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Formulation and optimization of nutrient rich functional food products fortified with garlic (allium sativum l.) And ginger (zingiber officinale)

Mr. Eknath Ashroba Langote[1], Dr. Kailash Sakharam Gadhe[2], Ms. Dipali Sakharam Sangekar[3], Dr. Vijaya Shivajirao Pawar[4], Dr. Bhagwan Vithalrao Asewar[5]

[1]Ph. D. Foods & Nutrition (Scholar), Dept. of Food Science & Nutrition, College of Community Science, V.N.M.K.V., Parbhani, MS-431 402 India

[2]Associate Professor & Head, Dept. of Food Chemistry & Nutrition, College of Food Technology, V.N.M.K.V., MS-431 402 India

[3]Ph. D. Foods & Nutrition (Scholar), Dept. of Food Science & Nutrition, College of Community Science, V.N.M.K.V., Parbhani, MS-431 402 India

[4]Professor and Head, Dept. of Food Process Technology, College of Food Technology, V.N.M.K.V., MS-431 402 India

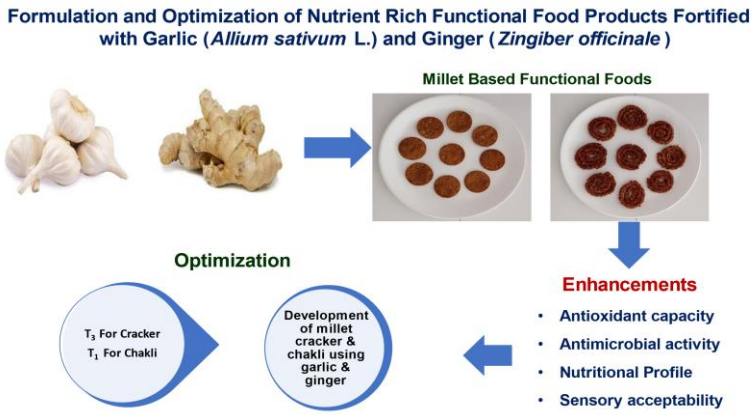
[5]Director of Instruction & Dean (F/A), V.N.M.K.V., Parbhani, MS-431 402 India.

ABSTRACT

The fortification of food products with bioactive compounds is an effective strategy to enhance nutritional quality and confer health benefits. This study aimed to develop and optimize millet-based functional snacks millet cracker and millet chakli enriched with garlic (Allium sativum L. var. Shweta) and ginger (Zingiber officinale var. Nadia) to improve their antioxidant capacity, antimicrobial activity, and nutritional profile. Four millet varieties finger millet (Eleusine coracana), barnyard millet (Echinochloa frumentacea), foxtail millet (Setaria italica), and proso millet (Panicum miliaceum) were utilized in combination with varying levels of garlic (5-20%) and ginger (2.5-10%). Sensory evaluation identified the T3 formulation for crackers and T1 formulation for chakli as optimal based on taste, texture, and overall acceptability. Proximate analysis revealed significant enhancements in protein, dietary fiber, ash content, and essential minerals, while antioxidant assays demonstrated increased phenolic content and free radical scavenging activity. The incorporation of bioactive ingredients not only improved the nutritional composition but also enhanced functional properties, suggesting that these millet-based snacks have potential as nutraceutical foods for preventive nutrition and health promotion.

Keywords: *Functional foods, Millets, Garlic, Ginger, Antioxidants, Nutraceuticals.*

Graphical Abstract



Practical applications:

The incorporation of garlic and ginger into millet-based snacks such as crackers and chakli offers enhanced nutritional and functional benefits, including increased protein, fiber, antioxidants, and essential minerals. These products can serve as

convenient, shelf-stable, health-oriented snack alternatives for consumers seeking functional foods. Their antimicrobial and antioxidant properties also support preventive health and may be of interest to food industries aiming to develop value-added products targeting immunity and chronic disease management

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1. INTRODUCTION

Functional foods fortified with bioactive compounds have emerged as promising solutions to improve nutritional quality and promote health benefits. Millets, known for their rich nutrient profile and sustainability, are gaining attention as excellent bases for such functional food products. Their natural gluten-free status and high content of proteins, fibers, and antioxidants make them ideal candidates for developing health-promoting snacks.

Incorporating bioactive ingredients like garlic (*Allium sativum* L.) and ginger (*Zingiber officinale*) into millet-based snacks offers additional functional advantages. Both garlic and ginger are recognized for their antioxidant, antimicrobial, and immunomodulatory properties, contributing to disease prevention and overall wellness. These bioactives are rich in organosulfur compounds and phenolics, which have been linked to anti-inflammatory and cardioprotective effects.

This study focuses on the formulation and optimization of two millet-based snack products cracker and *chakli* enriched with garlic and ginger extracts. Various millet varieties, including finger millet, barnyard millet, foxtail millet, and proso millet, were used to develop the products. The aim was to enhance the antioxidant potential, antimicrobial activity, and overall nutritional composition of the snacks while maintaining consumer acceptability. Sensory evaluation and proximate analysis were conducted to identify the best formulations, highlighting the potential of these enriched millet snacks as functional foods with significant health benefits.

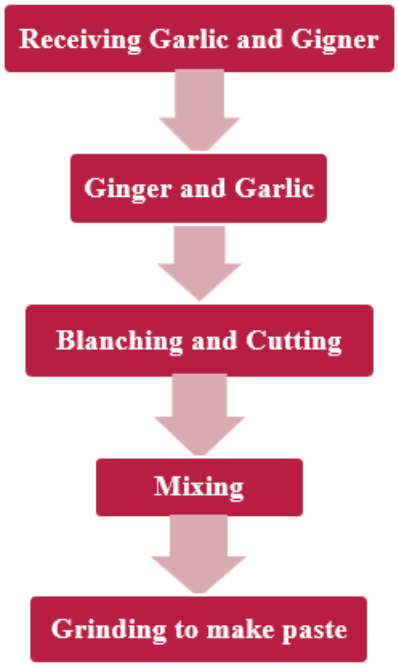
2. MATERIALS AND METHODS

This study developed millet cracker and millet *chakli* by fortifying them with garlic (*Allium sativum L., var. Shweta*) and ginger (*Zingiber officinale, var. Nadia*). Four millet varieties finger millet (*Eleusine coracana*), barnyard millet (*Echinochloa frumentacea*), foxtail millet (*Setaria italica*), and proso millet (*Panicum miliaceum*) were procured, cleaned, dried, and milled. Garlic and ginger were processed into paste before incorporation. Formulations included varying garlic (5-20%) and ginger (2.5-10%) levels across treatment groups (T_1-T_4) to analyze their impact on sensory, nutritional, and functional properties. Standardized processing involved mixing, kneading, shaping, and frying under controlled conditions.

Sensory attributes were assessed via a 9-point Hedonic Scale, and proximate composition was analyzed following AOAC (2016) methods. Protein content was estimated using the Kjeldahl method, fat via Soxhlet extraction, and fiber through acid-alkali digestion. Amino acid profiling was conducted using High-Performance Liquid Chromatography (HPLC), while essential minerals were quantified via Atomic Absorption Spectroscopy (AAS). Antioxidant activity was measured using the DPPH radical scavenging assay, and microbial safety was assessed per BIS (2002) guidelines. These evaluations ensured functional, sensory, and nutritional optimization of millet-based snacks.

Statistical analysis was conducted by using SPSS software (Version 22.0, IBM Corp., Armonk, NY, USA). Results are expressed as means ± standard deviations. One-way ANOVA followed by Duncan's Multiple Range Test was used to compare treatment means. Significance was accepted at $p < 0.05$. All analyses were performed in triplicate.

Fig. 1 Preparation of garlic and ginger paste



Functional food product formulations

Table 1: Overview of functional food product ingredients and processing

S No.	Functional Food Products	Main Ingredients Used (Basic) (per 100g)	Main Ingredients Replaced (Value added) (per 100g)	Processing Method
1	Millet Cracker	Wheat flour (89%) Oil (10%) Salt (1%)	Multi Millet flour (32%), Rice (8%) Bengal gram flour (5%), Wheat Flour (11%), Garlic (15%), Ginger (7.5%), Gingelly seeds (5%), Spices (6.5%) & oil (10ml).	Milling, Kneading, rolling, Frying
2	Millet *Chakli*	Rice flour (30%), Bengal gram flour (30%), Sago flour (30%), Gingelly seeds (5%), Spices (5%)	Multi Millet flour (32%), Rice (8%) Bengal gram flour (11%), Garlic (20%), Ginger (2.5%), Gingelly seeds (5%), Spices (6.5%) *Chakli* Masala (5%) and oil (10 ml)	Milling, Kneading, rolling, Frying

Table 1 summarizes the formulation and processing of two millet-based functional snack products. Traditional ingredients were partially replaced with multi-millet flour, garlic, and ginger to enhance nutritional value. In millet crackers, wheat flour was substituted with multi-millet flour (32%), rice (8%), Bengal gram flour (5%), garlic (15%), and ginger (7.5%).

This modification improves dietary fibre and introduces bioactive compounds with antioxidant and antimicrobial properties. Similarly, millet *chakli* was reformulated using multi-millet flour (32%), Bengal gram flour (11%), garlic (20%), and ginger (2.5%), providing improved functional and health-promoting attributes. Standard processing steps milling, kneading, rolling, and frying were applied to maintain product quality. These formulations offer healthier alternatives to conventional snacks through the integration of nutrient-dense and functional ingredients

Ingredients breakdown

Table 2: Millet cracker composition

Table 3: Millet *chakli* composition S No.	Particular	Quantity (%)
1	Finger millet	8
2	Barnyard millet	8
3	Foxtail millet	8
4	Proso millet	8
5	Rice	8
6	Bengal gram flour	11
7	Garlic	20
8	Ginger	2.5
9	Ajwain	2
10	Salt	2
11	Oil	10
12	Chill powder	2.5
13	Gingelly seeds	5
14	*Chakli* masala	5
15	Total	100

Optimization of garlic and ginger proportions

Table 4: Garlic & ginger in millet cracker (Treatments)

S No.	Particular	Quantity (%)
1	Finger millet	8
2	Barnyard millet	8
3	Foxtail millet	8
4	Proso millet	8
5	Rice	8
6	Bengal gram flour	5
7	Wheat flour	11
8	Garlic	15
9	Ginger	7.5
10	Ajwain	2
11	Salt	2
12	Oil	10
13	Chill powder	2
14	Gingelly seeds	5
15	Turmeric	0.5
16	Total	100

S No.	Millet cracker	T_1	T_2	T_3	T_4
1	Garlic (%)	5	10	`15	20
2	Ginger (%)	2.5	5	7.5	10

Table 4 shows millet cracker formulations (T_1-T_4) with increasing garlic (5-20%) and ginger (2.5-10%) levels. These bioactive ingredients improve antioxidant and antimicrobial properties. Among them, T_3 (15% garlic, 7.5% ginger) was found to be the most acceptable, balancing enhanced functionality with favorable sensory qualities. Higher levels may impact taste, so T_3 offers an optimal blend for health and palatability.

Fig. 2 Different treatments of millet cracker

Control **T_1** **T_2** **T_3** **T_4**

Table 5: Garlic & ginger in millet *chakli* (Treatments)

S No.	Millet *chakli*	T_1	T_2	T_3	T_4
1	Garlic (%)	20	15	10	5
2	Ginger (%)	2.5	5	7.5	10

Table 5 presents four treatment variations (T_1-T_4) of millet *chakli* with varying proportions of garlic and ginger paste. Garlic content decreased from 20% in T_1 to 5% in T_4, while ginger content increased from 2.5% to 10%. Higher garlic levels (T_1, T_2) enhance antimicrobial activity and flavor intensity, whereas increased ginger concentrations (T_3, T_4) contribute anti-inflammatory and digestive benefits. These variations influence sensory characteristics, texture, and functional properties. Sensory evaluation indicated that T_1, with the highest garlic content, was the most acceptable formulation, balancing flavor and health benefits effectively.

Fig. 3 Different treatments of millet *chakli*

Control **T_1** **T_2** **T_3** **T_4**

3. RESULTS AND DISCUSSION

Table 6: Sensory evaluation scores of millet cracker

Variations	Mean sensory scores					
	Appearance	Colour	Taste	Flavor	Texture	Overall acceptability
Control	8.0	8.0	7.9	7.8	8.0	7.9
T1	8.2	8.2	8.0	8.0	8.2	8.2
T2	7.9	7.9	7.8	7.8	7.8	7.9
T3	8.5	8.2	8.2	8.4	8.5	8.4
T4	7.8	7.9	7.8	7.8	7.8	7.9
SE ±	0.14	0.15	0.21	0.17	0.18	0.20
CD ($p < 0.05$)	0.36	0.38	0.54	0.44	0.47	0.51
F-value	2.5 ^{NS}	1.9^{NS}	3.6^{NS}	2.2 ^{NS}	2.8 ^{NS}	2.4^{NS}

NS-Non significant

The sensory evaluation of millet crackers yielded mean scores between 7.8 and 8.5 across all assessed attributes, including appearance, color, taste, flavor, texture, and overall acceptability. Among the treatments, T_3 received the highest scores for appearance (8.5), taste (8.2), flavor (8.4), texture (8.5), and overall acceptability (8.4), indicating a marginal preference. However, statistical analysis showed that the differences among treatments were not significant (F-values ranging from 1.9 to 3.6; $p > 0.05$), confirming comparable sensory acceptability across all formulations. These results are consistent with previous studies (Pandit, 2021; Ghosh et al., 2019), which demonstrated that millet-based snacks fortified with bioactive ingredients like garlic and ginger maintain favorable sensory qualities. Therefore, the inclusion

of these functional ingredients enhances the nutritional profile of millet crackers without compromising consumer acceptance.

Fig. 4 Sensory evaluation scores of cracker

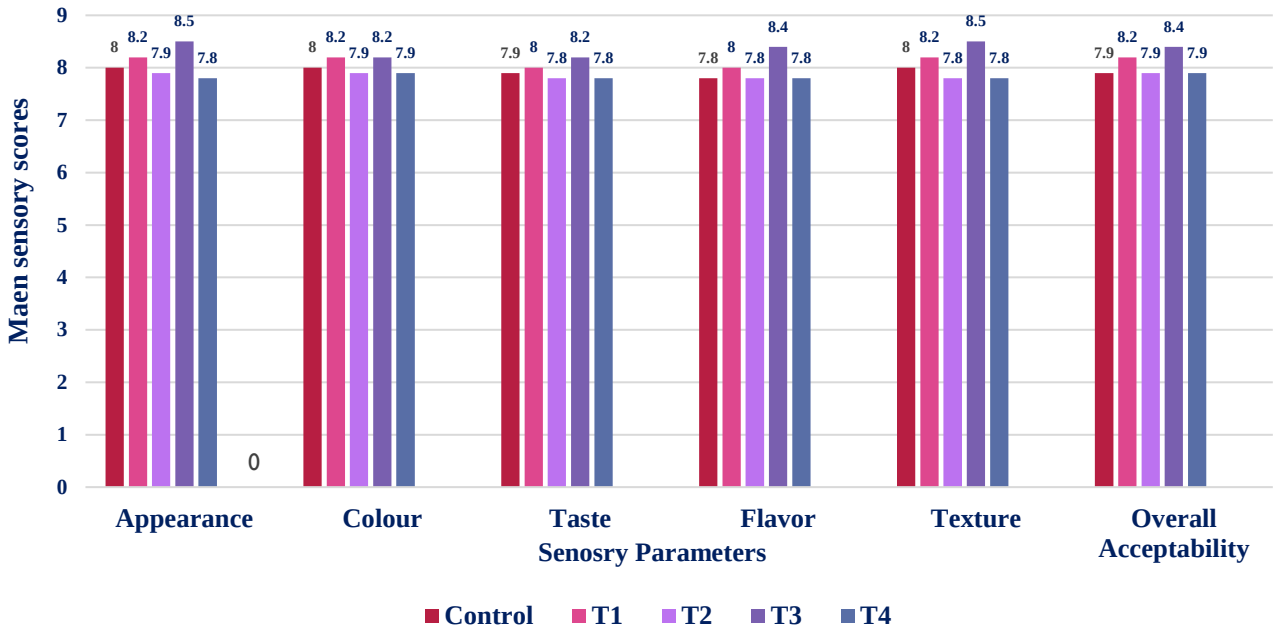


Table 7: Sensory evaluation scores of millet *chakli*

Variations	Mean sensory scores					
	Appearance	**Colour**	**Taste**	**Flavor**	**Texture**	**Overall acceptability**
Control	7.8	7.8	7.5	7.7	7.6	7.6
T1	8.9	8.8	8.7	8.7	8.8	8.8
T2	6.7	6.7	6.7	6.7	6.7	6.7
T3	7.5	7.5	7.5	7.6	7.5	7.5
T4	7.7	7.6	8.6	7.6	8.6	8.6
SE ±	0.075	0.073	0.046	0.054	0.082	0.081
CD ($p < 0.05$)	0.25	0.24	0.152	0.17	0.26	0.265
F-value	2.1 ^{NS}	1.9 ^{NS}	1.4 ^{NS}	1.4^{NS}	3.8 ^{NS}	2.3 ^{NS}

NS-Non significant

Sensory evaluation of millet *chakli* showed that treatment T_1 was the most preferred, with the highest scores across appearance (8.9), color (8.8), taste (8.7), flavor (8.7), texture (8.8), and overall acceptability (8.8). Treatment T_2 received the lowest uniform scores (6.7), indicating poor acceptability. Although T_4 also scored well in taste, texture, and overall acceptability (8.6), statistical analysis revealed no significant differences ($p > 0.05$) among treatments. These results align with previous (Chawla & Sharma, 2021) studies highlighting the importance of functional ingredients and balanced seasoning for sensory appeal in millet snacks. The findings confirm that millet *chakli* is a promising functional snack when optimally formulated.

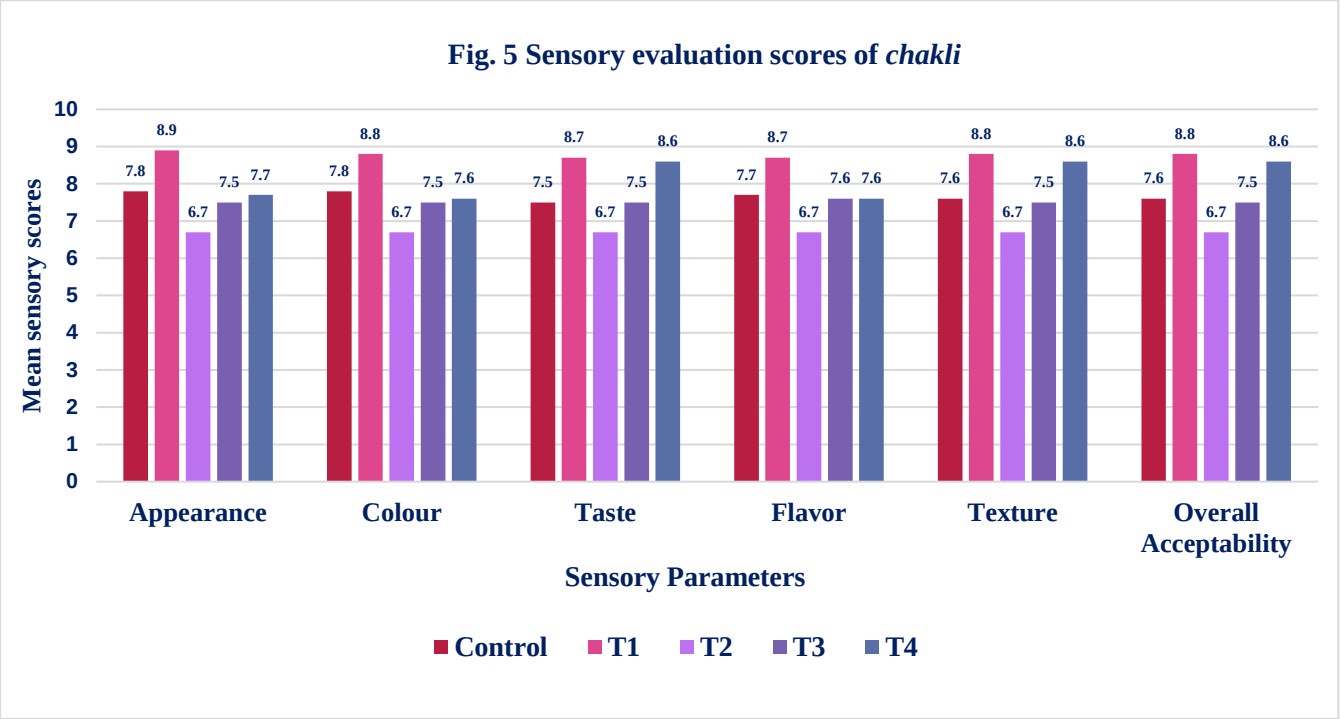


Table 8: Nutrient composition of basic and value-added millet cracker

S No	Basic cracker Nutrients	Composition (%)	Value added millet cracker nutrients	Composition (%)
	Moisture (g)	2.58	Moisture (g)	2.49
	Protein (g)	9.17	Protein (g)	13.28
	Fat (g)	22	Fat (g)	20.08
	Crude Fiber (g)	4.16	Crude Fiber (g)	6.13
	Ash	2.2	Ash	4.79
	Phenols	102	Phenols	193.47
	Flavonoids	1300	Flavonoids	1506
	Phytates	150	Phytates	282
	Total Antioxidant Activity	103.2	Total Antioxidant Activity	162.04
0	Calcium (mg)	1800	Calcium (mg)	3122
1	Iron (mg)	78	Iron (mg)	106.06

Table 8 compares the nutrient composition of basic and millet-enriched crackers, highlighting clear nutritional enhancements in the value-added formulation. The moisture content slightly decreased from 2.58 per cent to 2.49 per cent, suggesting better shelf stability. A marked increase in protein (13.28% vs. 9.17%) reflects the protein-rich nature of millets, while a reduction in fat (20.08% vs. 22%) may result from reduced oil absorption due to higher fiber content. Crude fiber increased from 4.16% to 6.13%, promoting digestive health and satiety. The ash content more than doubled (4.79% vs. 2.2%), indicating improved mineral availability. The value-added cracker also contained significantly higher levels of phenols (193.47 mg/100g) and flavonoids (1506 mg/100g), contributing to its enhanced antioxidant activity (162.04 µmol TE/100g vs. 103.2 µmol TE/100g).

Although phytate content increased (282 mg/100g vs. 150 mg/100g), its antioxidant properties may offer health benefits when consumed in moderation. Furthermore, calcium (3122 mg/100g vs. 1800 mg/100g) and iron (106.06 mg/100g vs. 78 mg/100g) levels rose significantly, highlighting the product's potential to combat micronutrient deficiencies. In summary, the millet-based cracker demonstrated superior nutritional and functional properties, supporting its application

as a health-promoting and nutraceutical snack option.

Tabel 9: Nutrient composition of basic and value added millet *chakli*

S No.	Basic *chakli* Nutrients	Composition (%)	Value added millet *chakli* nutrients	Composition (%)
1	Moisture (g)	3.09	Moisture (g)	2.79
2	Protein (g)	10.84	Protein (g)	15.45
3	Fat (g)	24.08	Fat (g)	22.08
4	Crude Fiber (g)	1.74	Crude Fiber (g)	6.23
5	Ash	3.11	Ash	4.75
6	Phenols	100	Phenols	195.3
7	Flavonoids	950	Flavonoids	1508
8	Phytates	185	Phytates	285
9	Total Antioxidant Activity	100.5	Total Antioxidant Activity	165.07
10	Calcium (mg)	1920	Calcium (mg)	3234
11	Iron (mg)	80	Iron (mg)	107.6

Table 9 presents a comparative analysis of the nutrient composition of basic *chakli* and value-added millet *chakli*. The results demonstrate that millet incorporation significantly enhances the nutritional quality of the product. The moisture content decreased from 3.09% in basic *chakli* to 2.79% in millet *chakli*, suggesting improved shelf stability. A substantial increase in protein content (15.45% vs. 10.84%) reflects the protein-rich nature of millets. Fat content slightly declined (22.08% vs. 24.08%), possibly due to reduced oil absorption during frying, while crude fiber content increased markedly (6.23% vs. 1.74%), improving dietary fiber intake. An increase in ash content (4.75% vs. 3.11%) indicates a higher total mineral content. The millet *chakli* also exhibited elevated levels of bioactive compounds, with phenols rising from 100 to 195.3 mg/100g and flavonoids from 950 to 1508 mg/100g. This was reflected in the enhanced antioxidant activity (165.07 vs. 100.5 µmol TE/100g), supporting the functional food potential of the product.

Although phytates increased (285 vs. 185 mg/100g), they may offer health benefits in moderation. Importantly, the levels of calcium and iron were significantly higher in millet *chakli* (3234 mg and 107.6 mg, respectively), enhancing its value in addressing micronutrient deficiencies. These findings underscore the potential of millets to enhance traditional snacks nutritionally, making them suitable for health-conscious consumers and nutritional intervention programs.

4. CONCLUSIONS

This study successfully formulated and optimized millet-based cracker and *chakli* products enriched with garlic (*Allium sativum L.*) and ginger (*Zingiber officinale*). Sensory evaluation indicated high consumer acceptability, with the T_3 variant for crackers and T_1 for *chakli* rated highest in texture, flavor, and overall appeal. Nutritional analysis confirmed substantial enhancements in protein, dietary fiber, antioxidant activity, and mineral content, underscoring the value of these products as functional snacks. The integration of bioactive ingredients further contributed to potential health benefits, including antioxidant, anti-inflammatory, and antimicrobial effects, supporting their role in preventive and health-promoting nutrition.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTION

Eknath Ashroba Langote conceptualized the study, carried out the experimental work, data analysis, and drafted the manuscript. Dr. Kailash Sakharam Gadhe supervised the research, contributed to the design, and provided critical revision of the manuscript. Ms. Dipali Sakharam Sangekar assisted in data collection and product development. Dr. V. S. Pawar contributed in critical rivision and guide for manuscript preparation. Dr. Bhagwan Vithalrao Asewar provided administrative and institutional support. All authors read and approved the final manuscript for submission.

ORCID ID

1 E. A. Langote https://orcid.org/0009-0005-3571-5684
2 Dr. K. S. Gadhe https://orcid.org/0009-0005-0504-9166
3 D. S. Sangekar https://orcid.org/0009-0000-5728-3476
4 Dr. V. S. Pawar https://orcid.org/0009-0005-3264-5647
5 Dr. B. V. Asewar https://orcid.org/000-0001-7231-2204

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