisture increased from 1.90% to 3.12%, whereas T3 simultaneously demonstrated the lowest measured water activity. Moisture content and water activity are related but distinct properties. Water activity reflects the thermodynamic availability of water rather than simply the total amount of water present in the product, and interactions with proteins, fibers, sugars, salts, and other matrix constituents can alter the proportion of available water (21,22).

The low measured water activities are technologically relevant because water availability strongly influences microbial growth and food stability. However, low water activity cannot independently establish microbiological safety or commercial shelf life. Pathogenic microorganisms can survive for prolonged periods in some low-water-activity foods, and safety also depends on processing lethality, post-process contamination, packaging, sanitation, ingredient quality, storage conditions, oxidative deterioration, and moisture migration (21,22). Accordingly, the water-activity findings in the present study should not be interpreted as direct evidence of a defined shelf life.

The pH increased modestly from 6.59 in T0 to 6.82 in T3. These measurements characterize physicochemical differences among the formulations, but pH alone cannot be interpreted as evidence of microbial safety. Microbial stability in low-moisture foods depends on the interaction of water activity, organism characteristics, processing, storage environment, and other intrinsic and extrinsic factors (21,22).

Instrumental texture showed a consistent shift toward a firmer and less deformable cookie as hemp flour increased. Hardness increased from 45.2 N to 60.9 N, an approximately 35% increase, whereas deformation distance decreased from 4.83 mm to 1.60 mm. Such responses are compatible with the broader literature showing that replacement of wheat flour by plant proteins or fiber-containing ingredients changes dough structure, water interactions, gluten continuity, starch availability, and mechanical characteristics of baked products (3,11–15).

The effect of hemp ingredients on texture is not necessarily uniform across bakery matrices. Mikulec et al. reported substantial effects of hemp flour on the texture and physicochemical properties of wheat bread (14), while Sharma and Prabhasankar demonstrated changes in dough rheology and product structure following whole-hempseed-flour incorporation (15). More recent work has likewise shown that the magnitude and direction of technological effects depend on hemp concentration, product composition, and processing conditions (13,16). The increase in hardness observed in the present cookies should therefore be interpreted as a formulation-specific response rather than an invariant property of all hemp-enriched bakery products.

T3 also had the greatest fracturability force and shortest break distance. Together with the hardness and deformation measurements, these results indicate that the highest-hemp treatment produced a mechanically stronger and less deformable structure. Previous protein-enriched cookie studies have similarly demonstrated that plant-protein source and concentration can substantially affect hardness, geometry, color, crumbliness, and related technological characteristics (3,17).

Importantly, greater instrumental hardness did not correspond to poorer sensory acceptance in the present panel. T3 achieved the highest mean overall acceptability score, while the statistical grouping for T2 overlapped those of both T1 and T3. This illustrates the distinction between instrumental texture measurements and multidimensional sensory liking. A formulation can become mechanically firmer while remaining acceptable when flavor, sweetness, aroma, visual properties, and the perceived texture of the finished product are collectively favorable. Sensory research using the 9-point hedonic scale similarly emphasizes that liking represents an affective consumer response rather than a direct surrogate for an individual instrumental property (19,20).

The sensory results also need to be interpreted in relation to the formulation. Chocolate chips, nuts, vanilla, cinnamon, sugar, and butter could have influenced flavor and texture perceptions and may have moderated characteristics associated with hemp flour. Plant-protein cookie research indicates that consumer acceptance is strongly dependent on ingredient source and concentration and that some enriched formulations remain acceptable despite measurable changes in texture or appearance (3,17). In the present study, the highest-hemp formulation remained favorably rated within the range evaluated. Only overall acceptability was available as a complete treatment-wise sensory comparison across all four formulations. Color and taste comparisons between T0 and T3 and the reported T3 texture and flavor values provide additional information, but interpretation of individual sensory attributes across all

treatment levels is consequently more limited than interpretation of overall acceptability. The overall-acceptability data nevertheless demonstrate that incorporating hemp flour up to the highest tested nominal level did not reduce liking in this panel.

This finding is relevant because greater substitution of wheat flour with non-wheat plant ingredients can introduce darker color, bitterness, unfamiliar flavor, roughness, or excessive firmness. Studies of hemp and other plant proteins in cookies have documented changes in appearance, taste, texture, crumbliness, and overall acceptability, with the magnitude of sensory effects depending on protein source and inclusion level (3,17). Direct sensory testing is therefore essential when nutritional enrichment alters the physical characteristics of a bakery product.

The study has several strengths. Nutritional, physicochemical, mechanical, and sensory dimensions were examined within the same product-development system, providing a broader evaluation than compositional analysis alone. Proximate measurements were performed in triplicate, and instrumental texture analysis provided objective mechanical measurements alongside hedonic sensory evaluation.

Several limitations should be considered. Only three nominal hemp-flour treatment levels were investigated beyond the control. Protein digestibility, amino-acid composition, fatty-acid profile, individual minerals, antioxidant activity, and energy density were not measured. These limitations are important because crude protein and total ash cannot establish protein quality or specific micronutrient enhancement (2,6,7).

The sensory panel was small and consisted of 22 untrained assessors, which limits generalizability to larger consumer populations. Hedonic scaling is appropriate for measuring liking, but sensory outcomes can be influenced by participant characteristics, product presentation, and experimental context (19,20). Larger blinded consumer studies would therefore provide a stronger estimate of population-level acceptance.

Shelf life and microbiological safety were also not evaluated directly. Although T3 had the lowest water activity, low-water-activity foods can permit long-term survival of some foodborne pathogens even when microbial multiplication is restricted (21,22). Future storage studies should therefore incorporate microbiological testing, oxidative-stability assessment, packaging conditions, environmental exposure, water-activity monitoring, and repeated sensory evaluation rather than inferring shelf stability from a single physicochemical measurement.

Future investigations should additionally define the flour-replacement proportions on an exact mass basis, employ independent production batches, and evaluate a wider hemp concentration range. Protein digestibility and amino-acid profiling would be particularly valuable when positioning the product as protein enriched because processing can influence hemp-protein quality and functionality (2,6,7). Complete mineral, lipid, and dietary-fiber characterization would also permit more precise nutritional claims, while larger blinded sensory panels could establish whether the favorable acceptance observed at the highest treatment level is reproducible in broader consumer populations.

CONCLUSION

Incorporation of hemp flour into wheat-oat cookies produced clear increases in crude protein, fiber, and ash content. At the 15% treatment level, protein increased from 14.20% to 17.25% and fiber increased from 6.50% to 10.08% relative to the control, while calculated carbohydrate-by-difference decreased from 50.14% to 40.05%.

Higher hemp incorporation also increased cookie hardness and fracturability and reduced deformation before fracture. Despite this firmer instrumental texture, the 15% formulation achieved the highest overall sensory acceptability score.

The findings support hemp flour as a promising ingredient for protein- and fiber-enriched composite cookies within the tested formulation range. Shelf life, microbiological safety, protein digestibility, detailed nutrient composition, and broader consumer acceptance require further evaluation.

LIMITATIONS

Only three hemp-flour treatment levels beyond the control were evaluated.

The exact mass-replacement basis of the nominal 5%, 10%, and 15% treatment design was not available for further formulation analysis.

Long-term shelf life and microbiological safety were not assessed.

Protein digestibility, amino-acid composition, lipid quality, individual mineral concentrations, and bioavailability were not measured.

The sensory panel was relatively small and consisted of untrained assessors.

Only one source of hemp flour was evaluated.

RECOMMENDATIONS

Future studies should define hemp substitution on an exact mass basis and maintain consistent non-hemp formulation components across treatment groups.

A wider concentration range should be evaluated to determine the point at which nutritional enrichment begins to compromise texture or sensory acceptance.

Shelf-life studies should include microbiological assessment, oxidative stability, packaging conditions, water activity, and repeated sensory measurements.

Protein digestibility, amino-acid profile, fatty-acid composition, individual minerals, and total dietary fiber should be evaluated.

Larger blinded consumer studies should assess acceptance in more diverse populations.

REFERENCES

1. Rizzo G, Storz MA, Calapai G. The role of hemp (*Cannabis sativa* L.) as a functional food in vegetarian nutrition. *Foods*. 2023;12(18):3505. doi:10.3390/foods12183505.
2. Karabulut G, Kahraman O, Pandalaneni K, Kapoor R, Feng H. A comprehensive review on hempseed protein: Production, functional and nutritional properties, novel modification methods, applications, and limitations. *Int J Biol Macromol*. 2023;253(Pt 7):127240. doi:10.1016/j.ijbiomac.2023.127240.
3. Nemš A, Miedzianka J, Kita A. Quality and nutritional value of cookies enriched with plant-based protein preparations. *J Sci Food Agric*. 2022;102(11):4629–4639. doi:10.1002/jsfa.11821.
4. Apetroaei VT, Pricop EM, Istrati DI, Vizireanu C. Hemp seeds (*Cannabis sativa* L.) as a valuable source of natural ingredients for functional foods—a review. *Molecules*. 2024;29(9):2097. doi:10.3390/molecules29092097.
5. Callaway JC. Hempseed as a nutritional resource: an overview. *Euphytica*. 2004;140:65–72.
6. House JD, Neufeld J, Leson G. Evaluating the quality of protein from hemp seed (*Cannabis sativa* L.) products through the use of the protein digestibility-corrected amino acid score method. *J Agric Food Chem*. 2010;58(22):11801–11807. doi:10.1021/jf102636b.
7. Khalesi M, Gcaza L, FitzGerald RJ. In vitro digestibility, biological activity, and physicochemical characterization of proteins extracted from conventionally and organically cultivated hempseed (*Cannabis sativa* L.). *Molecules*. 2023;28(3):915. doi:10.3390/molecules28030915.
8. Leszczyńska D, Wirkijowska A, Gasiński A, Średnicka-Tober D, Trafiałek J, Kazimierczak R. Oat and oat processed products—technology, composition, nutritional value, and health. *Appl Sci*. 2023;13(20):11267. doi:10.3390/app132011267.
9. Sushytskyi L, Synytsya A, Čopíková J, Lukáč P, Rajsiglová L, Tenti P, et al. Perspectives in the application of high, medium, and low molecular weight oat β -D-glucans in dietary nutrition and food technology—a short overview. *Foods*. 2023;12(6):1121. doi:10.3390/foods12061121.
10. Negu A, Zegeye A, Astatkie T. Development and quality evaluation of wheat based cookies enriched with fenugreek and oat flours. *J Food Sci Technol*. 2020;57(10):3573–3580. doi:10.1007/s13197-020-04389-3.
11. Singh M, Mohamed A. Influence of gluten-soy protein blends on the quality of reduced-carbohydrate cookies. *LWT Food Sci Technol*. 2007;40(2):353–360. doi:10.1016/j.lwt.2005.09.013.
12. Sudha ML, Vetrimani R, Leelavathi K. Influence of fibre from different cereals on the rheological characteristics of wheat flour dough and on biscuit quality. *Food Chem*. 2007;100(4):1365–1370. doi:10.1016/j.foodchem.2005.12.013.
13. Marinopoulou A, Sevastopoulou N, Farmouzi K, Konstantinidou E, Alexandri A, Papageorgiou M. Impact of hemp (*Cannabis sativa* L.) protein addition on the rheological properties of wheat flour dough and bread quality. *Appl Sci*. 2024;14(24):11633. doi:10.3390/app142411633.
14. Mikulec A, Kowalski S, Sabat R, Skoczylas Ł, Tabaszewska M, Wywrocka-Gurgul A. Hemp flour as a valuable component for enriching physicochemical and antioxidant properties of wheat bread. *LWT*. 2019;102:164–172. doi:10.1016/j.lwt.2018.12.028.
15. Sharma S, Prabhasankar P. Effect of whole hempseed flour incorporation on the rheological, microstructural and nutritional characteristics of chapati—Indian flatbread. *LWT*. 2021;137:110491. doi:10.1016/j.lwt.2020.110491.

16. Del Vecchio L, Chiodetti M, Cirlini M, Ricci S, Di Fazio A, Caligiani A, et al. Hemp flour in breadmaking: circularity and opportunities for bread quality and stability during storage. *Eur Food Res Technol*. 2025;251:1047–1060. doi:10.1007/s00217-025-04687-0.
17. Juhász R, Hajas L, Csajbókné Csobod É, Pálkás Z, Szilágyi-Utczás M, Benedek C. Impact of pumpkin seed, brown rice, yellow pea, and hemp seed proteins on the physicochemical, technological, and sensory properties of green lentil cookies. *Foods*. 2025;14(9):1518. doi:10.3390/foods14091518.
18. Latimer GW Jr, editor. *Official Methods of Analysis of AOAC International*. 21st ed. Gaithersburg, MD: AOAC International; 2019.
19. Wichchukit S, O'Mahony M. The 9-point hedonic scale and hedonic ranking in food science: some reappraisals and alternatives. *J Sci Food Agric*. 2015;95(11):2167–2178. doi:10.1002/jsfa.6993.
20. Xia Y, Song J, Zhong F, Halim J, O'Mahony M. The 9-point hedonic scale: Using R-Index Preference Measurement to compute effect size and eliminate artifactual ties. *Food Res Int*. 2020;133:109140. doi:10.1016/j.foodres.2020.109140.
21. Beuchat LR, Komitopoulou E, Beckers H, Betts RP, Bourdichon F, Fanning S, et al. Low-water activity foods: increased concern as vehicles of foodborne pathogens. *J Food Prot*. 2013;76(1):150–172. doi:10.4315/0362-028X.JFP-12-211.
22. Olaimat AN, Osaili TM, Al-Holy MA, Al-Nabulsi AA, Obaid RS, Alaboudi AR, et al. Microbial safety of oily, low water activity food products: a review. *Food Microbiol*. 2020;92:103571. doi:10.1016/j.fm.2020.103571.