Sensory Acceptability, Shelf Stability, Microbial Safety, And Economic Viability Of Functional Foods Formulated With Garlic And Ginger

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ABSTRACT

The increasing demand for functional foods has spurred interest in products enriched with bioactive compounds like garlic (Allium sativum L.) and ginger (Zingiber officinale), known for their antioxidant, anti-inflammatory, and antimicrobial properties. This study evaluated the sensory acceptability, shelf stability, microbial safety, and economic viability of millet-based functional snacks specifically crackers and chakli fortified with garlic and ginger. Sensory analysis indicated high acceptability across parameters such as appearance, flavor, and texture, with no significant differences among treatments. Aluminum pouches demonstrated superior preservation of sensory attributes over 60 days compared to LDPE and HDPE packaging. Microbial assessments confirmed product safety with no significant contamination during storage. Economic analysis supported the cost-effectiveness and market potential of these fortified snacks. These findings validate the development of health-promoting, shelf-stable millet-based products incorporating garlic and ginger, offering a viable option for functional food innovation.

Keywords: *Functional foods, Garlic, Ginger, Millet snacks, Sensory evaluation*.

Graphical Abstract

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1. INTRODUCTION

Functional foods, defined as foods that provide health benefits beyond basic nutritional requirements, are gaining increasing attention for their role in promoting health and reducing the risk of chronic diseases (Doyon and Labrecque, 2008). These foods are often enhanced with bioactive compounds such as antioxidants, phytochemicals, and dietary fibers (Granato et al., 2010). Among these, garlic (*Allium sativum L.*) and ginger (*Zingiber officinale*) are notable for their long-standing use in traditional medicine and documented nutraceutical properties.

Garlic contains sulfur-containing compounds, particularly allicin, which exhibit strong antimicrobial, antihypertensive, and cardioprotective activities (Rahman, 2007). Similarly, ginger possesses pharmacologically active components such as gingerols and shogaols that have demonstrated anti-inflammatory, antioxidant, and gastroprotective effects (Mao et al., 2019). These properties make garlic and ginger ideal ingredients for developing functional food products.

Millets are nutrient-dense, gluten-free cereals rich in dietary fiber, polyphenols, and essential micronutrients, and are gaining prominence in functional food formulations (Saleh et al., 2013). Traditional millet-based snacks like crackers and *chakli* are regionally popular and present an opportunity for innovation through functional ingredient incorporation.

However, for functional foods to succeed in the market, factors such as sensory acceptability, microbial safety, and shelf life must be addressed. Packaging materials such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), and aluminum pouch a crucial role in preserving food quality by acting as barriers to oxygen, moisture, and microbial contamination (Robertson, 2010).

This study aims to develop millet-based functional foods crackers and *chakli* fortified with garlic and ginger, and to evaluate their sensory qualities, shelf stability using different packaging materials, microbial safety during storage, and economic feasibility.

2. MATERIAL AND METHODS

Product Development

Functional food products millet crackers and millet *chakli* were developed by incorporating garlic (*Allium sativum* L., var. Shweta) and ginger (*Zingiber officinale*, var. Nadia) into a composite flour made from finger millet (*Eleusine coracana*), barnyard millet (*Echinochloa frumentacea*), foxtail millet (*Setaria italica*), and proso millet (*Panicum miliaceum*). The millets were cleaned, dried, and milled using standard methods (Shobana & Malleshi, 2007). Garlic and ginger were processed into fresh paste. Four treatment formulations (T_1-T_4) were designed by varying garlic (5-20%) and ginger (2.5-10%) levels.

Select fresh garlic and ginger
↓
Wash thoroughly
↓
Blanching
↓
Peel garlic and ginger
↓
Cut into small pieces
↓
Grind to a smooth paste
↓
Add salt or vinegar (optional)
↓
Store in clean container
↓
Keep in refrigerator

Flow Sheet 1: Preparation of garlic & ginger paste

Table 1: Garlic & ginger in millet cracker & millet *chakli* (Treatments)

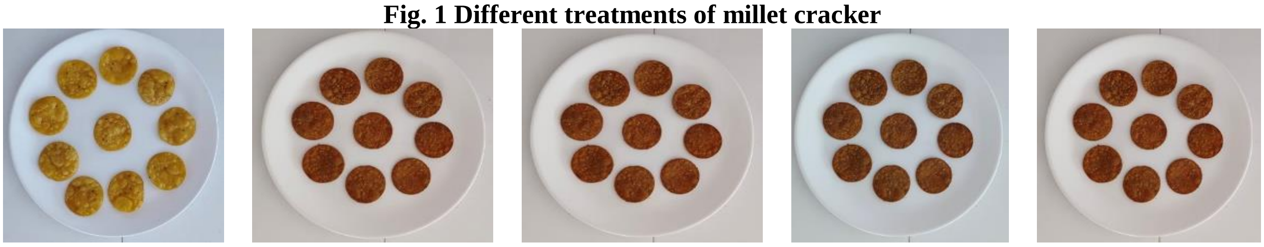
Product	Treatments	Garlic (%)	Ginger (%)
Millet cracker	T_1	5	2.5
	T_2	10	5

	T_3	15	7.5
	T_4	20	10
Millet *chakli*	T_1	20	2.5
	T_2	15	5
	T_3	10	7.5
	T_4	5	10

Collect ingredients
↓
Clean garlic & ginger
↓
Make paste of garlic & ginger
↓
Mix Millet Flour + Garlic-Ginger paste + Salt + Spices
↓
Add oil and water → Knead into dough
↓
Rest the Dough (10-15 minutes)
↓
Roll & cut into thin crackers
↓
Deep fry at 170-180°C until golden brown
↓
Drain excess oil → cool → pack

Flow Sheet 2: Preparation of millet cracker

Fig. 1 Different treatments of millet cracker



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

Collect ingredients
↓
Clean garlic & ginger
↓
Grind into fine paste
↓
Mix millet flour + rice flour + garlic-ginger paste + spices + sesame Seeds
↓
Add hot oil → Mix well
↓
Add water gradually → Knead to soft dough
↓
Load dough into *chakli* press
↓
Shape *chaklis* on Butter Paper or Plate
↓
Deep fry at 170-180°C until crisp & golden
↓
Drain excess oil → cool → pack

Flow sheet: 3 Preparation of millet *chakli*

Fig. 2 Different treatments of millet *chakli*

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

Sensory Evaluation

Sensory attributes appearance, flavor, taste, texture, and overall acceptability were evaluated using a 9-point Hedonic Scale (Stone & Sidel, 2004) by a semi-trained panel of 20 members.

Shelf Stability and Packaging

Shelf-life studies were conducted for 60 days using three packaging materials: low-density polyethylene (LDPE), high-density polyethylene (HDPE), and aluminum foil pouches. Sensory and microbial assessments were conducted at regular intervals (Manohar & Rao, 1997).

Microbial Analysis

Microbial safety, including total plate counts, yeast, and mold counts, was assessed as per Bureau of Indian Standards (BIS, 2002) specifications for functional food products.

Economic Analysis

Economic viability was evaluated by calculating raw material cost, processing expenses, yield, and projected market price, as suggested by Pathania et al. (2018).

Statistical Analysis

All experiments were conducted in triplicate, and results were reported as mean ± standard deviation. Statistical analysis was performed using SPSS software version 22.0 (IBM Corp., Armonk, NY, USA). One-way ANOVA followed by Duncan's Multiple Range Test (DMRT) was applied to determine significance at $p < 0.05$ (Gomez & Gomez, 1984).

3. RESULTS AND DISCUSSION

Table 2: 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 showed (table 2) mean scores ranging from 7.8 to 8.5 across all attributes. The T_3 variation received the highest ratings for appearance (8.5), taste (8.2), flavor (8.4), texture (8.5), and overall acceptability (8.4), indicating a slight preference. However, F-values (1.9 to 3.6) were non-significant ($p > 0.05$), suggesting no statistically meaningful differences among the treatments. These findings confirm that all formulations were well accepted.

The results align with Pandit (2021) and Ghosh et al. (2019), who found that millet-based snacks enriched with ingredients like ginger and garlic maintained good sensory qualities. Thus, millet crackers with functional ingredients are both nutritious and consumer-acceptable.

Fig. 3 Sensory evaluation scores of cracker

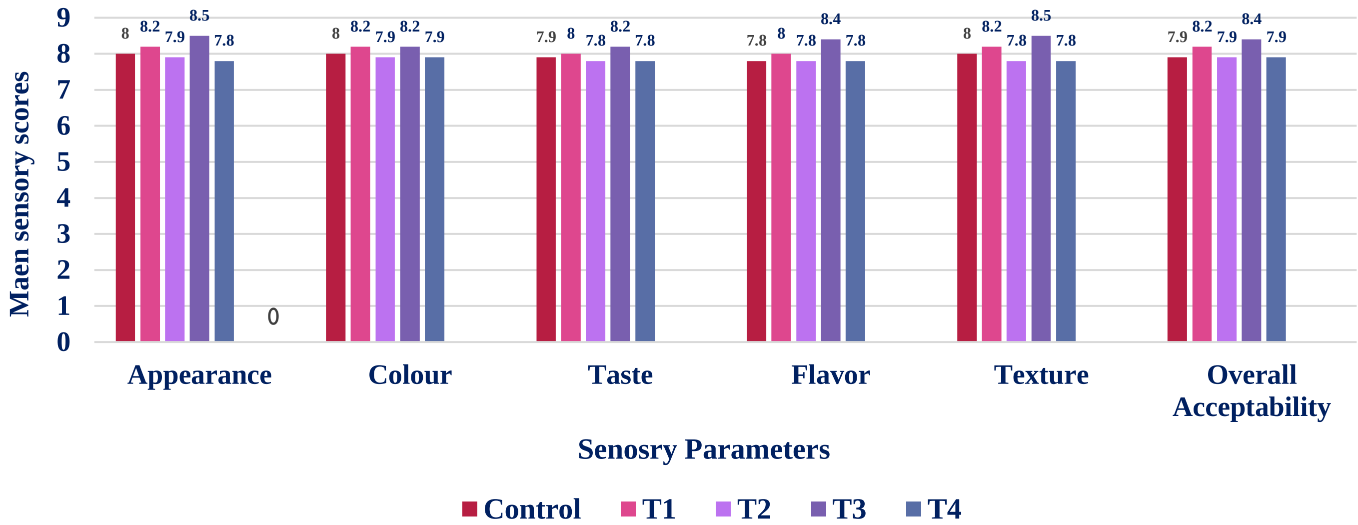


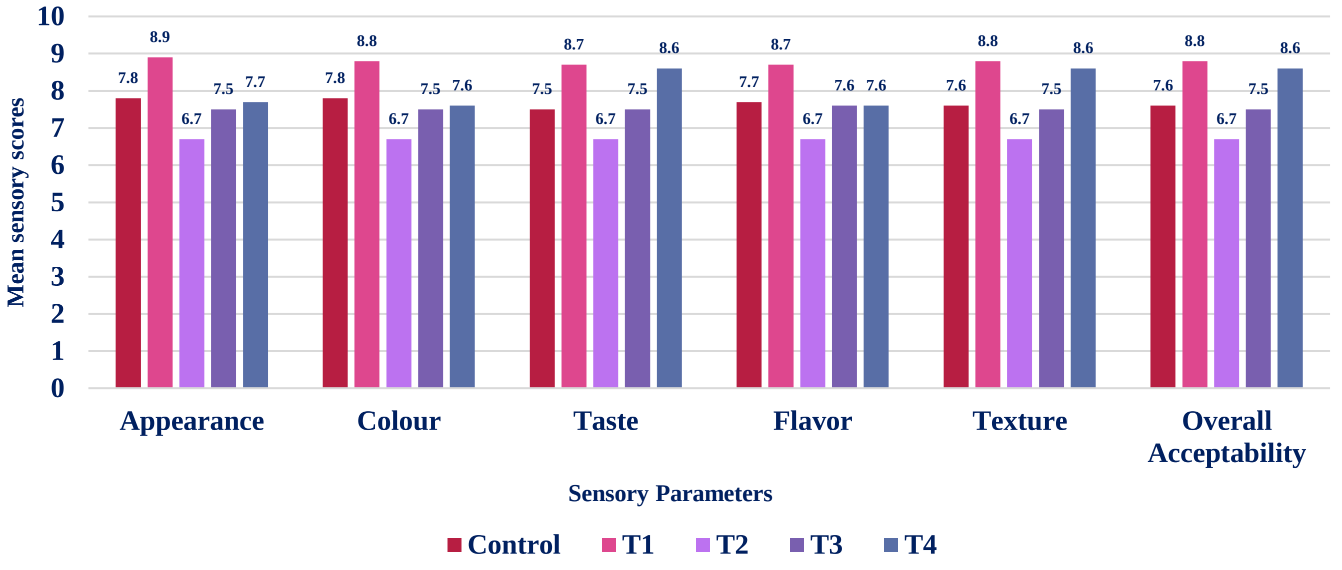
Table 3: Sensory Evaluation Scores of Millet *Chakli*

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

The sensory evaluation revealed that T_1 was the most preferred millet chakli, scoring highest in appearance (8.9), colour (8.8), taste (8.7), flavor (8.7), texture (8.8), and overall acceptability (8.8) in table 3. In contrast, T_2 received the lowest uniform score of 6.7 across all attributes, indicating poor acceptability. While T_4 showed high scores in taste, texture, and overall acceptability (8.6), statistical analysis (F-values 1.4 to 3.8, all NS) indicated no significant differences ($p > 0.05$) among treatments.

Fig. 4 Sensory evaluation scores of *chakli*



These findings suggest that most formulations, especially T_1 and T_4, were well accepted. The results support studies by Jha et al. (2020) and Joshi & Rane (2021), which emphasized the role of functional ingredients and proper seasoning in enhancing the sensory appeal of millet snacks. Poor performance of T_2 aligns with Chawla & Sharma (2021), who reported that imbalanced ingredient combinations reduce product acceptability. Overall, the study confirms that millet *chakli* is a viable functional snack when optimally formulated.

The table 4 study demonstrated that sensory qualities of millet crackers declined gradually over 60 days of storage, with the rate of decline varying by packaging material. At day 0, all crackers stored in LDPE, HDPE, and aluminum pouches scored high (8.5-8.6) in all sensory attributes, indicating uniform freshness. Over time, LDPE-packaged crackers showed the greatest decline, with overall acceptability dropping to 7.6 by day 60. HDPE performed slightly better, ending at 7.9, while aluminum pouches preserved the sensory attributes most effectively, maintaining an overall acceptability score of 8.2 at day 60.

Table 4: Effects of Packaging Material and Storage on Sensory Qualities of Millet cracker

Packaging Material	Storage Period (Days)	Appearance	Colour	Falvour	Taste	Texture	Overall acceptability
LDPE	0	8.5	8.5	8.6	8.6	8.5	8.6
	15	8.4	8.4	8.3	8.3	8.2	8.4
	30	8.0	8.0	7.9	7.9	7.9	8.1
	45	7.9	7.9	7.8	7.8	7.6	7.8
	60	7.8	7.8	7.6	7.6	7.4	7.6
HDPE	0	8.5	8.5	8.6	8.6	8.5	8.6
	15	8.4	8.4	8.4	8.4	8.3	8.4
	30	8.3	8.3	8.2	8.2	8.1	8.2
	45	8.1	8.1	8.1	8.1	7.9	8.0
	60	8.0	8.0	7.9	7.9	7.8	7.9
Aluminium Pouch	0	8.5	8.5	8.6	8.6	8.5	8.6
	15	8.4	8.4	8.42	8.42	8.4	8.5
	30	8.3	8.3	8.4	8.4	8.3	8.3

	45	8.2	8.2	8.3	8.3	8.2	8.2
	60	8.1	8.1	8.2	8.2	8.1	8.2
SE ±	-	0.033	0.033	0.042	0.042	0.036	0.034
CD @ 5%	-	0.117	0.117	0.146	0.146	0.125	0.119

The superior performance of aluminum packaging is attributed to its low permeability to moisture and oxygen, which reduces oxidative and microbial degradation (Sharma et al., 2019; Singh & Patel, 2020). In contrast, LDPE and HDPE, although commonly used, allow more gas and moisture exchange, leading to faster loss of texture and flavor (Kumar et al., 2021). The observed changes were statistically significant for texture and overall acceptability, as shown by the CD @ 5% values, highlighting the importance of choosing appropriate packaging for shelf-life extension. Therefore, aluminum pouches are recommended for prolonged storage, while LDPE and HDPE are suitable only for short-term preservation of millet crackers.

Fig. 5 Effects on Packaging Material & Storage on Sensory Qualities of Cracker

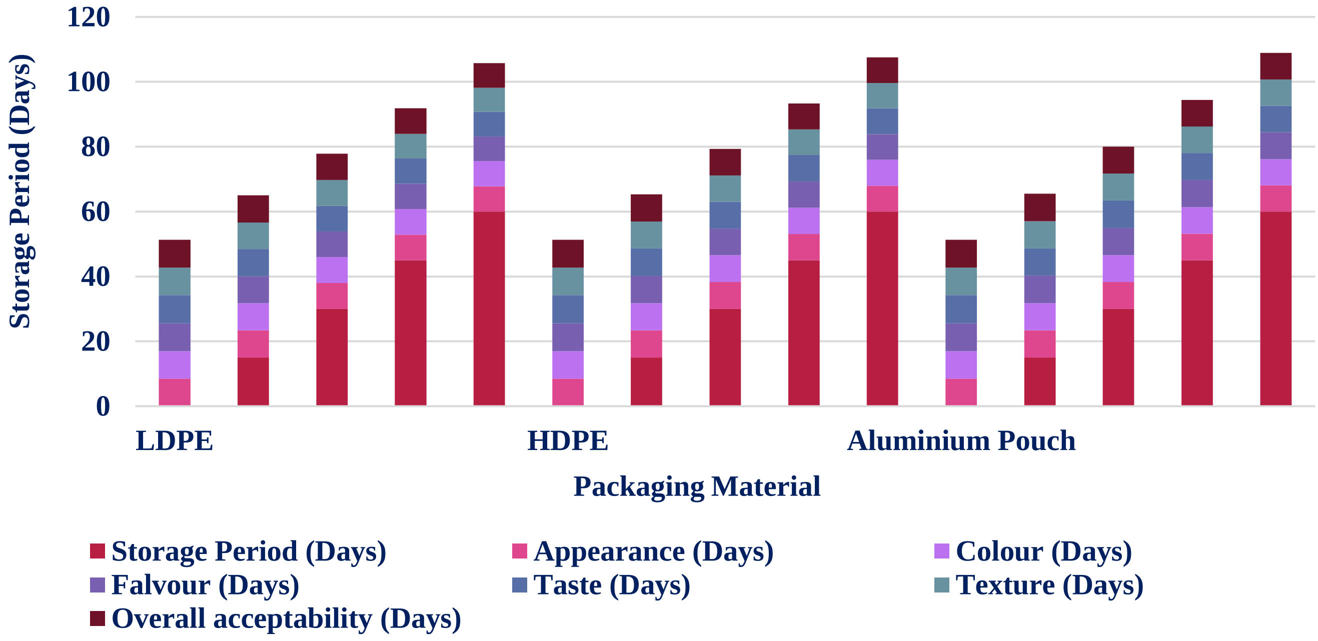


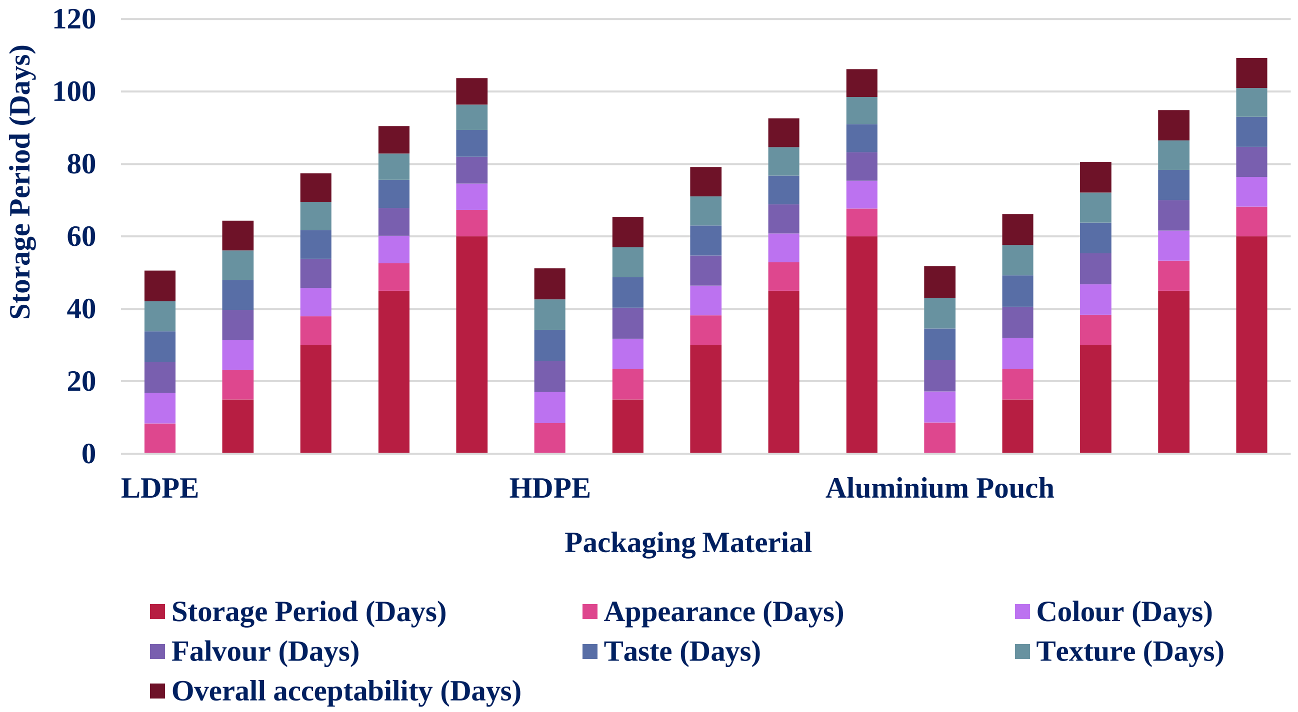
Table 5: Effects of Packaging Material and Storage on Sensory Qualities of Millet *Chakli*

Packaging Material	Storage Period (Days)	Appearance	Colour	Falvour	Taste	Texture	Overall acceptability
LDPE	0	8.4	8.4	8.5	8.5	8.3	8.5
	15	8.2	8.2	8.3	8.3	8.1	8.2
	30	7.9	7.9	8.0	8.0	7.7	7.9
	45	7.6	7.6	7.7	7.7	7.3	7.6
	60	7.3	7.3	7.4	7.4	7.0	7.3
HDPE	0	8.5	8.5	8.6	8.6	8.4	8.6
	15	8.4	8.4	8.5	8.5	8.2	8.4
	30	8.2	8.2	8.3	8.3	8.0	8.2
	45	7.9	7.9	8.0	8.0	7.8	8.0
	60	7.7	7.7	7.8	7.8	7.5	7.7

Aluminium Pouch	0	8.6	8.6	8.7	8.7	8.5	8.7
	15	8.5	8.5	8.6	8.6	8.4	8.6
	30	8.4	8.4	8.5	8.5	8.3	8.5
	45	8.3	8.3	8.4	8.4	8.1	8.4
	60	8.2	8.2	8.3	8.3	8.0	8.3
SE ±	-	0.031	0.031	0.038	0.038	0.035	0.034
CD @ 5%	-	0.115	0.115	0.140	1.140	1.128	0.122

The study examined the effects of packaging material and storage time on millet *chakli's* sensory properties in table 5. Initially, all packaging materials (LDPE, HDPE, and aluminum pouches) preserved high sensory scores, with aluminum pouches performing the best (overall acceptability 8.7). However, as storage time increased, all materials showed a decline in sensory qualities.

Fig. 6 Effects of Packaging Material & Storage on Sensory Qualities of *Chakli*



LDPE showed the most significant deterioration, dropping to 7.3 overall acceptability at 60 days, while HDPE fared slightly better with a score of 7.7. Aluminum pouches exhibited the least decline, with a final score of 8.3. This suggests that aluminum pouches are the most effective at maintaining sensory quality due to their superior barrier properties against moisture and oxygen, which reduce oxidative damage and maintain product integrity (Kumar et al., 2021; Sharma & Singh, 2022). In conclusion, aluminum pouches are the best choice for long-term storage, while

HDPE offers moderate protection and LDPE is less effective.

Table 6: Microbial Study of Millet cracker

Packaging Material	**Days**	**TPC (cfu/g × 10²)**	**TPC (cfu/g ×10²)**	**YMC (cfu/g ×10²)**	**YMC (cfu/g ×10²)**	**Coliform (cfu/g × 10²)**	**Coliform (cfu/g × 10²)**
		Control	**M Cracker**	**Control**	**M Cracker**	**Control**	**M Cracker**

LDPE	0	ND	ND	ND	ND	ND	ND
	15	1.2	1.3	ND	ND	ND	ND
	30	2.6	2.8	0.4	0.3	ND	ND
	45	4.2	4.5	0.8	0.6	ND	ND
	60	5.9	6.1	1.2	1.0	ND	ND
HDPE	0	ND	ND	ND	ND	ND	ND
	15	0.9	1.0	ND	ND	ND	ND
	30	2.1	2.3	0.3	0.2	ND	ND
	45	3.5	3.7	0.6	0.5	ND	ND
	60	4.8	5.0	0.9	0.7	ND	ND
Aluminium pouch	0	ND	ND	ND	ND	ND	ND
	15	0.6	0.7	ND	ND	ND	ND
	30	1.4	1.5	0.2	0.1	ND	ND
	45	2.6	2.7	0.5	0.4	ND	ND
	60	3.8	4.0	0.7	0.6	ND	ND

TPC- Total plate count, YMC-Yeat & mold count, M-cracker -Millet cracker

The results of table 6 demonstrated that the packaging material significantly influences the microbial stability and shelf life of millet crackers. At Day 0, no microbial contamination was detected in any of the packaging materials, indicating that the crackers were free from contamination at the time of production. However, as storage time progressed, microbial growth increased in all packaging types. LDPE packaging allowed the highest microbial growth, with TPC rising from 1.3 cfu/g × 10^2 at Day 15 to 6.1 cfu/g × 10^2 by Day 60. In contrast, HDPE packaging exhibited a slightly lower increase in TPC, with values reaching 5.0 cfu/g × 10^2 by Day 60. The best results were observed with aluminum pouch packaging, which showed the lowest microbial growth, with TPC increasing to 4.0 cfu/g × 10^2 at Day 60. Yeast and mold counts (YMC) followed a similar trend, with aluminum pouches again showing the best preservation. Throughout the storage period, coliform counts remained undetectable in all packaging materials, indicating the absence of fecal contamination. These findings are consistent with previous research by Choi et al. (2019) and Santos et al. (2021), which suggest that LDPE, with its lower barrier properties, allows greater microbial growth compared to HDPE and aluminum pouches. Aluminum pouches, known for their superior moisture, oxygen, and light barrier properties, were the most effective in limiting microbial growth, preserving the quality of the millet crackers over the 60-day storage period. This study highlights the crucial role of packaging material in extending shelf life and maintaining the microbial quality of food products.

Table 7: Microbial Study of Millet *Chakli*

Packaging Material	**Days**	**TPC (cfu/g × 10²)**	**TPC (cfu/g ×10²)**	**YMC (cfu/g ×10²)**	**YMC (cfu/g ×10²)**	**Coliform (cfu/g ×10²)**	**Coliform (cfu/g ×10²)**
LDPE		**Control**	**M *Chakli***	**Control**	**M *Chakli***	**Control**	**M *Chakli***
	0	ND	ND	ND	ND	ND	ND
	15	0.9	1.0	ND	ND	ND	ND
	30	1.8	2.0	ND	ND	ND	ND
	45	3.6	3.8	ND	ND	ND	ND
HDPE	60	5.2	5.4	ND	ND	ND	ND
	0	ND	ND	ND	ND	ND	ND
	15	0.8	0.9	ND	ND	ND	ND

	30	1.5	1.6	ND	ND	ND	ND
	45	3.1	3.2	ND	ND	ND	ND
Aluminium pouch	60	4.5	4.6	ND	ND	ND	ND
	0	ND	ND	ND	ND	ND	ND
	15	0.6	0.7	ND	ND	ND	ND
	30	1.1	1.2	ND	ND	ND	ND
	45	2.0	2.1	ND	ND	ND	ND
	60	3.3	3.4	ND	ND	ND	ND

TPC- Total plate count, YMC-Yeat & mold count, M-*chakli* -Millet *Chakli*

The microbial study of millet *chakli* examined (table 7) the impact of different packaging materials (LDPE, HDPE, and aluminum pouches) on microbial growth over 60 days. At Day 0, no microbial contamination was detected in any packaging material. Over time, microbial growth increased, with LDPE and HDPE showing similar increases in total plate count (TPC), reaching 5.2 cfu/g × 10^2 and 5.4 cfu/g × 10^2, respectively, by Day 60. Aluminum pouches exhibited the lowest TPC increase, reaching 3.4 cfu/g × 10^2.

Yeast and mold counts were undetectable throughout the storage period in all packaging materials. Coliform counts remained absent, indicating no fecal contamination. These results align with previous studies, suggesting that aluminum pouches, with superior barrier properties, are the most effective in preserving microbial quality compared to LDPE and HDPE (Choi et al., 2019; Santos et al., 2021).

Table 8: Technoeconomic feasibility of millet cracker and *chakli*

No.	roduct	aw Material Cost (Rs./kg)	rocessing Cost (20%) (Rs./kg)	otal Production Cost (Rs./kg)
	Iillet Cracker	13.00	2.78	56.98
	Iillet *Chakli*	76.60	5.32	11.92

Table 8 indicates that the production cost of millet cracker (₹256.98/kg) is higher than that of millet chakli (₹211.92/kg), primarily due to the cost of nutrient-rich raw materials such as barnyard millet, garlic, and ginger. Garlic alone contributed ₹4.8 per 15g in crackers and ₹6.4 per 20g in chakli, enhancing antioxidant and antimicrobial properties (Sinha et al., 2021; Gupta et al., 2019). Processing costs, estimated at 20% of raw material costs, reflect typical small-scale production inputs.

Though slightly cost-intensive, these functional foods demonstrate strong market potential, driven by consumer interest in high-fiber, gluten-free, and health-promoting snacks (Zhao et al., 2020). Cost efficiency may improve through scale-up and process optimization (Singh et al., 2022).

4. CONCLUSIONS

The study successfully developed millet-based functional food products enriched with garlic and ginger, specifically in the form of millet crackers and millet *chakli*. Sensory evaluations revealed that the inclusion of garlic and ginger did not negatively impact the products' sensory qualities, with formulations containing garlic and ginger receiving high acceptability scores. Among the treatments, millet crackers with garlic and ginger (T_3) and millet *chakli* (T_1) were the most preferred by the panel.

The shelf-life study showed that packaging material significantly affected the stability of the products. Aluminum pouches were the most effective in preserving sensory attributes and microbial stability, maintaining high product quality for up to 60 days. In contrast, LDPE packaging led to a faster decline in product quality. Microbial analysis confirmed that the products remained safe, with no contamination detected throughout the study period.

In conclusion, the study demonstrated that millet-based snacks enriched with garlic and ginger can be developed into functional foods with good sensory quality, nutritional benefits, and shelf stability, particularly when packaged in aluminum pouches. These products have the potential to provide a nutritious, shelf-stable snack option enriched with the health benefits of garlic and ginger, making them suitable for the health-conscious consumer.

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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 revision and guide for manuscript preparation. Dr. Bhagwan Vithalrao Asewar provided administrative and institutional support. All authors read and approved the final manuscript for submission.

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