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Microbiological, Sensory, and Economic Evaluation of Chicken Meatballs Incorporated with Tulsi and Giloy Extracts

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ABSTRACT

This study investigated the effects of incorporating Tulsi (Ocimum sanctum) and Giloy (Tinospora cordifolia) extracts on the microbiological quality, sensory attributes, shelf-life, and production cost of chicken meatballs. Extracts were added at levels of 0.25%, 0.50%, and 0.75%, and the samples were stored at 4 ± 1°C for 15 days. Total plate counts increased significantly ($P < 0.05$) during storage; however, the treated samples consistently exhibited lower microbial loads than the control. Yeast and mould growth was observed only on day 15, and it remained within acceptable limits. No coliforms were detected in any of the samples throughout the storage period. Sensory scores declined gradually over time; however, the treated samples remained organoleptically acceptable for up to 15 days. Economic analysis revealed a progressive increase in production cost with higher extract concentrations, in the following order: Control $< T_1 < G_1 < T_2 < G_2 < T_3 < G_3$. In conclusion, the incorporation of Tulsi and Giloy extracts, particularly at the 0.75% level, improved microbial safety, extended shelf-life, and maintained sensory quality, with only a modest increase in production cost.

Keywords: Chicken meatballs; Tulsi extract; Giloy extract; Microbiological quality; Sensory evaluation; Shelf-life; Economic analysis

INTRODUCTION

Poultry meat, particularly chicken, has become the most widely consumed meat globally due to its favourable nutritional profile, affordability, and absence of major cultural or religious restrictions (FAO 2021; OECD-FAO 2023). In India, the high cost of mutton and chevon, restrictions on beef and pork, and limited availability of fish have further contributed to the growing preference for chicken (ICAR-DPR 2022). Rich in high-quality protein, essential polyunsaturated fatty acids (notably omega-3), vitamins, and minerals, chicken meat is also relatively low in saturated fat and calories, making it a preferred choice among health-conscious consumers (WHO 2020; USDA 2022).

Among the diverse poultry-based products, chicken meatballs (locally known as meat kofta) are widely consumed as street food and fast-food items. These emulsion-based products are valued for their palatability, digestibility, and nutritional quality (Sun et al. 2021). However, like other meat products, chicken meatballs are prone to oxidative spoilage, which adversely affects their shelf life, safety, and sensory attributes.

Traditionally, synthetic antioxidants have been used to retard oxidative degradation in meat products. Increasing consumer awareness of potential health risks associated with synthetic additives has, however, stimulated interest in natural alternatives (Manessis et al. 2020). Plant-derived antioxidants, with their free radical scavenging activity and health-promoting properties, are gaining recognition as viable substitutes.

Tulsi (*Ocimum sanctum*) and Giloy (*Tinospora cordifolia*), both well-known in Ayurveda and traditional Indian medicine, possess promising antimicrobial and antioxidant properties. Tulsi is rich in polyphenols, flavonoids, and phenolic compounds such as eugenol, rosmarinic acid, and apigenin, which exhibit strong antioxidant and antimicrobial activity (Chaudhary et al. 2020). Giloy, a climbing shrub of the Menispermaceae family, contains bioactive compounds including alkaloids, glycosides, and diterpenoids, and has demonstrated significant antioxidant and antimicrobial potential (Bharathi et al. 2022). These attributes make both herbs suitable candidates for use as natural preservatives in meat products.

Despite extensive documentation of their bioactivity, the application of Tulsi and Giloy extracts in processed poultry products remains limited. This study therefore investigates the incorporation of Tulsi and Giloy extracts into chicken meatballs, with emphasis on their effects on microbiological stability, sensory characteristics, and economic feasibility. By integrating traditional herbal knowledge with modern food technology, the research aims to contribute to the development of safe, natural, and economically viable poultry products that align with contemporary consumer preferences.

MATERIALS AND METHODS

Raw material preparation

Fresh boneless chicken meat was trimmed of fat, tendons, and connective tissue, packed in LDPE pouches, and stored at 4 ± 1 °C until use. Condiment paste was prepared from onion, garlic, and ginger in a 3:2:1 ratio. Spices were cleaned, oven-dried (60 ± 1 °C for 3 h), ground, sieved, and stored in airtight containers.

Preparation of tulsi extract

Fresh Tulsi leaves (*Ocimum tenuiflorum*) were washed, shade-dried, powdered, and extracted by mixing 10 g of powder with 50 ml of boiled distilled water. The mixture was incubated in a water bath at 60 °C for 3 h, filtered through Whatman No. 1 paper, and used fresh for each replication (Devatkal et al. 2012).

Preparation of giloy extract

Fresh stems of Giloy (*Tinospora cordifolia*) were collected from the herbal garden, washed with distilled water, shade-dried, and cut into small pieces. The dried material was ground to a fine powder. Ten grams of powder was mixed with 50 ml of boiled distilled water and incubated at 60 °C for 3 h. The mixture was filtered through Whatman No. 1 paper to obtain a clear extract, which was freshly prepared for each replication to ensure consistency (Devatkal et al. 2012).

Preparation of chicken meatballs

Meatball emulsion was prepared following Kumar (2001) with slight modifications. Lean chicken meat was minced using a meat mincer (SANCO, Model SFP-56, 4 mm plate). Refined vegetable oil was gradually incorporated during chopping. Condiment paste, spice mix, salt, sodium nitrite (0.01%), STPP (0.35%), and refined wheat flour were added, and chopping continued until a homogeneous emulsion was obtained. Seven emulsions were prepared: Control (no extract), Tulsi treatments (0.25% T1, 0.50% T2, 0.75% T3), and Giloy treatments (0.25% G1, 0.50% G2, 0.75% G3). Meatballs (~20 g each) were manually shaped, deep-fat fried at 135 °C for 2–3 min, cooled, packed in LDPE pouches, and stored at 4 ± 1 °C.

Evaluation of microbiological, sensory, and economic attributes

Meatballs were stored at 4 ± 1 °C and evaluated at 0, 5, 10, and 15 days. Microbiological analyses included total plate count (TPC), coliform count, and yeast and mould count (APHA 1984), expressed as log CFU/g. Sensory quality was assessed using a 9-point hedonic scale (Peryam and Pilgrim 1957) by a semi-trained panel of five judges for appearance, flavour, juiciness, tenderness, and overall acceptability. Shelf life was considered exceeded when microbial load reached 7–8 log CFU/g (Jeremiah 2001) or when sensory deterioration (off-odour, sliminess, discoloration) was observed. Production cost was calculated based on meat, non-meat ingredients, and processing expenses. The experiment was replicated four times (n = 4), and data were analysed using ANOVA (Snedecor and Cochran 1989) with significance at $P < 0.05$.

RESULTS AND DISCUSSION

In this study, chicken meatballs were formulated with tulsi (*Ocimum sanctum*) [a1] and giloy (*Tinospora cordifolia*) extracts at varying concentrations and stored at 4 ± 1 °C for 15 days. Microbiological quality, sensory attributes, and production cost were evaluated at 5-day intervals.

Microbiological characteristics

Mean values of microbiological parameters are presented in Table 1.

Total plate count (TPC)

TPC values increased significantly ($P < 0.05$) with storage time in both control and treated samples. However, treated groups consistently showed lower counts than the control. The reduction in microbial load can be attributed to the antimicrobial activity of Tulsi and Giloy extracts, which extended product shelf life under refrigeration (Nikmaram et al. 2018). Alo et al. (2012) reported that compounds such as ursolic acid, apigenin, and luteolin in *O. sanctum* possess broad-spectrum antimicrobial activity. Similarly, Giloy [a1] treatments (G1, G2, G3) showed significantly lower TPC values than the control at all storage intervals, likely due to phenolic compounds and other bioactive constituents (Reddy and Reddy 2015; Mittal et al. 2014). Comparable reductions in TPC have been reported in chevon sausages with **Giloy** extract (Kalem et al. 2018), Tulsi-incorporated chicken nuggets (Tanwar et al. 2016), and **Tulsi**-based beef meatballs (Siddiqua et al. 2018).

Yeast and mould count

Yeast and mould were undetectable in both control and treated samples up to day 10. On day 15, control samples showed significantly ($P < 0.05$) higher counts compared to treated groups. The lower counts in **Tulsi**- and **Giloy**-treated samples may be attributed to the antifungal properties of these extracts (Mishra et al. 2014; Kumar et al. 2013). Suppression of yeast and mould growth during early storage could also be linked to adequate heat treatment during cooking. Similar findings have been reported in **Tulsi**-incorporated chicken nuggets (Tanwar et al. 2016), **Giloy**-treated chevon sausages (Kalem et al. 2018), and fermented bamboo shoot-based chicken nuggets (Das et al. 2013).

Coliform count

No coliforms were detected in any sample throughout the storage period. This absence is likely due to destruction of coliforms during cooking at >140 °C, well above their thermal death point of 57 °C. The results confirm that heat processing, hygienic handling, and proper packaging effectively controlled coliform growth. Similar findings of zero coliform counts have been reported in chicken sausages (Bhat et al. 2015), chicken nuggets (Tanwar et al. 2016), and chevon sausages (Kalem et al. 2018).

Table 1. Effect of incorporation of Tulsi and Giloy extracts on microbiological qualities (mean ± SE) of chicken meatballs stored at refrigeration temperature (4 ± 1 °C)

Days	C	T1	T2	T3	G1	G2	G3
Total Plate Count							
Day	$2.282^{Ad}\pm0.035$	$2.056^{BCd}\pm0.037$	$1.784^{Dd}\pm0.033$	$1.567^{Ed}\pm0.033$	$2.141^{Bd}\pm0.016$	$1.964^{Cd}\pm0.032$	$1.690^{Dd}\pm0.040$
5 Day	$2.922^{Ac}\pm0.039$	$2.564^{BCc}\pm0.064$	$2.306^{DEc}\pm0.095$	$2.056^{Fc}\pm0.035$	$2.649^{Bc}\pm0.018$	$2.395^{CDc}\pm0.015$	$2.223^{EFc}\pm0.100$
10 Day	$3.795^{Ab}\pm0.016$	$3.333^{Bb}\pm0.017$	$3.039^{Db}\pm0.036$	$2.750^{Fb}\pm0.072$	$3.414^{Bb}\pm0.014$	$3.149^{Cb}\pm0.016$	$2.906^{Eb}\pm0.012$
15 Day	$4.780^{Aa}\pm0.042$	$4.111^{BCa}\pm0.026$	$3.842^{Da}\pm0.033$	$3.659^{Ea}\pm0.041$	$4.205^{Ba}\pm0.017$	$4.020^{Ca}\pm0.041$	$3.839^{Da}\pm0.023$
Yeast and Mould Count							
Day	ND	ND	ND	ND	ND	ND	ND
5 Day	ND	ND	ND	ND	ND	ND	ND
10 Day	ND	ND	ND	ND	ND	ND	ND
15 Day	$2.002^{A}\pm0.007$	$1.737^{C}\pm0.016$	$1.581^{DE}\pm0.022$	$1.415^{F}\pm0.031$	$1.837^{B}\pm0.054$	$1.645^{D}\pm0.011$	$1.500^{EF}\pm0.037$
Coliform Count							
Day	ND	ND	ND	ND	ND	ND	ND
5 Day	ND	ND	ND	ND	ND	ND	ND
10 Day	ND	ND	ND	ND	ND	ND	ND
15 Day	ND	ND	ND	ND	ND	ND	ND

Means in a row bearing a common superscript capital letter do not differ significantly ($P < 0.05$).

Means in a column bearing a common superscript small letter do not differ significantly ($P < 0.05$).

n = 4 for each treatment. C: Control (without Tulsi and Giloy extract), T1: 0.25% Tulsi extract, T2: 0.50% Tulsi extract, T3: 0.75% Tulsi extract, G1: 0.25% Giloy extract, G2: 0.50% Giloy extract, G3: 0.75% Giloy extract

Sensory evaluation

Mean sensory scores for control and treatment groups are presented in Table 2.

Appearance: Scores declined significantly ($P < 0.05$) with storage in both control and treated samples. This reduction may be attributed to pigment and lipid oxidation, leading to non-enzymatic browning. Comparable decreases have been reported in chicken nuggets (Tanwar et al. 2016) and chicken sausages (Bhat et al. 2015).

Flavour: Control samples generally retained significantly ($P < 0.05$) higher flavour scores compared to treated groups, except T1. Higher concentrations of Giloy (G2, G3) imparted slight bitterness, resulting in lower scores. Flavour scores declined progressively across all groups with storage, consistent with increased TBARS values under aerobic conditions (Tarladgis et al. 1960). Similar declines have been reported in clove oil-incorporated chicken sausages (Sharma et al. 2017) and olive leaf extract-treated mutton meatballs (Rubel et al. 2020).

Juiciness: Juiciness scores decreased significantly ($P < 0.05$) with storage, except for T1, which remained comparable to control on day 15. The decline is likely due to gradual moisture loss. Similar trends have been observed in Tulsi-incorporated chicken nuggets (Tanwar et al. 2016), Giloy-treated chevon sausages (Kalem et al. 2018), and clove oil-treated chicken nuggets (Para et al. 2017).

Tenderness: Tenderness scores declined with storage, though differences were generally non-significant ($P > 0.05$), except for T1 and G3, which showed significant ($P < 0.05$) reductions. Loss of moisture, fat breakdown, and microbial activity may have contributed to textural hardening (Jay, 1996). Similar declines have been reported in Giloy-treated chevon sausages (Kalem et al. 2018), cabbage powder-incorporated mutton patties (Malav et al. 2015), chicken patties (Jamwal et al. 2015), and chicken sausages (Zargar et al. 2014). Tulsi-incorporated chicken nuggets showed comparable tenderness to controls (Tanwar et al. 2016).

Table 2. Effect of incorporation of Tulsi and Giloy extracts on sensory scores (Mean ± SE) of chicken meatballs stored at refrigeration temperature (4 ± 1 °C)

Treatment	C	T1	T2	T3	G1	G2	G3

Appearance							
0 Day	$8.500^{Aa}\pm0.118$	$8.208^{Ba}\pm0.080$	$7.917^{Ca}\pm0.160$	$7.375^{Da}\pm0.105$	$8.333^{ABa}\pm0.096$	$8.167^{Ba}\pm0.068$	$^{Ca}7.750\pm0.108$
5 Day	$8.292^{Aab}\pm0.125$	$7.958^{Bb}\pm0.080$	$7.667^{Cab}\pm0.068$	$7.125^{Eab}\pm0.125$	$8.083^{Bab}\pm0.068$	$^{BCb}7.792\pm0.042$	$^{Db}7.458\pm0.042$
10 Day	$8.042^{Ab}\pm0.042$	$7.750^{Bb}\pm0.108$	$7.33^{Cb}3\pm0.068$	$6.792^{Db}\pm0.105$	$7.875^{ABb}\pm0.080$	$^{Cc}7.417\pm0.144$	$^{Dc}7.042\pm0.080$
15 Day	$7.667^{Ac}\pm0.068$	$7.333^{Bc}\pm0.068$	$6.792^{CDc}\pm0.125$	$6.334^{Ec}\pm0.096$	$7.417^{Bc}\pm0.160$	$^{Cd}6.958\pm0.125$	$^{Dd}6.667\pm0.068$
Flavour							
0 Day	$8.583^{Aa}\pm0.160$	$8.417^{ABa}\pm0.048$	$8.208^{BCa}\pm0.142$	$7.958^{CD}\pm0.080$	$8.209^{BCa}\pm0.158$	$7.708^{Da}\pm0.142$	$7.125^{Ea}\pm0.142$
5 Day	$8.292^{Aab}\pm0.172$	$8.083^{Ab}\pm0.048$	$7.750^{Bb}\pm0.048$	$7.583^{B}\pm0.048$	$8.042^{Aa}\pm0.080$	$7.667^{Ba}\pm0.118$	$7.042^{Ca}\pm0.105$
10 Day	$8.000^{Abc}\pm0.118$	$7.875^{ABc}\pm0.080$	$7.583^{Bb}\pm0.048$	$7.250^{C}\pm0.220$	$7.750^{ABab}\pm0.083$	$7.167^{Cb}\pm0.068$	$6.667^{Db}\pm0.068$
15 Day	$7.667^{Ac}\pm0.068$	$7.333^{ABd}\pm0.068$	$6.958^{CDc}\pm0.125$	$6.750^{D}\pm0.108$	$7.250^{BCb}\pm0.210$	$6.792^{Db}\pm0.142$	$6.375^{Eb}\pm0.080$
Juiciness							
0 Day	$8.542^{Aa}\pm0.080$	$8.458^{Aa}\pm0.105$	$8.292^{ABa}\pm0.142$	$8.083^{BCa}\pm0.083$	$8.292^{ABa}\pm0.080$	$8.042^{BCa}\pm0.080$	$7.833^{Ca}\pm0.118$
5 Day	$8.167^{Aab}\pm0.152$	$8.042^{ABb}\pm0.042$	$7.875^{BCb}\pm0.125$	$7.583^{DEb}\pm0.160$	$7.917^{ABab}\pm0.108$	$7.708^{CDab}\pm0.080$	$7.375^{Eb}\pm0.080$
10 Day	$7.875^{Abc}\pm0.125$	$7.667^{ABc}\pm0.118$	$7.542^{ABbc}\pm0.080$	$7.167^{CDc}\pm0.152$	$7.750^{ABb}\pm0.083$	$7.417^{BCb}\pm0.160$	$7.042^{Dc}\pm0.105$
15 Day	$7.667^{Ac}\pm0.068$	$7.417^{ABc}\pm0.048$	$7.167^{BCc}\pm0.068$	$6.875^{CDd}\pm0.080$	$7.292^{Bc}\pm0.185$	$6.958^{CDc}\pm0.142$	$6.792^{Dc}\pm0.080$
Tenderness							
0 Day	8.250a±0.048	8.209a ±0.125	8.083a±0.144	7.958a±0.142	8.167a±0.118	8.000a±0.068	7.875a±0.080
5 Day	7.958ab±0.080	7.917b±0.048	7.833ab±0.068	7.750ab±0.108	7.875b±0.105	7.792ab±0.042	7.667b±0.068
10 Day	7.708bc±0.080	7.667c±0.096	7.583bc±0.108	7.458±0.080bc	7.625±0.080bc	7.500bc±0.068	7.375c ±0.080
15 Day	7.417c±0.144	7.375d±0.080	7.292c±0.125	7.250±0.108c	7.375c±0.080	7.292c±0.184	7.167d ±0.068
Overall Acceptability							
0 Day	$8.333^{Aa}\pm0.068$	$8.208^{ABa}\pm0.105$	$8.167^{ABa}\pm0.118$	$8.042^{BCa}\pm0.080$	$8.125^{ABa}\pm0.042$	$7.917^{CDa}\pm0.083$	$7.750^{Da}\pm0.108$
5 Day	$8.125^{Ab}\pm0.042$	$8.042^{ABab}\pm0.080$	$7.958^{ABab}\pm0.080$	$7.750^{BCb}\pm0.083$	$7.875^{BCab}\pm0.105$	$7.625^{Bab}\pm0.080$	$7.458^{Cab}\pm0.142$
10 Day	$7.792^{Ac}\pm0.048$	$7.750^{Ab}\pm0.042$	$7.667^{ABbc}\pm0.068$	$7.500^{Dbc}\pm0.068$	$7.583^{ABbc}\pm0.083$	$7.417^{CDb}\pm0.108$	$7.250^{Db}\pm0.083$
15 Day	$7.417^{Ad}\pm0.042$	$7.458^{Ac}\pm0.080$	$7.375^{Ac}\pm0.080$	$7.333^{Ac}\pm0.068$	$7.375^{Ac}\pm0.125$	$7.250^{ABc}\pm0.048$	$7.125^{Bb}\pm0.068$

Means in a row bearing a common superscript capital letter do not differ significantly (P < 0.05).

Means in a column bearing a common superscript small letter do not differ significantly (P < 0.05).

n = 4 for each treatment. C: Control (without Tulsi and Giloy extract), T1: 0.25% Tulsi extract, T2: 0.50% Tulsi extract, T3: 0.75% Tulsi extract, G1: 0.25% Giloy extract, G2: 0.50% Giloy extract, G3: 0.75% Giloy extract

Overall acceptability: Scores ranged from desirable to slightly desirable throughout storage. Declines reflected reductions in appearance, flavour, juiciness, and tenderness. Differences were generally non-significant, except for G3 on day 15, which scored lower than control. Similar decreasing trends have been reported in Tulsi-treated chicken sausages (Bhat et al. 2015), Giloy-incorporated chevon sausages (Kalem et al. 2018), and other herbal-treated meat products (Tanwar et al. 2016; Habib et al. 2018; Zargar et al. 2014).

Shelf life study

Sensory scores for all parameters declined progressively with storage; however, all products remained acceptable up to 15 days under refrigeration (4 ± 1 °C). Chicken meatballs containing 0.75% Tulsi extract and 0.50% Giloy extract were particularly well appreciated in sensory evaluation. Based on microbiological analysis, incorporation of 0.75% extract was identified as the most satisfactory level compared to other treatments. Microbial loads of all products remained below threshold values throughout the 15-day storage period, and no physical signs of spoilage such as sliminess, off-odour, or discoloration were observed in any treatment group.

Cost of production

The cost of production of chicken meatballs prepared with Tulsi and Giloy extracts is presented in Table 3. The estimated costs (₹ per kg) for control, T1, T2, T3, G1, G2, and G3 groups were 308, 318, 328, 337, 319, 330, and 341, respectively. All treated groups showed higher production costs compared to the control, with T1 being the least expensive among treatments.

The overall trend in production cost was: Control < T1 < G1 < T2 < G2 < T3 < G3. The increased costs in treated groups were primarily due to the inclusion of Tulsi and Giloy extracts and the additional processing required for extract preparation. However, the rise in cost was modest (3–10%) and proportionate to the level of extract incorporation. Importantly, this additional cost is justified by the improved microbial safety, extended shelf-life, and better

Table 3. Approximate cost of production of chicken meatballs incorporated with different levels of Tulsi and Giloy extracts

Particulars	Market Price (₹/Kg)	Cost of the Product													
		C		T1		T2		T3		G1		G2		G3	
		Quantity (g)	Cost (₹)	Quantity (g)	Cost (₹)	Quantity (g)	Cost (₹)	Quantity (g)	Cost (₹)	Quantity (g)	Cost (₹)	Quantity (g)	Cost (₹)	Quantity (g)	Cost (₹)
Boneless chicken meat	340	700	238	700	238	700	238	700	238	700	238	700	238	700	238
Ice flakes	10	100	1	100	1	100	1	100	1	100	1	100	1	100	1
Vegetable oil	160	90	14.40	90	14.40	90	14.40	90	14.40	90	14.40	90	14.40	90	14.40
Refined wheat flour	40	36.5	1.46	36.5	1.46	36.5	1.46	36.5	1.46	36.5	1.46	36.5	1.46	36.5	1.46
Condiment mix	50	35	1.75	35	1.75	35	1.75	35	1.75	35	1.75	35	1.75	35	1.75
Spice mix	780	20	15.60	20	15.60	20	15.60	20	15.60	20	15.60	20	15.60	20	15.60
Salt	18	15	0.27	15	0.27	15	0.27	15	0.27	15	0.27	15	0.27	15	0.27
STPP	468	3.4	1.59	3.4	1.59	3.4	1.59	3.4	1.59	3.4	1.59	3.4	1.59	3.4	1.59
Sodium nitrite	730	0.1	0.07	0.1	0.07	0.1	0.07	0.1	0.07	0.1	0.07	0.1	0.07	0.1	0.07
Tulsi Extract	320	-	-	25	8	50	16	75	24	-	-	-	-	-	-
Giloy Extract	360	-	-	-	-	-	-	-	-	25	9	50	18	75	27
Processing cost	-	-	20	-	20	-	20	-	20	-	20	-	20	-	20
Product Yield (g)	-	954.6	-	951.0	-	946.4	-	943.1	-	950.4	-	946.0	-	942.8	-
Cost of the prepared product (₹)	-	-	294.14	-	302.14	-	310.14	-	318.14	-	303.14	-	312.14	-	321.14
Cost of the product (₹/Kg)	-	-	308	-	318	-	328	-	337	-	319		330		341

sensory acceptability observed in treated samples. Thus, the incorporation of Tulsi and Giloy extracts, particularly at higher concentrations, can be considered economically viable for commercial application, as the benefits outweigh the marginal increase in production cost.

CONCLUSION

Chicken meatballs incorporated with Tulsi (*Ocimum sanctum*) and Giloy (*Tinospora cordifolia*) extracts exhibited improved microbial safety, acceptable sensory quality, and extended shelf life under refrigerated storage (4 ± 1 °C). Treated samples remained safe and organoleptically acceptable for 15 days, with 0.75% Tulsi and 0.50% Giloy ensuring good sensory acceptability, while 0.75% of both extracts provided optimal microbial safety. Although production costs increased modestly due to extract incorporation, the benefits in safety, shelf life, and quality justify the expense, making these formulations economically viable for commercial application.

COMPETING INTERESTS

The authors do not have any competing interests among themselves or others related to this research work.

ETHICS STATEMENT

Not applicable

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