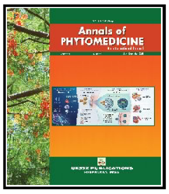
Annals of Phytomedicine 14(2): 542-551, 2025

DOI: http://dx.doi.org/10.54085/ap.2025.14.2.53

Annals of Phytomedicine: An International Journal
http://www.ukaazpublications.com/publications/index.php

Print ISSN : 2278-9839 Online ISSN : 2393-9885



Original Article : Open Access

Development and optimization of millet processing waste incorporated groundnut chikki as a functional and sustainable snack

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Article Info

Article history
Received 22 September 2025
Revised 25 October 2025
Accepted 26 October 2025
Published Online 30 December 2025

Keywords
Millet processing waste
Functional foods
Nutritional enrichment
Antioxidant properties
Sustainable food production
Value added snacks

Abstract

The present study developed and optimized a nutrient enriched groundnut chikki by incorporating millet processing waste derived from kodo (*Paspalum scrobiculatum* L.), barnyard (*Echinochloa frumentacea* Roxb.) and foxtail (*Setaria italica* L.) millets using response surface methodology (RSM). Three independent variables like millet processing waste, groundnut and jaggery were optimized to evaluate their effects on protein, fibre, hardness and overall acceptability. The optimized formulation (30 g millet waste, 70 g groundnut and 60 g jaggery) exhibited significantly higher protein (20.88 g/100 g), dietary fibre (2.31 g/100 g), calcium (93 mg/100 g), iron (2.11 mg/100 g) and total phenolic content (115.24 mg GAE/100 g) compared to the control. The enriched product demonstrated superior antioxidant potential while maintaining desirable textural hardness (43.85 N) and high sensory acceptability score (8.4). Incorporation of millet processing residues markedly improved the nutritional and functional quality of chikki without compromising palatability. The valorization of nutrient rich millet by-products supports functional food development, promotes sustainable food production and contributes to waste reduction. Hence, millet waste incorporated chikki represents a cost effective, eco-friendly and nutritionally superior alternative to conventional snacks. The aim of the study was to enhance the nutritional, functional and antioxidant properties of traditional groundnut chikki while promoting the sustainable utilization of millet processing waste.

1. Introduction

Minor millets are a group of small seeded cereals that include kodo millet (*P. scrobiculatum*), barnyard millet (*E. frumentacea*) and foxtail millet (*S. italica*). According to the Ministry of Agriculture and Farmers Welfare (2023), minor millets in India are mainly cultivated in States such as Karnataka, Tamil Nadu, Andhra Pradesh and Madhya Pradesh. These crops collectively produce around 2 to 3 million tonnes annually, accounting for nearly 10 percentage of the country's total millet production. Small millets have garnered increasing attention as nutrient dense, climate resilient crops with significant potential for sustainable agriculture. Their rich composition of dietary fiber, essential amino acids and micronutrients, along with bioactive compounds such as phenolics and flavonoids, imparts antioxidant and metabolic health benefits (Polisetty *et al.,* 2025; Devadarshini *et al.,* 2025).

Kodo millet is nutritionally superior among cereals, being rich in protein, dietary fibre, minerals, polyphenols and essential amino acids. It provides approximately 353 kcal per 100 g of grain and contains 8.3% of protein, 66.6% of carbohydrate, 1.4% of fat, 2.4% of minerals, 2% of ash, and 9% of crude fibre significantly higher than wheat. The protein fraction is primarily glutelin and includes essential amino acids such as lysine, threonine, valine and sulphur containing amino acids, though it is deficient in tryptophan (Chandel *et al.,* 2014). Kodo millet is also rich in micronutrients, particularly calcium, magnesium, potassium, zinc and iron (25.86 to 39.60 ppm) and contains B-complex vitamins such as B_3, B_6 and folic acid. Its magnesium content aids in reducing migraine and cardiac risks, while phosphorus plays a vital role in energy metabolism (Mishra and Satheesh, 2024). Chandrasekara and Shahidi (2011) reported that phytochemical analysis of kodo millet revealed the presence of both soluble and bound phenolics, quantified as 32.39 ± 0.93 µmol FAE/g and 81.64 ± 0.15 µmol FAE/g, respectively. Major phenolic acids include gallic, protocatechuic, caffeic, ferulic and para-coumaric acids, alongside diverse flavonoids such as catechin, quercetin, luteolin, apigenin and vitexin which exhibit potent antioxidant, anti-inflammatory and anticancer properties (Nithiyanantham, 2019). Chethan and Malleshi (2007) reported that kodo millet possesses one of the highest dietary fiber contents among cereals (37 to 38 %), attributed to its seed coat, which is rich in pectin, cellulose and hemicelluloses. These components are known to positively influence glucose absorption and cholesterol metabolism. Furthermore, kodo millet demonstrates potent free radical scavenging activity (DPPH), exceeding that of sorghum and finger millet, which may help mitigate oxidative stress and support glucose homeostasis in type 2 diabetes

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(Hegde and Chandra, 2005). Its gluten free nature, high digestibility, and rich content of polyunsaturated fatty acids position kodo millet as a functional food with notable nutraceutical potential (Ranjan *et al.,* 2023).

Saleh *et al.* (2013) reported that barnyard millet underutilized minor millet, is highly nutritious and recognized for its balanced nutrient composition and rich nutraceutical profile. It contains 65.5 to 68.8 g /100 g of carbohydrates, 10.4 to 11.5 g/100 g of protein, 3.5 to 4.3 g/ 100 g of fat, 4.5 to 7.2 g/100 g of dietary fiber and providing 320 to 350 kcal of energy. These characteristics make barnyard millet an excellent source of complex carbohydrates and plant-based protein. It is rich in minerals such as iron 4.0 to 5.0 mg/100 g, calcium 16 to 20 mg/100 g, phosphorus 280 to 300 mg/100 g, magnesium 130 to 140 mg/100 g and zinc 2.1 to 2.8 mg/100 g and its amino acid profile is notable, with leucine 6.2 mg/100 g, isoleucine 3.1 mg/100 g, lysine 2.4 mg/100 g and methionine 1.2 mg/100 g contributing to good protein quality (Arya and Bisht, 2022). From a nutraceutical perspective, barnyard millet is rich in total phenolics 120 to 145 mg GAE/100 g, flavonoids 35 to 50 mg CE/100 g and tannins 0.3 to 0.5% (Chandrasekara and Shahidi, 2011; Hegde *et al.,* 2005). It has a low glycemic index 41 to 50 making it beneficial for diabetic and obese individuals (Ugare *et al.,* 2014). Its high dietary fiber, resistant starch and bioactive phytochemicals support slow glucose release, regulate lipid metabolism and promote gut health. Moreover, polyphenols and flavonoids in barnyard millet display anti-diabetic, anti-inflammatory and antioxidant properties, which help prevent metabolic disorders such as type 2 diabetes and cardiovascular diseases (Singh *et al.,* 2022).

Kalsi and Bhasin (2023) reported that foxtail millet contains 60.9 to 72.6 g/100 g of carbohydrates, 10.3 to 12.3 g/100 g of protein, 3.5 to 4.3 g/100 g of fat and 7.0 to 8.0 g/100 g of dietary fiber. It is also a good source of essential amino acids, including leucine 5.5 to 6.1 mg/ 100 g, isoleucine 2.8 to 3.2 mg/100 g and methionine 1.3 to 1.6 mg/ 100 g. Mineral composition analysis indicates iron 2.8 to 5.5 mg/100 g, calcium 17 to 31 mg/100 g, phosphorus 290 to 320 mg/100 g, magnesium 130 to 140 mg/100 g and zinc 2.3 to 3.1 mg/100 g highlighting its micronutrient richness. The grain is also a significant reservoir of phenolic compounds 105 to 130 mg GAE/100 g, flavonoids 30 to 45 mg CE/100 g and tannins 0.3 to 0.5%, which exhibit strong antioxidant activity DPPH radical scavenging 65 to 80% (Chandrasekara and Shahidi, 2011). Foxtail millet has a glycemic index ranging from 50 to 59 making it a low GI food beneficial for glycemic control (Hegde *et al.,* 2005). Its rich dietary fiber and resistant starch enhance satiety and gut health, while polyphenols and flavonoids contribute to antidiabetic, antioxidant and cardio protective effects (Awasthi *et al.,* 2025). These nutritional and nutraceutical attributes position foxtail millet as a functional food for managing lifestyle related disorders.

Processing of millets including dehulling, polishing, flaking, milling and sieving generates significant amount of by-products such as bran, husk, broken grains and flake residues. These wastes are typically underutilized, despite being rich in dietary fiber, proteins, minerals and bioactive compounds with health promoting properties. Millet processing waste obtained during polishing of kodo, barnyard and foxtail millets is nutritionally rich and offers significant nutraceutical potential. The bran layer is typically discarded as waste, contains higher amounts of protein (11 to 15%), dietary fiber (12 to 20%), fat (4 to 6%) and minerals compared to polished grains. Kodo millet waste is especially high in crude fiber 17.2 g/100 g and total polyphenols 215 to 280 mg GAE/100 g, contributing to its strong antioxidant activity. Barnyard millet processing waste retains 10.8 to 12.5% protein, 15 to 18% dietary fiber, 4.2 to 5.1% fat and phenolic content of 185 to 240 mg GAE/100 g, with flavonoids ranging from 45 to 60 mg CE/100 g, reflecting its potential as a functional ingredient with antioxidant and anti-diabetic properties. Similarly, foxtail millet waste exhibits 11 to 14% protein, 13 to 16% dietary fibre, 4 to 5% fat and phenolic compounds in the range of 190 to 230 mg GAE/100 g, along with significant levels of flavonoids 40 to 55 mg CE/100. The presence of bioactive compounds such as polyphenols, flavonoids, phytosterols and resistant starch enhances the antioxidant, anti-inflammatory and hypoglycemic properties of these by-products. Nutritionally, these fractions are also rich in minerals like iron 4 to 8 mg/100 g, calcium 20 to 35 mg/100 g, magnesium 130 to 160 mg/100 g and phosphorus 300 to 360 mg/100 g, making them valuable sources for food fortification. Thus, the processing waste of kodo, barnyard and foxtail millets are not mere by-products but represents the functional raw materials with significant potential for use in health foods, nutraceutical formulations and dietary fiber enrichment (Barbhai, 2020).

Groundnut chikki is a traditional Indian sweet confection prepared from roasted groundnuts (*Arachis hypogaea* L.) and jaggery is widely consumed for its nutty flavor, crunchy texture and long shelf life (Pallavi *et al.,* 2014). Incorporating millet processing waste into chikki offers an innovative strategy to valorised nutrient and bioactive rich agro industrial by-products generated during flaking of kodo, barnyard and foxtail millets. Residues such broken and unflaked grains are rich in dietary fiber, proteins, essential minerals and bioactive compounds including phenolics, flavonoids, tannins and phytosterols, which provide antioxidant, antidiabetic, cardioprotective and anti-inflammatory benefits. The inclusion of these residues enhances the nutritional and functional profile of chikki, while jaggery contributes natural sweetness along with minerals and antioxidants.

This approach produces a functional, cost effective and consumer friendly snack that aligns with modern trends in health promoting and sustainable foods. Millet enriched chikki not only supports glycemic control, cardiovascular health and gut health but also contributes to the sustainable utilization of agro industrial by products, minimizing waste. By converting underutilized millet processing residues into value added food products, this strategy demonstrates the dual advantage of promoting functional food development and advancing nutraceutical applications, thereby providing a promising avenue for the production of nutrient dense and health beneficial snacks.

2. Materials and Methods

2.1 Plant material authentication

This research was carried out at the Department of Food Science and Nutrition, Community Science College and Research Institute, Tamil Nadu Agricultural University (TNAU), Madurai. Grains of kodo millet (*P. scrobiculatum*) variety CO_3, barnyard millet (*E. frumentacea*) variety MDU 1 and foxtail millet (*S. italica*) variety CO_7 were procured from the Department of Millets, TNAU, Coimbatore, Tamil Nadu, India. Kodo millet CO_3 is a TNAU released selection, originally derived from the Georgia type and maintained by the Department of Millets, TNAU. Barnyard millet MDU 1 is a pure line selection identified from the Aruppukottai region and released by TNAU. Foxtail millet CO_7 is a high yielding, short duration variety developed and released by TNAU through pure line selection. All chemicals used in the study were of analytical grade.

2.2 Preparation of millet processing waste incorporated chikki

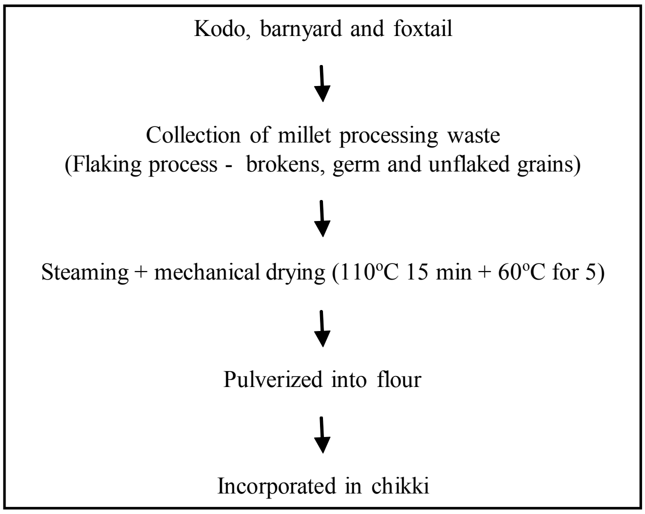

Figure 1: Flowchart for preparation of millet processing waste into flour.

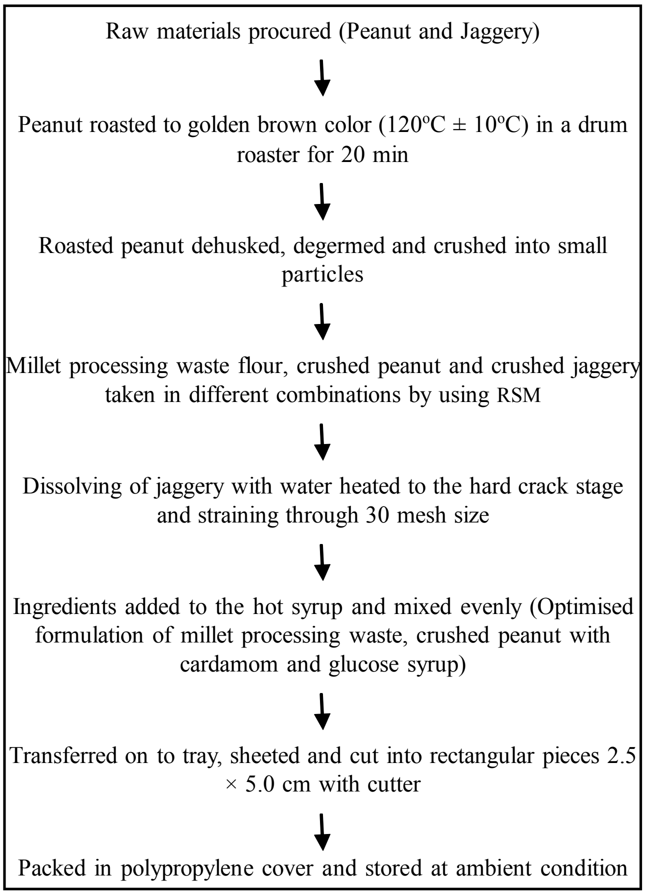

Figure 2: Flowchart for preparation of millet processing waste incorporated chikki.

Figure 1 outline the systematic process for preparing millet processing waste into flour. It emphasizes a sustainable strategy for byproduct valorization. Flaking kodo, barnyard and foxtail millets produces substantial processing residues mainly brokens, germ and unflaked grains. These fractions, often discarded or used for low value purposes are nutritionally dense and have considerable value addition potential. In this study, collected waste was steamed at 110^{0}C for 15 min and then mechanically dried at 60^{0}C for 5 h. This treatment reduces antinutritional factors, improves product stability and functional quality. The dried material was pulverized into fine flour and incorporated into traditional snacks such as chikki.

Figure 2 shows the preparation of millet processing waste incorporated chikki emphasizing the use of underutilized byproducts in traditional snacks. The process starts by roasting peanuts at 120 ± 10^{0}C for 20 min to enhance flavor, improve crispness and reduce moisture, extending shelf-life. The roasted peanuts are dehusked, degermed and crushed for uniform mixing. Jaggery syrup heated to the hard crack stage and strained its acts as a binding medium. Millet processing waste, crushed peanuts, jaggery, cardamom powder (2 g) and liquid glucose (3 g) are blended in varying proportions using response surface methodology (RSM) to optimize the formulation. The mixture is sheeted, cut into rectangles and packed in polypropylene covers to preserve quality during ambient storage (Figure 3).

Control

Incorporated chikki

Figure 3: Millet processing waste incorporated chikki.

2.3 Physiochemical properties of incorporated chikki

The proximate analysis of the millet processing waste incorporated chikki determined the moisture content by using the hot air oven drying method following the AOAC (1995) protocol; protein was analyzed by the Kjeldahl method (AOAC, 2005); fat content was estimated according to the method given by Carpenter (2010); carbohydrate content was assessed using the procedure described by Kurzyna Szklarek *et al.* (2022); crude fiber was analyzed according to Sadasivam and Manickam (1996), the mineral content, *viz.,* calcium and iron were analyzed using atomic absorption spectrometry (AAS). The method gives a good precision and accuracy (Da Col *et al.,* 2009). The hardness (N) was analyzed the texture analyzer (TA. XT Plus), the test speed of 60 mm/min and a maximum force of 100 N with the aid of probe (Fakirrao, 2021). Total phenol content was estimated by the procedure described by Sadasivam and Manickam (2008) and overall acceptability was determined by 9 point Hedonic rating by semi-trained panel members.

2.4 Statistical analysis

Statistical analysis was conducted using by Design Expert (Version 14.0) software. The data were evaluated for significant differences ($p<0.05$) through one way ANOVA with Least significant differences testing.

2.4.1 Experimental design in design expert

The experimental design for the development of chikki incorporated with millet processing waste was formulated using a face centered central composite design (FCCCD) under response surface methodology (RSM). Three independent variables like millet processing waste, groundnut and jaggery were selected to evaluate their effects on the dependent variables namely protein content, fibre content, hardness and overall acceptability of the chikki. The FCCCD comprised 20 experimental trials, as presented in Table 1, with formulation ranges determined through preliminary trials. Each experimental run was performed in triplicate and the response values were expressed as mean values of these replications. The combined influence of the three independent variables on the response parameters was analyzed using a second order polynomial (quadratic) model, expressed by Equation (1). Analysis of variance (ANOVA) was applied to estimate the linear, interaction and quadratic effects of the process parameters, with the level of significance set at $p<0.02$ (Table 2).

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{11} X_1X_1 + \beta_{22} X_2X_2 + \beta_{33} X_3X_3 + \beta_{12} X_1X_2 + \beta_{13} X_1X_3 + \beta_{23} X_2X_3 \ldots (1)$$

In this model, Y denotes the response variables corresponding to protein, fibre, hardness and overall acceptability of the millet waste incorporated chikki, with β_0 representing the intercept (constant). The coefficients β_1, β_2, and β_3 correspond to the linear regression coefficients, while β_{11}, β_{22}, and β_{33} represent the quadratic coefficients. The interaction coefficients are denoted by β_{12}, β_{13} and β_{23}. The relationships between the independent and dependent variables were further illustrated using three dimensional surface plots, which depicted the interaction effects of the variables on each response. Model adequacy was assessed through R^2, adjusted R^2, predicted R^2 and p-values. The coefficient of determination (R^2) indicates the proportion of variance explained by the model, where higher R^2 values signify a stronger model fit and better prediction accuracy.

2.4.2 Optimization of process parameters

The numerical optimization technique was employed to minimize experimental trials and effort in evaluating the multifactorial and multi response process. This method integrates multiple response variables into a single desirability function, ranging from 0 (completely undesirable) to 1 (fully desirable). The independent variables were adjusted to obtain the optimal formulation, while the dependent responses of protein, fiber, hardness and overall acceptability were optimized simultaneously. The most suitable combination of formulation variables was determined through statistical analysis, yielding the highest overall desirability value that represented the optimized chikki formulation.

3. Results

3.1 Influence of millet processing waste incorporation on the nutritional and sensory attributes of chikki

The variation in proportions of millet processing waste, groundnut and jaggery exerted a marked influence on the nutritional and sensory characteristics of chikki (Table 1). The protein content ranged from 18.18 to 22.46 g/100 g, with the lowest value recorded in run 20 (30 g millet waste, 60 g groundnut and 50 g jaggery) and the highest in run 17 (40 g millet waste, 73 g groundnut and 55 g jaggery). This trend indicates that protein levels were primarily enhanced by higher groundnut inclusion, with formulations containing 70 to 73 g consistently yielding elevated protein values. Fibre content varied between 3.75 and 6.29 g/100 g, with the minimum observed in run 13 (23 g millet waste, 65 g groundnut and 55 g jaggery) and the maximum in run 19 (56 g millet waste, 65 g groundnut and 55 g jaggery), confirming that fibre was directly proportional to the level of millet processing waste, which served as a functional ingredient. The overall acceptability of the formulations ranged from 7.5 to 8.9, with the lowest scores (7.5) recorded in runs 1, 4, 7, 8, 11, and 15, while the highest acceptability (8.9) was obtained in run 10 (30 g millet waste, 70 g groundnut and 60 g jaggery). These results emphasize that optimum sensory quality was achieved through balanced proportions of ingredients, where moderate millet waste (30 to 40 g), higher groundnut (65 to 70 g) and adequate jaggery (50 to 55 g) contributed to superior product acceptance. Collectively, the findings highlight that groundnut acts as the primary contributor to protein density, millet waste enhances fibre enrichment and an optimized blend of all three ingredients ensures both nutritional value and consumer preference in the developed chikki.

3.2 Regression analysis and model significance for nutritional and sensory attributes

The regression analysis and ANOVA results revealed that protein, fibre, hardness and overall acceptability of millet processing waste incorporated chikki were significantly influenced by the model factors. Protein content showed a highly significant model fit ($R^2 = 0.987$, $p<0.0001$), with strong contributions from linear factors A, B, and C and quadratic effects of A^2 and B^2. Fibre content exhibited the best model adequacy ($R^2 = 0.9999$, $p<0.0001$), where both linear (A, B) and quadratic (A^2, B^2) terms were highly significant, supported by a very low CV (0.1794). Hardness was mainly influenced by factor A and quadratic terms A^2 and C^2 ($R^2 = 0.9476$, $p<0.0001$), while factors B and C had little effect. Overall acceptability was significantly affected by factor A and the quadratic terms A^2, B^2 and C^2 ($R^2 = 0.8428$, $p = 0.0050$), though with lower predictive reliability compared to protein and fibre models. These findings indicate that while protein and fibre responses were highly predictable and stable, hardness and overall acceptability were more dependent on specific formulation factors and quadratic interactions, emphasizing the importance of optimization to achieve desirable nutritional and sensory qualities (Tables 2 and 3).

Table 1: Actual values of the response variable obtained by experimentation for millet processing waste incorporated chikki

Independent variables				Dependent variables			
Run	A: Millet processing waste (g)	B: Groundnut (g)	C: Jaggery (g)	Protein^a (g/100 g)	Fibre^a (g/100 g)	Hardness^a (N)	Overall acceptability^a
1	40	65	55	20.26	5.05	41.32	7.5
2	50	60	60	19.72	5.63	41.85	7.7
3	50	70	50	22.31	5.94	41.11	7.7
4	40	65	55	20.26	5.05	41.32	7.5
5	40	65	46	20.22	5.02	42.16	7.9
6	30	60	60	18.22	4.13	40.12	8.3
7	40	65	55	20.26	5.05	41.32	7.5
8	40	65	55	20.26	5.05	41.32	7.5
9	50	60	50	19.69	5.64	41.24	7.8
10	30	70	60	20.84	4.44	41.15	8.9
11	40	65	55	20.26	5.05	41.32	7.5
12	50	70	60	22.35	5.96	42.51	7.6
13	23	65	55	18.85	3.75	38.11	8
14	30	70	50	20.81	4.43	38.85	8.4
15	40	65	55	20.26	5.05	41.32	7.5
16	40	65	63	20.29	5.04	43.45	7.9
17	40	73	55	22.46	5.28	41.75	8.2
18	40	56	55	19.05	4.76	41.34	8.2
19	56	65	55	20.99	6.29	41.45	7.9
20	30	60	50	18.18	4.12	40.24	8.2

^{a}Values observed in mean value of the three replications

Table 2: Regression coefficient and ANOVA estimated for protein and fibre of the millet processing waste incorporated chikki

Factors	Protein				Fibre				
	DF	Coefficient estimate	Sum of square	F value	*P*-value	Coefficient estimate	Sum of square	F value	*P*-value
Model	9	20.26	26.79	85.55	0.0001	5.05	8.13	11.08	0.0001
Liner									
A	1	0.704	6.78	194.73	0.0001	0.7558	7.80	189.77	0.0001
B	1	1.19	19.30	554.73	0.0001	0.1556	0.3305	154.14	0.0001
C	1	0.018	0.0049	0.1398	0.7163	0.0047	0.0003	3.63	0.0858
Interaction									
AB	1	0.0001	0.0001	0.0001	1.000	0.0012	0.0001	0.1531	0.7038
AC	1	0.0001	0.0001	0.0001	1.000	0.0013	0.0001	0.1531	0.7038
BC	1	0.0001	0.0001	0.0001	1.000	0.0037	0.0001	1.38	0.2676

Quadratic									
A²	1	0.130	0.2448	7.04	0.0242	0.0075	0.0008	10.04	0.0100
B²	1	0.164	0.3917	11.26	0.0073	0.0075	0.0008	10.04	0.0100
C²	1	0.011	0.0020	0.0587	0.8135	0.0040	0.0008	2.83	0.1234
Lack of fit	0.347					0.0008			
Mean ± SD	20.28 ± 0.186					5.04 ± 0.0090			
R^2	0.987					0.9999			
Adjusted R^2	0.975					0.9998			
Predicted R^2	0.902					0.9992			
CV	0.91					0.1794			

The *p* values indicated that to check the significance level of each coefficient. The *p* values <0.005 are indicated as significant effect of independent factor on response variables at 5%; DF- degree of freedom; SD- standard deviation; CV- Critical value.

Table 3: **Regression coefficient and ANOVA estimated for hardness and overall acceptability of the millet processing waste incorporated chikki**

		Hardness				**Overall acceptability**			
Factors	**DF**	**Coefficient estimate**	**Sum of square**	**F value**	***P*-value**	**Coefficient estimate**	**Sum of square**	**F value**	***P*-value**
Model	9	41.34	24.39	20.08	0.0001	7.50	2.38	5.96	0.0050
Liner									
A	1	0.8763	10.49	77.72	0.0001	0.2320	0.7350	16.54	0.0023
B	1	0.0629	0.0541	0.4010	0.5408	0.0439	0.0264	0.5933	0.4589
C	1	0.4657	2.96	21.95	0.0009	0.0293	0.0117	0.2637	0.6187
Interaction									
AB	1	0.1113	0.0990	0.7339	0.4117	0.1250	0.1250	2.81	0.1244
AC	1	0.0212	0.0036	0.0268	0.8733	0.1000	0.0800	1.80	0.2093
BC	1	0.4013	1.29	9.55	0.0114	0.0500	0.0200	0.4502	0.5175
Quadratic									
A²	1	0.6492	6.07	45.02	0.0001	0.1648	0.3914	8.81	0.0141
B²	1	0.0252	0.0091	0.0678	0.7999	0.2532	0.9238	20.79	0.0010
C²	1	0.0968	2.55	18.87	0.0015	0.1471	0.3119	7.02	0.0243
Lack of fit	1.35					0.4443			
Mean± SD	41.16 ± 0.3673					7.89 ± 0.2108			
R^2	0.9476					0.8428			
Adjusted R^2	0.9004					0.7012			
Predicted R^2	0.5830					0.2056			
CV	0.8924					2.67			

The *p* values indicated that to check the significance level of each coefficient. The *p* values <0.005 are indicated as significant effect of independent factor on response variables at 5%; DF- degree of freedom; SD- standard deviation; CV- Critical value.

3.3 Response surface analysis (3D) for nutritional and sensory attributes

Figure 4 illustrated the 3D surface plots for combined effect of formulation variables on protein, fibre, hardness and overall acceptability of millet processing waste incorporated chikki (Figure 3). Protein content showed a steady increase with higher incorporation of millet processing waste along with groundnut, indicating a strong positive linear relationship. Fibre content also increased significantly with the proportion of millet processing waste, highlighting their contribution as a rich dietary fibre source. Hardness values revealed a gradual rise with increasing levels of millet processing waste suggesting that millet addition enhanced the structural firmness of chikki. In contrast, overall acceptability displayed a curvilinear trend, with moderate levels of millet processing waste and groundnut yielding the highest scores, while extreme levels reduced consumer preference. These surface plots confirmed the ANOVA findings that protein and fibre were strongly influenced by linear effects, whereas hardness and overall acceptability were more dependent on quadratic interactions, emphasizing the importance of optimizing ingredient levels to achieve nutritionally superior and sensorially acceptable chikki.

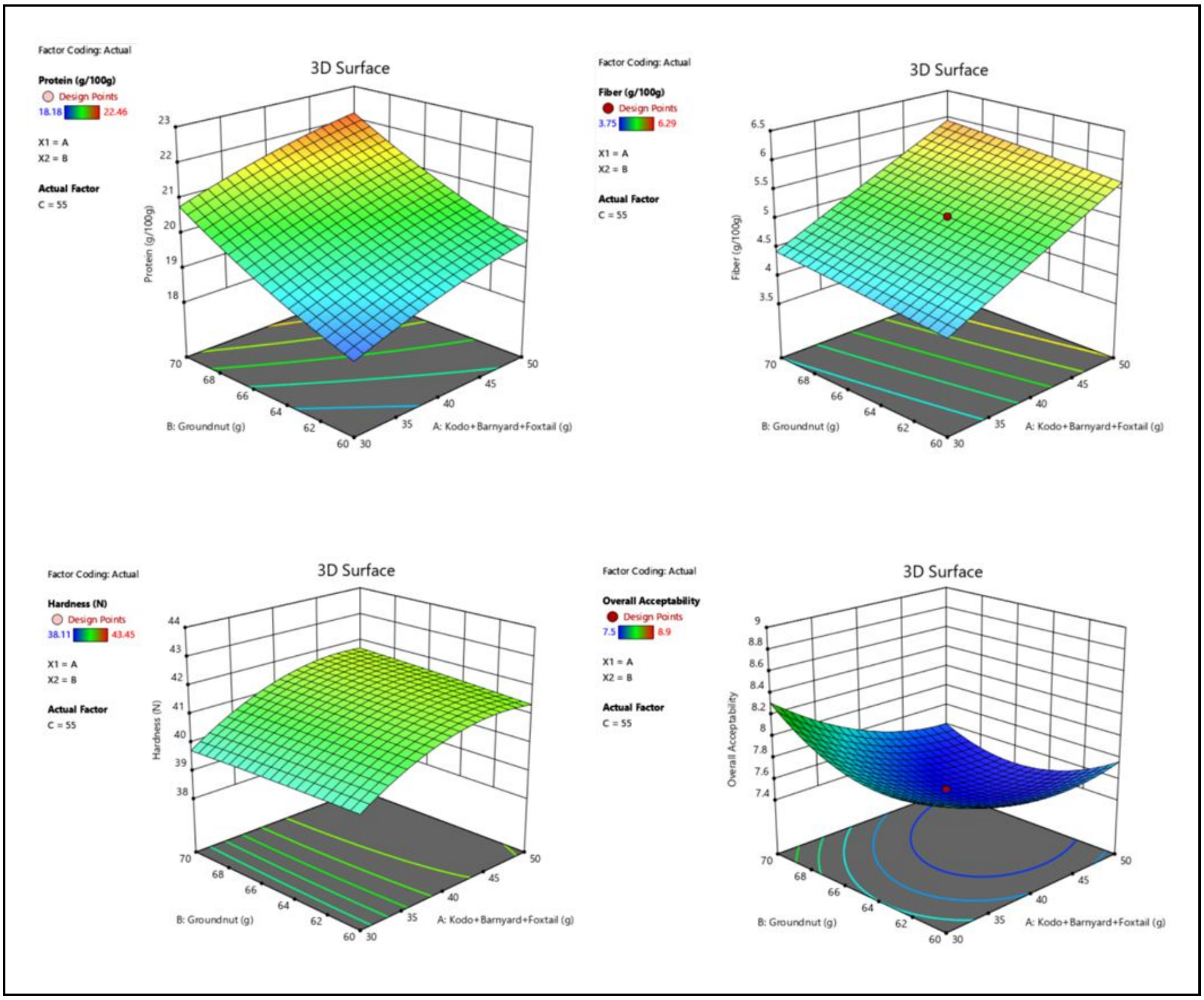

Figure 4: The 3D surface plots illustrated the protein, fibre, hardness and overall acceptability of millet processing waste incorporated chikki in different combinations.

Table 4: Constraints and solution of RSM

Name	Goal	Lower limit	Upper limit	Predicted solution
Independent variables				
A:Millet processing waste	is in range	30	50	30
B:Groundnut	is in range	60	70	70
C:Jaggery	is in range	50	60	60
Dependent variables				
Protein (g/100 g)	none	18.18	22.46	20.787
Fiber (g/100 g)	none	3.75	6.29	4.439
Hardness (N)	none	38.11	43.45	41.045
Overall acceptability	none	7.5	8.9	8.644

3.4 Optimization of formulation using response surface methodology (RSM)

The optimization of formulation using response surface methodology (RSM) identified the ideal combination of ingredients for millet processing waste incorporated chikki (Table 4). Among the independent variables, the optimum solution was obtained at 30 g millet processing waste, 70 g groundnut and 60 g jaggery. Under these conditions, the predicted responses for the dependent variables were 20.787 g/100 g protein, 4.439 g/100 g fibre, 41.045 N hardness and an overall acceptability score of 8.644. These values were within the acceptable range of experimental limits, indicating that the model was reliable in predicting the response. The solution ensured high nutritional quality with good protein and fibre content, acceptable textural properties and superior sensory acceptance, confirming that the optimized formulation successfully balanced nutritional enhancement with consumer preference.

Table 5: Comparative study on physicochemical properties of control and optimized composition of millet processing waste incorporated chikki

Nutritional parameters	T_0	T_1	CD @ 5%	CV %
Moisture (%)	$3.98 \pm 0.004^{*}$	$3.62 \pm 0.014^{*}$	0.30	3.52
Protein (g/100 g)	$16.78 \pm 0.10^{**}$	$20.88 \pm 0.52^{**}$	1.42	3.33
Fat (g/100 g)	$21.11 \pm 0.01^{**}$	$16.44 \pm 0.06^{**}$	1.38	3.26
Carbohydrate (g/100 g)	$59.14 \pm 1.60^{*}$	$62.45 \pm 0.72^{*}$	3.27	2.37
Fibre (g/100 g)	$2.08 \pm 0.02^{**}$	$2.31 \pm 0.01^{**}$	0.24	4.33
Calcium (mg/100 g)	$88 \pm 1.01^{*}$	$93 \pm 2.59^{*}$	4.18	2.04
Iron (mg/100 g)	$1.63 \pm 0.009^{**}$	$2.11 \pm 0.04^{**}$	0.20	4.02
Hardness (N)	$43.15 \pm 1.20^{*}$	$43.85 \pm 0.38^{*}$	1.55	072
Total Phenols (mg GAE/100 g)	$94.16 \pm 2.11^{**}$	$115.24 \pm 2.58^{**}$	4.83	2.04
Overall acceptability	$8.6 \pm 0.25^{*}$	$8.4 \pm 0.20^{*}$	0.23	1.22

Explanatory notes: values mentioned as mean ± standard deviation of three replicate analysis (n=3); CD- critical difference @ 5%; CV- Critical value. T_0: (Control chikki) and T_1: (30% of millet processing waste incorporated chikki)

3.5 Effect of millet processing waste incorporation on physicochemical and nutritional properties of chikki

Table 5 highlights the incorporation of 30% millet processing waste into chikki (T_1) significantly influenced its physicochemical and nutritional properties compared to the control (T_0). Moisture and fat content showed a significant decrease in T_1 (3.62% and 16.44 g/100 g, respectively) compared to T_0 (3.98% and 21.11 g/100 g), while protein, carbohydrate, fibre, calcium and iron content significantly increased ($p<0.05$). Specifically, protein content increased from 16.78 to 20.88 g/100 g, fibre from 2.08 to 2.31 g/100 g, calcium from 88 to 93 mg/100 g and iron from 1.63 to 2.11 mg/100 g. Total phenolic content was notably higher in T_1 (115.24 mg GAE/100 g) than T_0 (94.16 mg GAE/100 g), indicating enhanced antioxidant potential. There was no significant change in hardness (T_0: 43.15 N; T_1: 43.85 N) or overall acceptability (T_0: 8.6; T_1: 8.4) suggesting that product texture and sensory attributes were maintained. These findings indicate that millet processing waste can be effectively utilized to improve the nutritional profile of chikki without compromising its sensory.

4. Discussion

The present research successfully developed and optimized a functional groundnut chikki enriched with millet processing waste from kodo, barnyard and foxtail millets demonstrating significant nutritional and nutraceutical enhancement. The incorporation of 30% millet waste flour not only improved protein, fiber and mineral content but also substantially elevated total phenolic concentration and antioxidant capacity, validating its potential as a health promoting snack. The increase in protein (from 16.78 to 20.88 g/100 g) and fiber (from 2.08 to 2.31 g/100 g) content aligns with findings by Singh *et al.* (2022) and Ranjan *et al.* (2023), who reported that minor millets, particularly barnyard and kodo millets, are rich in quality plant proteins and insoluble dietary fiber beneficial for lipid regulation and glycemic control. The inclusion of millet bran and flake residues thus contributed functional macronutrients and bioactive compounds that support digestive and metabolic health.

A notable outcome of this study was the significant enhancement of total phenolic content in the optimized formulation (115.24 mg GAE/100 g), indicating strong antioxidant potential. Phenolic compounds such as ferulic, caffeic, and p-coumaric acids, abundantly present in kodo and foxtail millets (Chandrasekara and Shahidi, 2011; Nithiyanantham, 2019), play crucial roles in neutralizing free radicals and mitigating oxidative stress related disorders. Similar observations were made by Chethan and Malleshi (2007), who demonstrated that the polyphenol rich outer layers of millets possess strong DPPH radical scavenging activity, thereby contributing to the prevention of cardiovascular and neurodegenerative diseases. The enhanced antioxidant activity in the developed chikki may thus be attributed to the synergistic interaction between phenolic rich millet waste and antioxidant minerals like iron and magnesium, which promote redox balance and cellular defense mechanisms.

From a functional standpoint, the optimized formulation exhibited superior nutritional quality without compromising the sensory and textural properties. The hardness (43.85 N) and overall acceptability (8.4) remained within the desirable range, suggesting that the millet waste addition did not adversely affect the product's palatability. This observation is supported by Pallavi *et al.* (2014), who noted that moderate incorporation of cereal based fortificants in traditional confections maintains sensory acceptability while improving nutritional density. The balance between groundnut protein and millet fiber contributed to the crisp texture, while jaggery provided natural sweetness and binding properties along with inherent minerals and antioxidants, consistent with the findings of Sarkar *et al.* (2021) on traditional sweetmeat formulations enriched with natural ingredients.

The enriched chikki formulation serves as a promising intervention for fostering sustainable and circular food systems. During millet processing, substantial quantities of by-products such as bran, husk, and flake residues are generated, which are often underutilized or relegated to animal feed despite their rich nutritional potential. Subhash *et al.* (2024) reported that these residues contain 12-18% dietary fiber and 180-250 mg GAE/100 g of phenolic compounds, underscoring their applicability in functional food development. Incorporating these nutrient dense by-products into chikki production effectively converts agro-industrial waste into value-added food ingredients, thereby enhancing environmental sustainability and minimizing food waste. Furthermore, this circular utilization of millet processing residues directly contributes to the United Nations Sustainable Development Goal (SDG) 12: Responsible Consumption and Production, by promoting resource efficiency and nutritional security.

From a health perspective, the developed chikki provides multiple physiological advantages associated with its bioactive profile. The combination of high quality plant proteins, soluble and insoluble fibers and antioxidant compounds contributes to improved glycemic regulation, lipid metabolism and cardiovascular protection. Ugare *et al.* (2014) demonstrated that low glycemic index millets such as barnyard and foxtail reduce postprandial glucose response and support insulin sensitivity. Similarly, Awasthi *et al.* (2025) highlighted that millet based snacks enriched with polyphenols exhibited significant reductions in lipid peroxidation and improved antioxidant enzyme activities *in vivo*. Therefore, the millet waste incorporated chikki can serve as a functional snack for individuals seeking alternatives that promote metabolic health and oxidative stress management.

The findings substantiate that the inclusion of 30% millet processing waste in groundnut chikki results in a nutritionally dense, antioxidant rich and sensorial acceptable product. The elevated levels of phenolics and minerals, coupled with improved protein and fiber content, confer strong functional and health promoting properties. Supported by previous research on the antioxidant, hypoglycemic and cardioprotective potential of millets, this study confirms that millet waste valorization offers dual benefits to enhancing public health through functional food innovation and advancing sustainable food production practices. Hence, the developed product represents a scientifically validated, cost-effective and eco-friendly alternative to conventional energy dense snacks, paving the way for nutraceutical oriented confectionery development.

5. Conclusion

The present study demonstrated that the incorporation of millet processing waste into groundnut chikki significantly improved its nutritional, functional and antioxidant properties without compromising sensory quality. The optimized formulation of 30 g millet processing waste, 70 g groundnut and 60 g jaggery exhibited higher protein 20.88 g/100 g, dietary fibre 2.31 g/100 g, calcium 93 mg/100 g, iron 2.11 mg/100 g and total phenolic content 115.24 mg GAE/100 g compared to the control, reflecting enhanced nutritional density and antioxidant potential. The inclusion of bioactive rich millet residues contributed additional health promoting effects such as antidiabetic, cardioprotective and anti-inflammatory activities as supported by earlier studies on kodo, barnyard and foxtail millets. The developed product maintained desirable texture and consumer acceptability while promoting sustainable food production through the valorization of agro industrial by-products. Thus, millet waste incorporated chikki represents a functional, eco-friendly and nutritionally superior alternative to conventional snacks, supporting both public health and environmental sustainability.

Acknowledgements

The authors acknowledge the support of Tamil Nadu Agricultural University, Coimbatore and thanks to ICAR-AICRP on Women in Agriculture for their encouragement and financial support for my studies.

Conflict of interest

The authors declare no conflict of interest relevant to this article

References

AOAC (1995). Official Methods of Analysis of AOAC International. 16th Edition, Association of Official Analytical Chemists, Washington, DC, USA.

AOAC (2005). Official Methods of Analysis of the Association of Official Analytical Chemists International. 18th Edition, AOAC International, Gaithersburg, MD, USA.

Arya, C. and Bisht, A. (2022). Nutritional profile of small millets. In Small Millet Grains: The Superfoods in Human Diet., pp:15-47. Singapore: Springer Nature Singapore.

Awasthi, J.; Mishra, A.; Rathore, S.; Verma, S. and Pandey, A. K. (2025). A review of the nutraceutical composition of millets and their health benefits. Current Functional Foods, **3**(2):E160424228953.

Barbhai Mrunal, D. (2020). Development of designer products by incorporating millet bran and assessing their therapeutic potential, Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad, India.

Carpenter, C. (2010). "Determination of fat content." Food Analysis Laboratory Manual, **1**(1):29-37.

Chandel, G.; Meena, R. K.; Dubey, M. and Kumar, M. (2014). Nutritional properties of minor millets: Neglected cereals with potentials to combat malnutrition. Current Science (00113891), **107**(7).

Chandrasekara, A. and Shahidi, F. (2011). Antiproliferative potential and DNA scission inhibitory activity of phenolics from whole millet grains. Journal of Functional Foods, **3**(3):159-170.

Chethan, S. and Malleshi, N. G. (2007). Finger millet polyphenols: Characterization and their nutraceutical potential. American Journal of Food Technology, **2**(7):582-592.

Da-Col, J.A.; Domene, S.M.A. and Pereira-Filho, E.R. (2009). Fast Determination of Cd, Fe, Pb, and Zn in Food using AAS. Food Anal. Methods **2**:110-115

Devadarshini, C.; Sahoo, S. S.; Satapathy, P. and P. Parhi. (2025). Formulation and standardization of cookies with incorporation of finger millet and barnyard millet. Ann. Phytomed., **14**(1):898-906.

Devhare, P.F.; Kotecha, P.M.; Godase, S.N. and Chavan, U.D. (2021). Studies on utilization of pomegranate juice in the preparation of peanut chikki.Inter National of chemical studies. **9**(1):1532-1535.

Hegde, P. S.; Rajasekaran, N. S. and Chandra, T. S. (2005). Effects of the antioxidant properties of millet species on oxidative stress and glycemic status in alloxan-induced rats. Nutrition Research, **25**(12):1109-1120.

Kalsi, R. and Bhasin, J. K. (2023). Nutritional exploration of foxtail millet (*Setaria italica*) in addressing food security and its utilization trends in food system. E Food, 4(5):e111.

Kurzyna Szklarek, M.; Biernat, J. and Grajeta, H. (2022). Carbohydrates in human nutrition-importance and dietary recommendations. Nutrients, **14**(23):5038.

Mishra, R. and Satheesh, N. (2024). Kodo millet (*Paspalum scrobiculatum*) A nutri-rich millet crop: Nutritional composition, health benefits and food product developments. In: Millets and Other Potential Crops., pp:157-179. CRC Press.

Nithiyanantham, S.; Kalaiselvi, P.; Mahomoodally, M. F.; Zengin, G.; Abirami, A. and Srinivasan, G. (2019). Nutritional and functional roles of millets-A review. Journal of Food Biochemistry, **43**(7):e12859.

Pallavi, B. V.; Chetana, R. and Reddy, S. Y. (2014). Processing, physico-chemical, sensory and nutritional evaluation of protein, mineral and vitamin enriched peanut chikki-an Indian traditional sweet. Journal of Food Science and Technology, **51**(1):158-162.

Polisetty, S. K.; Ezhilarasi, T.; Ravikesavan, R.; Karthikeyan, R.; Maragatham, S. and Pushpa, R. (2025). A comprehensive review on exploring the nutritional profile of small millets. Ann. Phytomed., **14**(1):1110-1120.

Ranjan, R.; Singh, S.; Dhua, S.; Mishra, P.; Chauhan, A. K. and Gupta, A. K. (2023). Kodo Millet (*Paspalum scrobiculatum*). Nutri Cereals: Nutraceutical and Techno Functional Potential. pp:193-211. Research Gate.

Sadasivam, S. and Manickam, A. (1996). Biochemical Methods for Agricultural Sciences. Wiley Eastern Ltd., New Delhi, India.

Sadasivam, S. and Manickam, A. (2008). Biochemical Methods for Agricultural Sciences. New Age International Publishers, New Delhi, India.

Saleh, A. S.; Zhang, Q.; Chen, J. and Shen, Q. (2013). Millet grains: nutritional quality, processing, and potential health benefits. Comprehensive Reviews in Food Science and Food Safety, 12(3):281-295.

Sarkar, T.; Salauddin, M. and Chakraborty, R. (2021). Rasgulla the ethnic Indian sweetmeat delicacy and its evolutionary journey through contemporary research. Journal of Ethnic Foods, 8(1):11.

Singh, V.; Lee, G.; Son, H.; Amani, S.; Baunthiyal, M. and Shin, J. H. (2022). Anti-diabetic prospects of dietary bio-actives of millets and the significance of the gut microbiota: A case of finger millet. Frontiers in Nutrition, **9**:1056445.

Subhash, A. J.; Bamigbade, G. B. and Ayyash, M. (2024). Current insights into date by-product valorization for sustainable food industries and technology. Sustainable Food Technology, **2**(2):331-361.

Ugare, R.; Chimmad, B.; Naik, R.; Bharati, P. and Itagi, S. (2014). Glycemic index and significance of barnyard millet (*Echinochloa frumentacae*) in type II diabetics. Journal of Food Science and Technology, **51**(2):392-395.

Citation **R. Packiyalakshmi, G. Gurumeenakshi, G. Sashidevi, P. Geetha, M. Ilamaran and B. Sivasankari (2025). Development and optimization of millet processing waste incorporated groundnut chikki as a functional and sustainable snack. Ann. Phytomed., 14(2):542-551. http://dx.doi.org/10.54085/ap.2025.14.2.53.**