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Functional and Nutritional Enhancement of Brittle (Chikki) Using Puffed Kodo Millet and Palm Jaggery

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ABSTRACT

Background

India has a rich culinary heritage, with traditional sweets like brittle (chikki) being widely consumed across all age groups. While conventional brittle primarily consists of jaggery and roasted nuts, its nutritional value can be enhanced by incorporating additional health-promoting ingredients. This study aimed to develop a fortified brittle using nutrient-rich components to improve its functional benefits while ensuring affordability and consumer acceptability.

Methods

To achieve this, three formulations (T_1, T_2, and T_3) were developed using a combination of peanut, black dates powder (*Phoenix dactylifera L*), palm jaggery, puffed kodo millet, and kodo millet flour (*Paspalum scrobiculatum*). A control sample (T0) containing only peanut and jaggery was also prepared for comparison. The formulations were evaluated based on their physicochemical properties (nutrient content, texture, moisture content, and ash value), microbial stability, and sensory characteristics (taste, texture, aroma, and overall acceptability).

Results

Among the tested formulations, T_2 (10:20:45:20:05) was found to be the most favorable due to its superior nutritional composition, including higher carbohydrate (73.83%), protein (7.50%), fat (11.70%), ash (2.44%), and iron (5.83%) content. Sensory evaluation revealed that T_2 scored the highest in consumer acceptability, owing to its balanced texture, natural sweetness, and pleasant mouthfeel. Microbial analysis confirmed that the fortified brittle remained within permissible safety limits for up to four months, indicating good shelf stability. Additionally, the cost of production for the fortified brittle was found to be economically feasible, making it a viable option for large-scale manufacturing.

Conclusion

The development of this fortified brittle successfully combines nutritional enhancement, affordability, and consumer appeal, offering a healthier alternative to traditional brittle. The presence of iron-rich ingredients such as black dates powder and kodo millet flour makes this product particularly beneficial for individuals suffering from anemia and malnutrition. Given the increasing global interest in functional foods, this fortified brittle has the potential to be widely accepted as a nutritious, cost-effective, and convenient snack option.

Keywords: Kodo millet, palm jaggery, black dates powder, Kodo millet flour, puffed Kodo millet, peanuts.

Introduction

Brittle, widely known as "chikki" in India, is a traditional confection crafted from jaggery and nuts or seeds. Valued for its flavor and nutritional benefits, chikki is a popular snack across diverse communities. However, the growing prevalence of nutritional deficiencies and diet-related diseases highlights the need to enhance traditional foods with fortified ingredients. Incorporating millets into such snacks represents an innovative approach to addressing these challenges while promoting sustainable and nutrient-rich diets. Kodo millet (*Paspalum scrobiculatum*), a drought-resistant minor cereal, is a rich source of dietary fiber, proteins, and essential micronutrients such as calcium, iron, and magnesium. Additionally, it is abundant in bioactive compounds, including polyphenols and flavonoids, which exhibit antioxidant, anti-inflammatory, and antidiabetic properties (Chethan & Malleshi, 2007; Shobana et al., 2009). Despite its nutritional advantages and resilience in harsh growing conditions, millet consumption remains limited, often due to a lack of consumer awareness and integration into convenient food products (Sarita & Singh, 2016).

Fortifying chikki with puffed Kodo millet not only elevates its nutritional value but also provides a sustainable and culturally acceptable solution to combat malnutrition and hidden hunger, particularly in rural and underdeveloped regions. This fortification increases dietary fiber, improves the glycemic index, and enhances the availability of vital nutrients. Moreover, it aligns with global and national initiatives like the International Year of Millets 2023, which emphasizes the role of millets in ensuring food security and promoting sustainable agricultural practices (Chandrasekara & Shahidi, 2011; Nazni & Bhuvaneswari, 2015). Evaluating the sensory attributes, nutritional composition, and shelf-life stability of fortified chikki is critical to its acceptance and market potential. Sensory parameters such as taste, texture, and appearance are crucial for consumer satisfaction, while nutritional analysis confirms the health benefits. This study seeks to develop and assess the quality of fortified chikki prepared with puffed Kodo millet, offering a healthy and innovative alternative to conventional snacks while addressing essential nutritional needs.

Materials & Methods

Fortified Kodo millet Brittle (chikki) manufacturing materials

The material and methods to be adopted during this investigation are given below:

1. Palm Jaggery was purchased from local market.

2. Peanuts (ground nut) were purchased from local market.

3. Black dates were purchased from local market.

4. Kodo millets was purchased from local market.

The preparatory protocol of each step given in the Figure-1 to Figure-8. The physico- chemical analysis of raw peanuts, Kodo millet and black dates carried according to standard procedures and results were shown in Table-1.

Table-1: Different combinations of the multigrain chikki made for standardization

Trials	composition	Ratio
C	Roasted and coarsely grounded groundnut + jaggery + glucose	100
T_1	Kodo millets puffed + roasted kodo millet + finely grounded peanuts + white sesame seeds + jaggery, sugar, black dates powder + kodo flour + soy flour + desiccated carrot, coconut and sweet potato + pumpkin seeds	25:5:5:10:35:5:5:5:5
T_2	Kodo millets puffed + roasted kodo millet + finely grounded peanuts + black sesame seeds + jaggery + sugar + black dates powder + oats + soy flour + desiccated carrot, coconut and sweet potato + pumpkin seeds	20:5:5:10:35:10:5:10
T_3	Kodo millets puffed + roasted kodo millet + finely grounded peanuts + white & black sesame seeds + jaggery + sugar + black dates powder + roasted and finely grounded flex seed powder + soy flour + desiccated carrot, coconut and sweet potato + pumpkin seeds	25:5:5:5:35:10:5:5:5

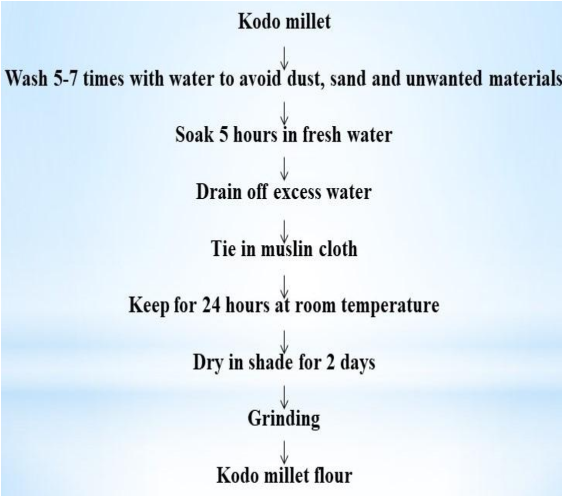


Figure-1: Flow diagram of Kodo millet flour preparation

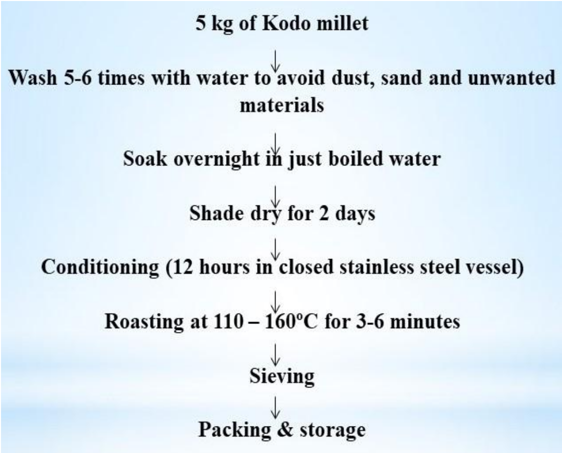


Figure-2: Flow diagram for puffed Kodo millet preparation

Figure-3: Flow diagram of black date powder and palm jaggery syrup

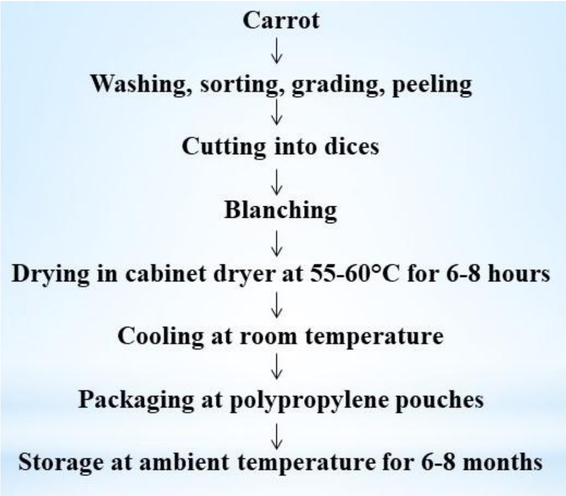


Figure-4: Flow diagram for preparation of desiccated carrot

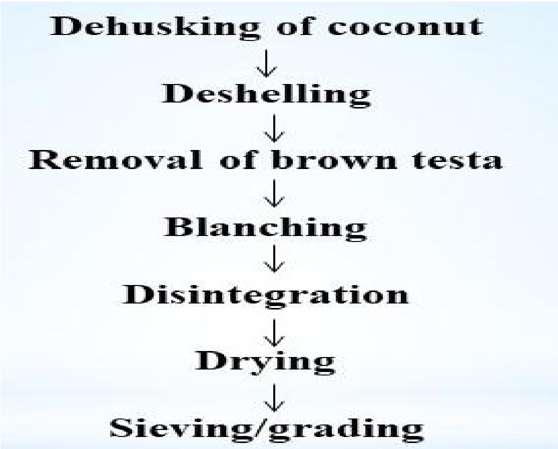


Figure-5: Flow diagram for preparation of desiccated coconut

Figure-6: Flowchart for the preparation of desiccated sweet potato

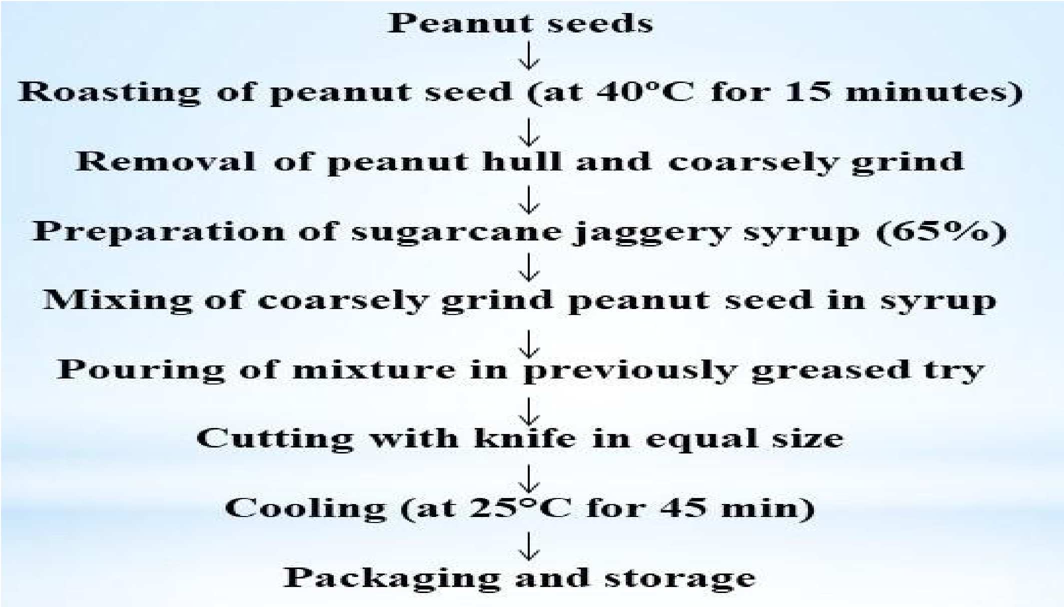


Figure-7: Flow diagram adopted for control sample

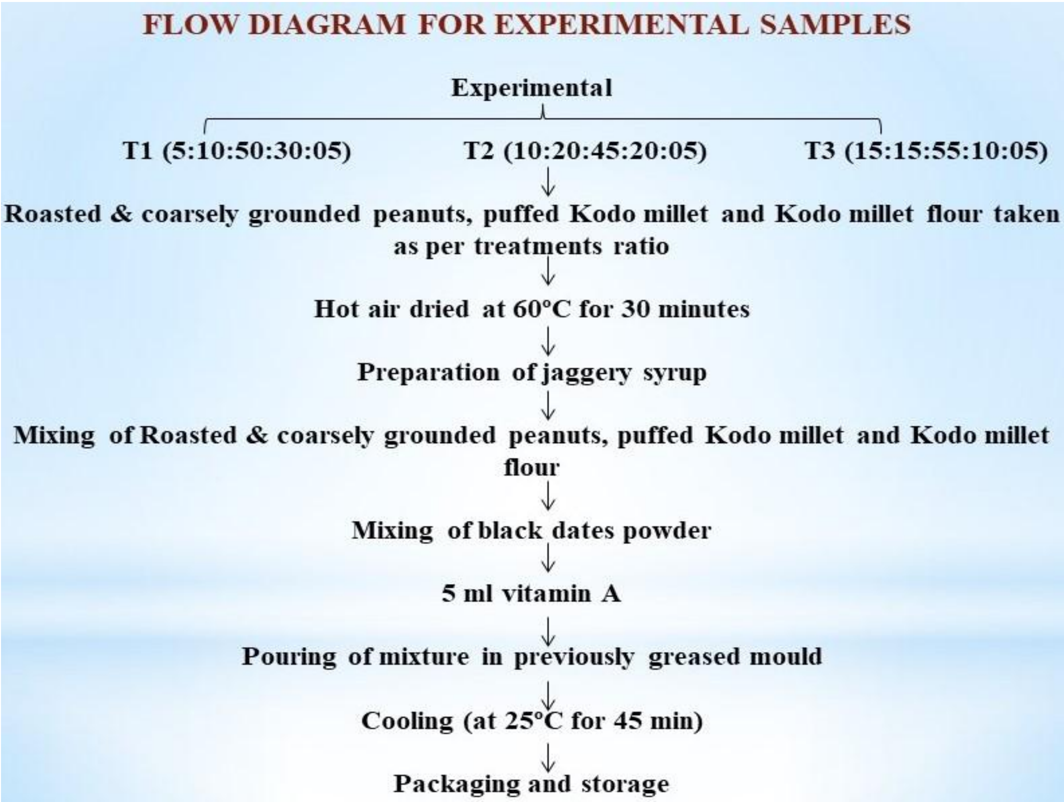


Figure-8: Flow diagram for experimental samples

Physico-chemical analysis of control and fortified kodo millet brittle (chikki)

Moisture

The moisture content was determined by drying the weighed sample in a hot air oven at 70 ± 2°C until a constant weight was achieved. After drying, the sample was allowed to cool to room temperature in a desiccator before being weighed again. The moisture content, expressed as a percentage, was then calculated using the following formula (Gandhi et al., 2020a):

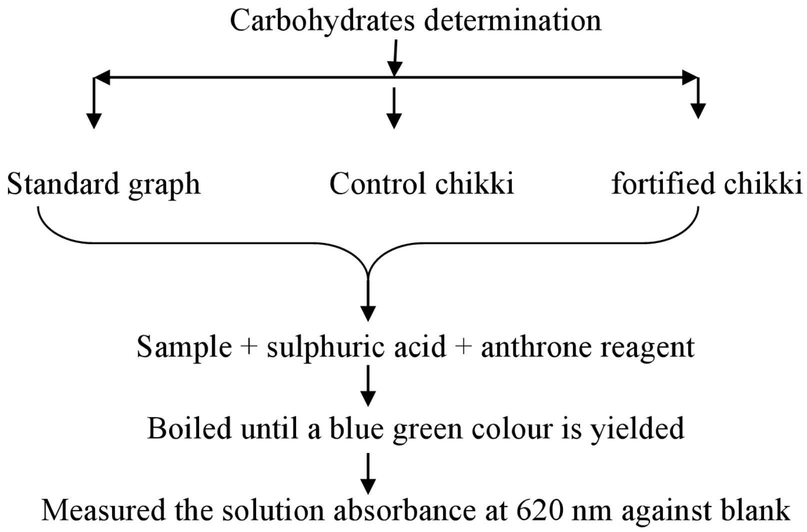
$$\text{Moisture (\%)} = \frac{\text{Weight of fresh sample} - \text{Weight of dried sample}}{\text{Weight of fresh sample}} \text{ X } 100$$

Total ash

The silica dishes were first weighed, after which 5-10 grams of the dried millet samples were placed into each dish. The samples were initially ignited using a Bunsen burner and then subjected to ashing in a muffle furnace at 525°C for 4-6 hours. After ashing, the dishes were allowed to cool before being weighed again. The difference in weight, representing the total ash content, was calculated and expressed as a percentage, following the method described by Ranganna (2007).

Determination of Carbohydrates

The total carbohydrate content in the ingredients, as well as in the control and fortified Kodo millet chikki, was determined using the anthrone method (Gandhi et al.,2019 & 2020b).

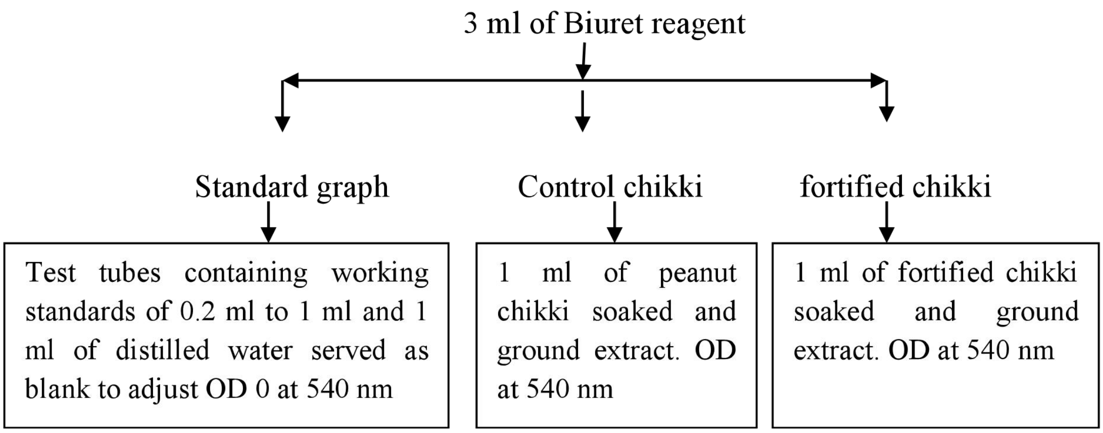


Crude Fibre Determination

The Weende method, as described by Pearson (1996), was employed for this analysis. A 5 g sample was precisely weighed and placed into a two-fold muslin cloth, which was then boiled in 200 mL of 1.25% H_2SO_4 under reflux for 30 minutes. After boiling, the cloth was thoroughly washed with boiling water. The cloth was then transferred to a boiling flask containing 1.25% NaOH solution and boiled again for 3 minutes under reflux. Following this, the cloths were washed and transferred to pre-weighed porcelain crucibles, which were labeled as [W_1]. The crucibles were then dried in an oven until a constant weight, labelled as [W_2], was achieved. The samples were subsequently ashed in a furnace at 550°C, cooled in a desiccator, and the final weight [W] was recorded.

Determination of Proteins

In a clean test tube, 1 mL of millet extract was added, and the volume was brought up to 2 mL using distilled water. Following this, 3 mL of biuret reagent was added to the mixture, which was then incubated at room temperature for 10 minutes. The resulting colour intensity was measured using a spectrophotometer at a wavelength of 540 nm, with a blank sample used to zero the instrument. This procedure was conducted according to the method described by Gandhi et al. (2017).



Fat determination

The solvent extraction process was carried out using a Soxhlet reflux apparatus, following the method described by Pearson (1996). Precisely 2 g of the sample was wrapped in a porous material, such as Whatman filter paper, and placed in the Soxhlet extraction chamber. A second 2 g sample was similarly prepared and placed in another Soxhlet chamber to serve as a replicate. The extraction chambers were positioned above pre-weighed oil extraction flasks, each containing 200 mL of petroleum ether. The Soxhlet apparatus was then assembled, and heat was applied using an electro-thermal heating mantle. The solvent was vaporized, condensed, and recirculated through the sample, allowing for continuous extraction. After 4 hours of extraction, the flasks were removed, and the residual solvent was evaporated by drying the flasks in an oven at 60°C for 3 minutes.

Titratable acidity

Titratable acidity was determined by titrating a measured volume of the sample with 0.1N NaOH solution, using phenolphthalein as an indicator. The titratable acidity was then expressed as a percentage of malic acid, following the method outlined by AOAC (1995).

$$\text{TA}(\%) = \frac{\text{Titre X Normality of alkali X Vol. made up X eq. weight of acid}}{\text{Vol. sample X vol. aliquot X 100}} \text{ X } 100$$

Sugars

A 25 g sample was placed in a 250 mL volumetric flask, and 100 mL of water was added. The solution was neutralized with 1N NaOH, followed by the addition of 2 mL of 45% lead acetate. The mixture was allowed to stand for 10 minutes. To remove excess lead acetate, 2 mL of 22% potassium oxalate was added to the solution in a 250 mL volumetric flask. After dilution to the mark, the solution was filtered, and the clear filtrate was used to estimate reducing sugars. The filtrate was titrated against known quantities of Fehling’s A and Fehling’s B solutions, using ethylene blue as an indicator, according to the method described by Lane and Eynon (1923). Reducing sugars were expressed as a percentage and calculated as outlined below.

$$\text{Reducing sugars}(\%) = \frac{\text{Factor X dilution}}{\text{Titre value X weight of the sample}} \text{ X } 100$$

Total sugars were estimated by adding 5 g of citric acid to a 50 mL sample solution and heating it for 10 minutes to ensure complete inversion of the sugars. After heating, the solution was neutralized with NaOH and diluted to a final volume of 250 mL in a volumetric flask. The total sugars were then estimated as a percentage and calculated as described below.

$$\text{Total invert sugar}(\%) = \frac{\text{Factor X dilution}}{\text{Titre value X weight of the sample}} \text{ X } 100$$

Texture measurement

The snap (breaking strength) of the Chikki was measured using the Universal Texture Measuring System (Model LR-5K, Lloyds, UK). Uniform-sized Chikki samples were subjected to a 3-point bending test with a 100 N load cell, conducting the test in triplicate at a crosshead speed of 50 mm/min. The force required to break the Chikki into two pieces was recorded as the breaking strength (snap) and expressed in Newtons (N).

Free fatty acid and Peroxide value

The free fatty acid and peroxide values of the samples were determined using the method described by Ranganna (1995). To convert the percentage of free fatty acids (expressed as oleic acid) to acid value, multiply the percentage by 1.99.

Mineral analysis by AAS

One gram of the sample was acid-digested using a triple acid mixture (nitric, sulfuric, and perchloric acids in a 9:2:1 ratio) in a sand bath until a clear solution was obtained. The solution was then filtered through Whatman No. 41 ashless filter paper. The filtrate was diluted to a final volume of 100 mL, and this triple acid extract (ash solution) was used for the estimation of iron, calcium, magnesium, phosphorus, and potassium. The clear extract was analyzed using an Atomic Absorption Spectrophotometer (AAS). In this process, the absorption of light by the vaporized sample's atoms was measured and related to the concentration of the metals present. The concentration of each mineral was determined by comparing the sample's absorbance with that of standards with known concentrations (Parvez & Vijaya, 2020).

Analysis of vitamin A

Vitamin A in Chikki was analyzed by digesting the sample with ethanolic pyrogallol and ethanolic KOH for 18 hours at 37°C. After digestion, Vitamin A was extracted into a hexane solvent layer, which was then separated and analyzed by high-performance liquid chromatography (HPLC). The HPLC system used was a Shimadzu LC-10AS (Shimadzu Corp., Tokyo, Japan) with a C-18 (ODS) column (25 cm × 4.6 mm id) from Supelco, Bellefonte, USA. The analysis was performed using an ultraviolet detector set to a wavelength of 320 nm. The mobile phase comprised 65% acetonitrile, 25% methanol, and 10% chloroform, with a flow rate of 1 mL/min, as described by Chase et al., (2004).

Determination of Amino acids

Titrimetric determination procedure followed described by Brashy and Ghannam 1996. An accurately measured volume of the sample solution (1–5 mg) is transferred to a small flask to begin the titration. To this, 2–3 drops of an indicator solution, such as methyl orange (MO) or amaranth, are added to facilitate endpoint detection. The sample is then titrated with a 5×10^{-3} M solution of dibromo hydantoin (DBH) or a 1×10^{-3} M solution of nitrobenzene-p-sulfonic acid (NBP) until the color of the indicator is discharged, signaling the reaction's completion. A blank solution is prepared using the same procedure, omitting the sample, to account for any background contributions. The volume of titrant used for the blank is subtracted from the endpoint reading of the sample titration to determine the precise analytic concentration (Vijaya et al., 2007, 2009, 2010). This procedure is straightforward yet effective for accurate titrimetric analysis.

Calorific value

Energy value was calculated by using the undermentioned formula:

Energy= [(9×g.fat)+(4×g.protein)+(4×g.carbohydrate)]

Storage and stability studies of control treatment and Fortified kodo millet Brittle (chikki)

The chikki samples were packed in polypropylene pouches and stored under two conditions: at ambient temperature (27°C± 3ºC) and at cold temperature (4 ± 2°C) for a period of 120 days. The storage stability was assessed by evaluating various physicochemical parameters and conducting sensory evaluations with two panel and each panel with 25 trained members.

Sensory evaluation of Fortified kodo millet Brittle (chikki)

To assess the quality and acceptability of the products, a panel of ten judges evaluated the chikki samples. Sensory parameters, including color, taste, flavor, texture, and overall acceptability, were assessed using a 9-point hedonic scale. The chikki samples, each assigned a code number, were presented one at a time for evaluation. Sensory assessments were conducted on freshly prepared chikki as well as on samples stored for 30, 60, 90, and 120 days at both 27 ± 2°C and 4 ± 2°C.

Statistical analysis

Data were statistically analysed using one-way ANOVA with GraphPad Prism 6.01 software (Gandhi et al., 2018; Gandhi et al., 2024; Gandhi & Vijaya 2024a, b). The results are presented as means with standard deviations. Differences between various treatments and the control were compared using Duncan's multiple-range test at a significance level of p.

Microbial examination of Fortified kodo millet Brittle (chikki)

The processed millet and peanut chikki samples were tested for microbial contamination at regular intervals of one month for up to four months. To assess microbial contamination, the pour plate method was employed. Various agar media were prepared for different types of microbial detection: nutrient agar for bacterial counts, EMB (eosin methylene blue) agar for Enterobacteriaceae and related coliforms, LB (Luria-Bertani) agar for E. coli, MacConkey's agar for the differential growth of Gram-negative bacteria, Czapek-Dox medium for mold counts, Sabouraud's agar for pathogenic fungi isolation, Potato Dextrose Agar (PDA) for the isolation of fungal and mushroom spores, and Yeast Malt Agar.For the analysis, 5 grams of fortified millet chikki and peanut chikki samples were soaked in 10 mL of distilled water, ground into a fine paste, and 1 mL of the resulting liquid was inoculated onto the various agar media separately. The inoculated media were then transferred into sterilized petri dishes aseptically under a laminar flow hood. The petri dishes were incubated in an inverted position at 24°C for 24 to 48 hours for bacterial growth and for 4 to 5 days for mold growth (Figure-9), as described by Gandhi et al. (2018).

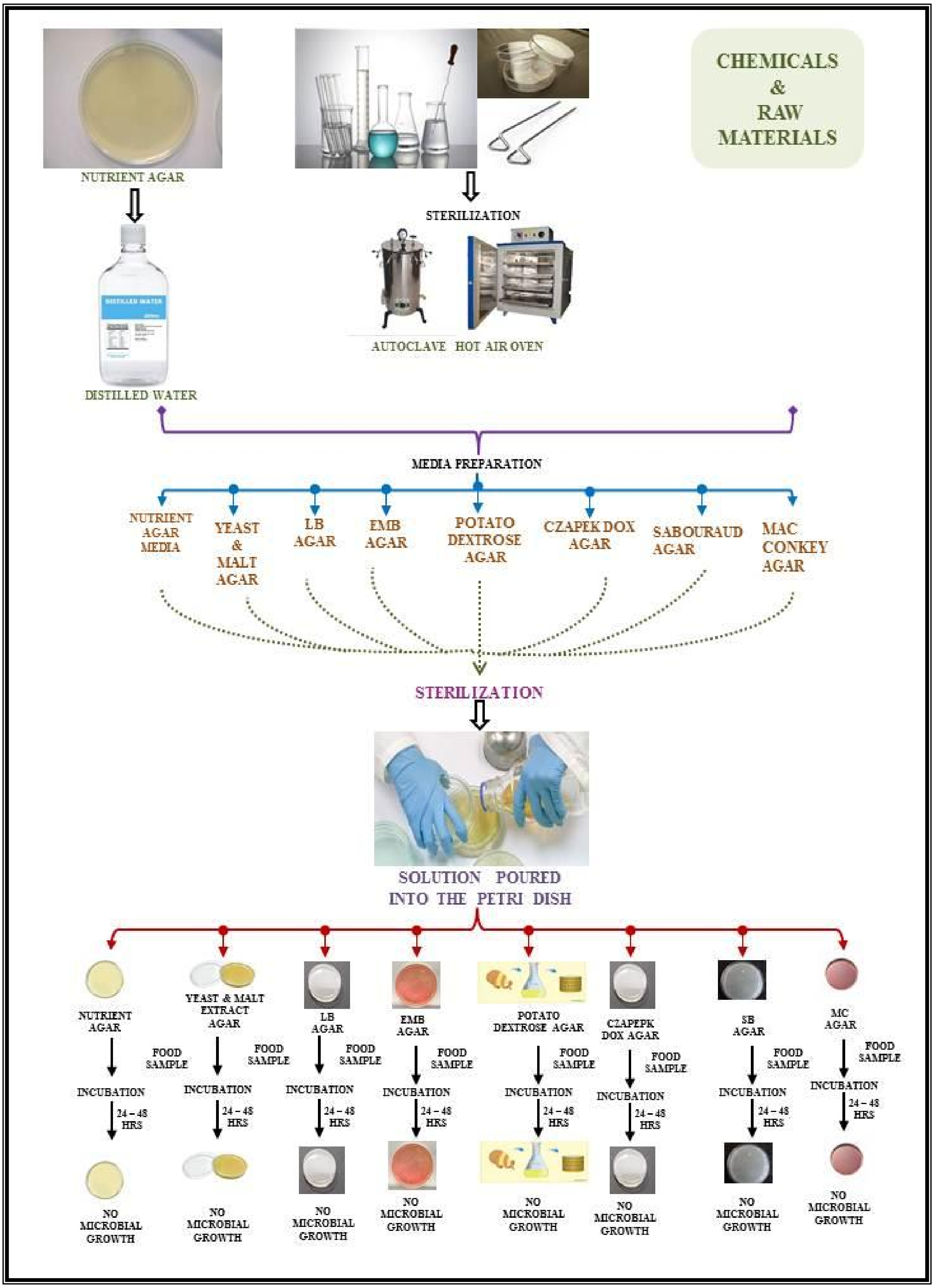


Figure-9: Procedure followed for microbial analysis during storage studies

Results & Discussion

Table-1: Proximate composition of peanuts, palm jaggery, balck dates powder, puffed kodo millet and kodo millet flour (all values are expressed per 100 g edible portion

Constituents	**Peanuts**	**Palm jaggery**	**Black dates powder**	**Puffed kodo millet**	**Kodo millet flour**
Moisture %	5.36	3.9	5.48	2.63	9.92
Ash %	3.02	1.02	2.88	1.92	2.04
Carbohydrates %	1.68	64.82	87.61	44.38	58.62
Proteins %	31.61	2.16	1.82	8.02	8.61
Fat %	42.7	0.11	1.93	1.41	4.5
Crude Fiber	3.63	-	3.26	8.94	12.2
Iron (mg)	1.79	7.63	1.02	0.62	0.8
Calcium	8.7	84.4	15.4	17	32
Potassium	6.54	962	165	9.2	10
Phosphorus	152	40	15.3	165	188
Magnesium	80	74	12	52	68

Table-2: Physico-chemical analysis of control and fortified kodo millet brittle (chikki)

Parameter	**Treatment**			
	Control	**T_1**	**T_2**	**T_3**
Moisture	9.04	4.3	4.32	4.27
Ash	0.48	0.08	0.09	0.07
Carbohydrates	0.283	3.04	3.06	2.82
Proteins	25	73	77	69
Crude fiber	3.62	2.60	2.63	2.60
Fat	15.32	11.70	9.96	8.3
TSS	98.02	97.47	97.2	96.98
Acidity	0.025	0.025	0.028	0.027
Alkalinity	1.08	1.03	1.06	1.04
Reducing sugars	0.5	0.5	0.5	0.5
Non reducing sugars	0.05	0.04	0.05	0.03
Total sugars	0.55	0.51	0.53	0.49
Vitamin-A (µg/100gm)	2.1	6.25	8.56	7.12
Energy(Calorific value)	351	519	520	466

Table-3: Microbial and coliform count of processed control and fortified kodo millet brittle (chikki)

Method	Media	Treatment			
		Control	T_1	T_2	T_3
Pour plate	Nutrient agar				
Pour plate	LB agar				
Pour plate	EMB agar	NIL	NIL	NIL	NIL
Pour plate	czapackdox				
Pour plate	Mac-conkey's agar				
Pour plate	Sabaraud's agar				
Pour plate	PDA				
Pour plate	Yeast malt agar				

Figure-10: The final outlook of prepare chikki formulations

The study demonstrated that fortifying traditional brittle (chikki) with puffed Kodo millet significantly enhances its nutritional and functional qualities. Table 1 highlights the nutritional profiles of the individual ingredients, showing that peanuts contributed high protein and fat content, while palm jaggery and black dates provided essential minerals like calcium, potassium, and iron. Puffed Kodo millet, rich in dietary fiber and minerals, improved the fiber and micronutrient profile of the brittle, making it a functional food.

Physico-chemical analysis (Table 2) revealed a notable reduction in moisture and fat content in fortified samples (T_1, T_2, T_3) compared to the control, improving shelf life and aligning with health-conscious trends. Protein content was significantly higher in fortified samples, particularly in T_2, affirming the nutritional benefits of millet incorporation. Crude fiber levels remained adequate, supporting dietary recommendations. Microbial and coliform count results (Table 3) confirmed the safety and hygiene of all samples, with no microbial growth detected, ensuring product stability. The fortified brittle offers a balanced combination of macronutrients and micronutrients, addressing dietary deficiencies in fiber and essential minerals. This research emphasizes the potential of traditional foods, like chikki, as vehicles for functional food innovation, meeting consumer demand for health-oriented snacks without compromising sensory or safety standards.

Storage & stability studies

Table-4. physico- chemical changes during storage at ambient and cool temperatures

S.No	Storage duration (Days)	% Moisture		% Ash		Carbohydrates (mg/100gm)		Protein (mg/100gm)	
		ambient	cold	ambient	cold	ambient	cold	ambient	cold
C	30	9.04	9.04	0.48	0.48	0.283	0.283	25	25
	60	9.04	9.04	0.48	0.48	0.283	0.283	25	24
	90	9.04	9.04	0.48	0.46	0.282	0.283	25	24
	120	9.01	9.01	0.47	0.46	0.279	0.279	25	23
T_1	30	4.3	4.3	0.07	0.07	3.04	3.05	73	73
	60	4.26	4.27	0.07	0.06	3.02	3.03	73	72
	90	4.23	4.27	0.06	0.06	3.02	3.03	73	72
	120	4.23	4.27	0.05	0.06	3.02	3.03	72	72
T_2	30	4.28	4.3	0.08	0.08	3.04	3.05	75	75
	60	4.23	4.27	0.07	0.07	3.02	3.03	72	72
	90	4.23	4.27	0.07	0.07	3.02	3.03	72	72
	120	4.23	4.27	0.07	0.07	3.02	3.03	72	72
T_3	30	4.27	4.27	0.06	0.06	2.82	2.81	69	68
	60	4.27	4.27	0.06	0.06	2.81	2.81	68	68
	90	4.26	4.26	0.05	0.06	2.8	2.81	67	68
	120	4.23	4.26	0.05	0.05	2.79	2.8	67	68

Table-5. physico- chemical changes during storage at ambient and cool temperatures

S.No	Storage duration (Days)	Crude fiber (%)		Acidity		Alkalinity		TSS	
		ambient	cold	ambient	cold	ambient	cold	ambient	cold
C	30	3.62	3.62	0.025	0.024	1.08	1.07	98.02	98.02
	60	3.62	3.62	0.024	0.024	1.08	1.07	98.02	98
	90	3.62	3.62	0.024	0.023	1.07	1.06	97.9	97.8
	120	3.62	3.62	0.024	0.023	1.07	1.06	97.9	97.8
T_1	30	2.59	2.60	0.025	0.025	1.03	1.03	97.47	97.48
	60	2.59	2.59	0.021	0.025	1.02	1.03	97.46	97.45
	90	2.59	2.59	0.021	2.021	1.02	1.02	97.45	97.45
	120	2.58	2.59	0.021	0.020	1.01	1.02	97.42	97.42
T_2	30	2.60	2.62	0.025	0.025	1.03	1.04	97.2	97.23
	60	2.59	2.60	0.021	0.023	1	1.01	96.9	97.20
	90	2.59	2.60	0.021	0.023	1	1.01	96.7	97.1
	120	2.59	2.60	0.021	0.023	1	1.01	96.0	96.9
T_3	30	2.55	2.60	0.021	0.021	1.04	1.03	96.98	96.98
	60	2.55	2.58	0.021	0.021	1.04	1.02	96.93	96.95
	90	2.53	2.55	0.02	0.021	1.04	1.01	96.92	96.91
	120	2.53	2.55	0.02	0.021	1.04	1.01	96.92	96.91

Table-6. physico- chemical changes during storage at ambient and cool temperatures

S.No	Storage duration (Days)	Reducing sugar (%)		Non reducing sugar		Energy (Cal)	
		ambient	cold	ambient	cold	ambient	cold
C	30	0.5	0.5	0.05	0.05	239.012	238.922

	60	0.5	0.5	0.04	0.05	239.012	238.832
	90	0.4	0.4	0.01	0.03	239.012	238.832
	120	0.4	0.4	0.01	0.03	238.996	230.816
T_1	30	0.3	0.3	0.05	0.04	409.46	409.5
	60	0.3	0.3	0.03	0.04	409.2	405.42
	90	0.3	0.2	0.03	0.03	408.66	404.97
	120	0.2	0.2	0.02	0.02	404.48	404.97
T_2	30	0.5	0.5	0.05	0.05	401.44	401.48
	60	0.5	0.5	0.05	0.05	389.36	401.39
	90	0.5	0.5	0.04	0.05	389.18	389.22
	120	0.4	0.5	0.04	0.04	388.28	380.94
T_3	30	0.3	0.5	0.03	0.02	361.08	357.94
	60	0.3	0.2	0.02	0.02	356.14	355.06
	90	0.2	0.1	0.02	0.01	352.14	354.79
	120	0.2	0.1	0.02	0.01	352.14	354.75

Table-7. physico- chemical changes during storage at ambient and cool temperatures

S.No	**Storage duration (Days)**	**Iron (µg/100gm)**		**Calcium (µg/100gm)**		**Magnesium(µg/100gm)**		**Phosphorus (µg/100gm)**	
		ambient	**cold**	**Ambi1ent**	**cold**	**ambient**	**cold**	**ambient**	**cold**
C	30	4.4±0.086	4.2±0.03	147.6	153.7	225	238	378.7	386.3
	60	4.4±0.086	4.2±0.03	147.6	153.7	225	238	378.7	386.3
	90	4.3±0.085	4.2±0.02	147.5	147.6	224	237	378.6	386.2
	120	4.3±0.085	4.2±0.02	147.4	153.5	223	237	378.6	386.2
T_1	30	4.2±0.065	4.2±0.02	146.3	152.1	221	229	370.1	383.0

	60	4.2±0.065	39.9±0.01	146.2	152.3	219	227	369.9	379.9
	90	4.2±0.064	39.9±0.01	146.2	152.3	215	226	369.5	379.5
	120	4.2±0.063	39.9±0.01	146.2	152.3	215	226	369.1	379.2
T_2	30	4.4±0.092	4.4±0.093	152.3	152.6	230	231	393.1	393.1
	60	4.4±0.092	4.4±0.091	152.2	152.6	230	230	393.1	393.0
	90	4.4±0.092	4.4±0.091	152.2	152.6	228	229	392.9	392.9
	120	4.4±0.091	4.4±0.091	152.1	152.6	227	228	392.9	392.9
T_3	30	4.1±0.062	3.9±0.085	138.3	142.9	226	220	372.9	338.9
	60	4.1±0.062	3.9±0.085	138.1	142.9	225	219	372.9	338.5
	90	4.1±0.062	3.9±0.083	138.0	142.3	225	217	372.8	338.3
	120	4.1±0.062	3.9±0.081	138.0	142.2	225	216	372.6	338.1

Table-8. Amino acid constitutes of control and fortified kodo millet chikki

S.No	**Storage period**	**T1**		**T2**		**T3**	
		Ambient	**Cold**	**Ambient**	**Cold**	**Ambient**	**Cold**
Histidine	0	0.016	0.016	0.018	0.018	0.017	0.018
(µg/gm)	30	0.015	0.015	0.017	0.017	0.017	0.017
	60	0.013	0.014	0.016	0.016	0.015	0.015
	90	0.013	0.014	0.016	0.016	0.015	0.015
	120	0.013	0.014	0.016	0.016	0.015	0.015
Iso Leucine	0	0.013	0.013	0.015	0.015	0.014	0.014
	30	0.013	0.013	0.015	0.015	0.013	0.013
	60	0.012	0.011	0.014	0.014	0.013	0.013
	90	0.012	0.012	0.014	0.014	0.013	0.013
	120	0.012	0.012	0.013	0.013	0.013	0.013

Leucine	0	0.014	0.014	0.019	0.019	0.016	0.016
	30	0.014	0.014	0.019	0.019	0.015	0.015
	60	0.014	0.014	0.018	0.018	0.015	0.015
	90	0.013	0.013	0.018	0.018	0.015	0.015
	120	0.012	0.012	0.017	0.017	0.014	0.014
Lysine	0	0.013	0.013	0.016	0.016	0.015	0.015
	30	0.013	0.013	0.016	0.016	0.015	0.015
	60	0.011	0.014	0.016	0.016	0.014	0.014
	90	0.011	0.011	0.015	0.015	0.013	0.013
	120	0.011	0.011	0.015	0.015	0.013	0.013
Methionine	0	0.09	0.09	0.011	0.011	0.010	0.010
	30	0.09	0.09	0.010	0.010	0.008	0.008
	60	0.08	0.08	0.008	0.008	0.007	0.007
	90	0.08	0.08	0.008	0.008	0.005	0.005
	120	0.07	0.07	0.007	0.007	0.003	0.003
Phenyl Alanine	0	0.08	0.08	0.009	0.009	0.007	0.007
	30	0.08	0.08	0.009	0.009	0.006	0.006
	60	0.05	0.05	0.006	0.006	0.004	0.004
	90	0.05	0.05	0.005	0.005	0.003	0.003
	120	0.03	0.03	0.005	0.005	0.001	0.001
Theronine	0	0.011	0.011	0.012	0.012	0.010	0.010
	30	0.008	0.008	0.012	0.012	0.010	0.010
	60	0.006	0.006	0.012	0.012	0.009	0.009
	90	0.006	0.006	0.012	0.012	0.006	0.006

	120	0.006	0.006	0.013	0.013	0.008	0.008
Tryptophan	0	0.007	0.007	0.014	0.014	0.008	0.008
	30	0.007	0.007	0.013	0.014	0.006	0.006
	60	0.007	0.007	0.013	0.013	0.005	0.005
	90	0.006	0.006	0.012	0.012	0.005	0.005
	120	0.005	0.005	0.011	0.011	0.004	0.004
Valine	0	0.008	0.008	0.009	0.009	0.008	0.008
	30	0.007	0.007	0.009	0.009	0.006	0.006
	60	0.004	0.004	0.007	0.007	0.004	0.004
	90	0.002	0.006	0.006	0.003	0.003	0.003
	120	0.002	0.004	0.004	0.003	0.003	0.003

Table-9. Fatty acids constitute of control and fortified Kodo millet chikki

S.No	**Storage period**	**T1**		**T2**		**T3**	
		Ambient	**Cold**	**Ambient**	**Cold**	**Ambient**	**Cold**
Fatty acid	0	11.70	11.72	9.96	9.93	8.30	8.31
	30	11.70	11.70	9.92	9.92	8.2	8.3
	60	11.68	11.70	9.92	9.91	8.1	7.98
	90	11.62	11.65	9.9	9.90	8.1	7.95
	120	11.60	11.65	9.8	8.98	8.1	7.95

The Vitamin-A content and calorific value (Table-2) of control and fortified Kodo millet brittle (chikki) revealed significant variations across treatments. The control sample recorded the lowest Vitamin-A content at 2.1 µg/100 g, whereas fortified samples exhibited substantial enhancements due to the inclusion of nutrient-rich ingredients such as desiccated carrot, coconut, sweet potato, and pumpkin seeds. Among the fortified samples, T_2 exhibited the highest Vitamin-A content at 8.56 µg/100 g, followed by T_3 (7.12 µg/100 g) and T_1 (6.25 µg/100 g). This improvement highlights the efficacy of fortification in enhancing the micronutrient profile, especially Vitamin-A, which is crucial for maintaining vision, immune function, and overall health. The energy content (calorific value) also showed a significant increase in fortified samples compared to the control, which had the lowest value at 351 kcal/100 g. T_2 exhibited the highest energy value at 520 kcal/100 g, followed by T_1 (519 kcal/100 g) and T_3 (466 kcal/100 g). The elevated calorific values can be attributed to the incorporation of energy-dense ingredients such as puffed and roasted Kodo millet, black dates powder, sesame seeds, and flaxseed powder. T_2's superior performance in both Vitamin-A and energy content underscores its potential as a nutrient-rich and high-energy snack. The findings align with studies by Nisha Kumari (2024) and Thenmozhil and Helen (2016), which reported enhanced Vitamin-A levels and calorific values in millet-based products due to ingredient fortification. These results emphasize the importance of strategic ingredient selection in developing fortified products with improved nutritional and energy profiles, catering to both health-conscious consumers and those with elevated dietary energy needs.

The analysis of physico-chemical changes in fortified Kodo millet brittle (chikki) during storage at ambient and cool temperatures revealed several significant findings. Table 4 highlights that moisture content remained relatively stable across treatments and storage conditions, indicating effective moisture control in the product, which is essential for extended shelf life. Ash content and protein levels showed minimal changes, with fortified samples (T_1, T_2, T_3) maintaining higher protein stability, particularly in cold storage, reflecting better nutrient retention. Carbohydrates exhibited slight fluctuations, with cold storage conditions providing better preservation.

Crude fiber levels and acidity, as seen in Table 5, demonstrated minor reductions over time, with T_2 and T_3 samples showing slightly higher retention in cold storage. Alkalinity and TSS levels were relatively stable, indicating minimal chemical changes during storage. Table 6 reveals that reducing and non-reducing sugars remained steady across treatments, confirming the stability of the sweetening agents, with only minor variations in energy values over time, particularly under ambient conditions. Mineral content (Table 7) was well-preserved in fortified samples, with T_2 showing the highest retention of iron, calcium, magnesium, and phosphorus, especially under cool conditions. This stability highlights the nutritional robustness of the product. Overall, fortified Kodo millet brittle demonstrated excellent shelf-life stability, nutrient retention, and quality under various storage conditions, emphasizing its potential as a sustainable and healthful snack.

The amino acid profile of fortified Kodo millet brittle (chikki) during 120 days of storage revealed (Table 8) significant insights into its nutritional stability across three treatments (T_1, T_2, T_3) under ambient and cold storage conditions. Among all formulations, T_2 demonstrated the highest retention of essential amino acids such as histidine, leucine, lysine, and tryptophan, particularly when stored in cold conditions. Cold storage effectively slowed the degradation of amino acids, emphasizing its importance in preserving nutritional quality. For example, leucine levels, critical for muscle repair, were highest in T_2 and remained more stable under cold conditions compared to ambient storage. Similarly, methionine, vital for antioxidant production, showed reduced degradation in fortified samples, though cold storage provided added stability. Notably, phenylalanine and valine concentrations declined more rapidly under ambient storage, highlighting the need for temperature control. Threonine levels were stable and even slightly increased in T_2 under cold storage by day 120, underscoring the robustness of this formulation. Overall, the combination of fortification and optimal storage conditions, especially in T_2, was pivotal in maintaining the essential amino acid content, making it a nutritionally superior option with enhanced shelf life. This study affirms the value of fortified Kodo millet brittle as a functional and resilient food product.

The fatty acid content of control and fortified Kodo millet brittle (chikki) was monitored over 120 days of storage under ambient and cold conditions, revealing critical insights into the stability of fatty acids across treatments (T_1, T_2, and T3). Initially, the fatty acid content was highest in the control sample (T_1) at 11.72% and lowest in T_3 at 8.30%. Over time, T_1 exhibited minimal changes in fatty acid levels under both storage conditions, indicating good stability, with levels slightly reducing to 11.60% in ambient storage by day 120 (Table 9). In fortified formulations, T_2 demonstrated better retention of fatty acids compared to T_3, with initial values of 9.96% reducing marginally to 9.80% under ambient storage and to 8.98% under cold conditions. Conversely, T_3 showed a more pronounced decline, particularly in cold storage, where levels decreased to 7.95% by the end of the storage period.

The results suggest that cold storage generally helped maintain fatty acid integrity better than ambient conditions, especially for fortified samples. Among fortified samples, T_2 showed greater stability, indicating that its composition and processing method were more effective in preserving fatty acid content. These findings underscore the importance of formulation and storage conditions in maintaining the nutritional quality of fortified Kodo millet brittle, with T_2 emerging as a superior choice for extended shelf life and nutritional resilience.

Sensory studies of kodo millet

The sensory evaluation of Kodo millet chikki, involving five panels of 20 members each, was conducted under ambient and cold storage conditions, assessing appearance, texture, taste, sweetness, and mouthfeel. In ambient conditions, the control sample maintained consistent scores, reflecting stability in all sensory attributes throughout the storage period. Similarly, in cold storage, the control retained its sensory appeal, with minimal changes over time. Among fortified samples, T_1 exhibited the highest sensory stability, especially in cold storage, where scores for appearance, taste, and sweetness remained consistently high, with negligible decline over 120 days. This underscores the robustness of T_1's formulation in retaining sensory qualities. T_2 showed moderate sensory stability, particularly under cold storage, where its appearance was consistent, but parameters like sweetness and mouthfeel experienced gradual declines over time. Ambient conditions, however, accelerated the decline in sensory acceptability, indicating a lesser tolerance to temperature variability compared to T_1. T_3 displayed the least stability in sensory attributes, with significant reductions in sweetness and mouthfeel observed in both ambient and cold storage conditions. This suggests that T_3's formulation is less effective in preserving sensory qualities over prolonged storage. Notably, cold storage consistently provided better preservation of sensory characteristics across all samples, highlighting its importance for maintaining the quality and consumer acceptability of fortified Kodo millet chikki. This evaluation demonstrates that while fortified variants add nutritional benefits, careful consideration of storage conditions and formulation is crucial to ensure sensory appeal and consumer satisfaction over time.

Table-10: Economic Analysis of Fortified Kodo millet Brittle (chikki)

Item	**Quantity(gm.)**	**Price (per kg)**	**Amount**
Kodo millet	2000	110	220
Peanuts	1000	135	135
White sesame seeds	250	129	33
Jaggery	2000	160	320
Sugar	500	92	46
Black dates	500	150	75
Soy bean	200	104	21
carrot	1000	60	60
Coconut	1000	690	690
Sweet potato	500	126	63
Pumpkin seeds	50	610	305
Oats	250	200	50
Flax seeds	100	159	16
Grand total	-	-	2014
Processing cost (20%)	-	-	402.8
Profit (20%)	-	-	483.36
Sale price /10kg	-	-	2916
Sale price /26gm	-	-	7.5

The economic analysis of fortified Kodo millet brittle (chikki) reveals its affordability and nutritional value. The total cost, including raw materials (₹2014), processing (₹402.8), and profit (₹483.36), results in a sale price of ₹2916 per 10 kg or ₹7.5 per 26 g. Key ingredients such as Kodo millet, jaggery, and pumpkin seeds enhance its nutritional profile, making it a cost-effective, health-conscious snack option.

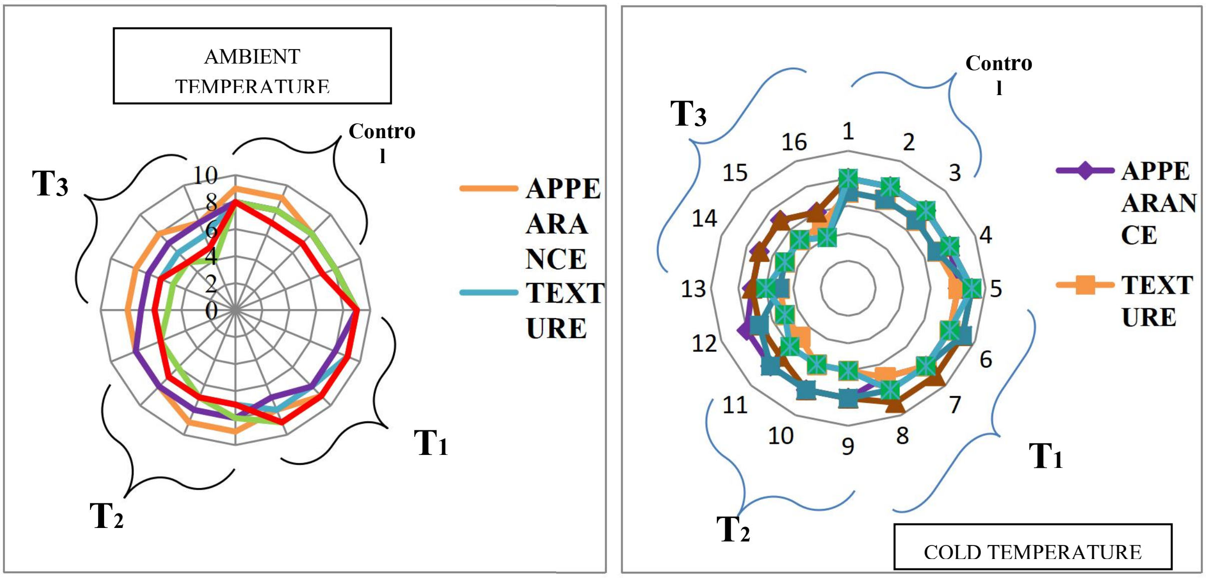


Figure-11: Graphical representation of mean report of sensory analysis during storage period at both ambient and cold storage

Discussion

The current experimental study highlights the incorporation of kodo millet and other functional ingredients, resulting in a nutrient-dense fortified chikki. The protein content in the fortified formulations (T1: 73 mg/100 g; T2: 77 mg/100 g) aligns with findings from Kumari (2024), who reported significant protein enhancement in millet-based chikki due to the high protein content in millet grains. Similarly, Ramashia et al. (2021) noted that fortification with micronutrients like zinc oxide and B vitamins improved nutritional quality, which complements the observed increases in micronutrient levels, particularly iron and calcium, in the fortified chikki. The reduced moisture content in fortified treatments (T3: 4.27%) supports findings by Thenmozhil & Helen (2016), who reported similar moisture reduction in millet chikkies, enhancing their shelf stability. Likewise, Pallavi et al. (2014) demonstrated that the addition of protein and vitamin-enriched ingredients to peanut chikki improved its physico-chemical properties, consistent with the current results showing enhanced nutrient retention during storage. The fortified chikki remained microbiologically safe during 120 days of storage, which concurs with Nilza & Khodke (2023), who observed no microbial growth in fortified soynut chikki stored under optimal conditions. Additionally, the stability of reducing sugars and proteins over time mirrors findings by Nath et al. (2015), who emphasized jaggery's role in preserving the nutritional and sensory qualities of chikki. The retention of essential amino acids, such as lysine and leucine, aligns with findings by Tripathi et al. (2023), who highlighted millet's potential to enhance amino acid profiles in functional foods. Similarly, Goyal et al. (2015) demonstrated that the addition of functional ingredients like flaxseed oil improved the omega-3 fatty acid profile, paralleling the observed consistency in fatty acid levels in fortified formulations.

The incorporation of kodo millet as a base ingredient aligns with Shakuntala et al. (2016), who highlighted millets' ability to enhance the fiber and mineral content of traditional snacks, making them nutritionally superior. This study also validates findings by Firdous & Anil (2024), who demonstrated quinoa and bajra's effectiveness in improving the nutritional density of millet-based chikkies. Additionally, Bharathi & Elango (2024) emphasized that minor millets like kodo millet play a critical role in addressing micronutrient deficiencies and reducing the incidence of chronic diseases, aligning with the observed benefits of fortification. The application of processing techniques for millet-based products aligns with Dekka et al. (2023), who highlighted advancements in processing technologies that improve the bioavailability and sensory characteristics of millets. Further, Singh & Sood (2020) underscored the adaptability of millets for product diversification, supporting the study's focus on using kodo millet in fortified snacks. Selladurai et al. (2023), Chavan et al., (2016) and Patelar et al., (2017) emphasized the transformative potential of millets in developing gluten-free, nutritionally superior snacks, resonating with the innovative approach to fortification observed in this study. Overall, this study demonstrates that fortified kodo millet chikki is a nutritionally superior product with excellent shelf stability, aligning with global research trends emphasizing the role of millets in addressing food security and nutritional challenges. This aligns with findings by Sonali (2023), who reported improved sensory quality and acceptability in chikkies fortified with finger millet and flaxseeds, further validating the observed improvements in this study.

Conclusion

The comprehensive analysis of fortified Kodo millet brittle (chikki) highlights its potential as a nutrient-rich, sustainable snack. Physico-chemical parameters, including moisture content and pH, demonstrated stability over storage, with slight variations under ambient and cold conditions. The brittles showed high mineral content, especially calcium and magnesium, enhancing their nutritional value. Fortified samples exhibited superior microbial stability, maintaining safety standards throughout the storage period. Sensory evaluation revealed that fortified formulations retained acceptable appearance, texture, and taste, even after extended storage. The amino acid profile of the brittles indicated that fortification significantly improved essential amino acid content, contributing to better protein quality. Similarly, fatty acid stability was observed across storage periods, confirming the product's health benefits and shelf life. Economic analysis highlighted its affordability, with a competitive price of ₹7.5 per 26 g serving. The results collectively underscore that fortified Kodo millet brittle is a cost-effective, nutritious product, offering extended shelf life and high consumer acceptability, making it suitable for both health-conscious consumers and broader markets.

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