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Research Article

Development of fibre, protein and essential nutrient rich traditional snack from incorporation of barnyard millet and soy flour

N. Gandhi[1,2,3,4], Y. Rama Govinda Reddy[4], K. Rama Naik[2,4], K. Mounika[1], Ch. Vijaya[5]*

[1]Department of Food Quality & Food Safety, Metagro Pvt, Ltd. Kavuri Hills, Jubilee Hills, Hyderabad, Telangana, India, [2]Department of Plant Nutrition, ISAAYU FARMS Pvt. Ltd. Amar Co-Operative Society, Kavuri Hills, Jubilee Hills, Hyderabad, Telangana, India, [3]Department of Food and Dairy Sciences, Reddys Agricultural Institute and Research Council, Ibrahimpatnam, Ranga Reddy, Telangana, India, [4]Department of Crop Physiology, Green Fields Institute of Agriculture Research and Training, Mangalpally, Ibrahimpatnam, Rangareddy, India, [5]Department of Marine Biology, Vikrama Simhapuri University, Nellore, Andhra Pradesh, India

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*Corresponding Author: Ch. Vijaya (E-mail: vijayalch@gmail.com)

ABSTRACT

Chikki, a traditional Indian confectionery made using groundnut and jaggery, is popular across all age groups. This study aimed to enhance its nutritional profile by developing a multigrain Nutri-chikki enriched with barnyard millet, soy flour, sesame seeds, puffed barnyard millet, dry black dates powder (iron source), desiccated carrot, coconut, sweet potato, and pumpkin and flax seeds. The nutritional content and storage stability of the Nutri-chikki were assessed. The multigrain Nutri-chikki was organoleptically evaluated using a nine-point hedonic scale with a sensory panel of 20 trained members. The results revealed that the Nutri-chikki formulations (T_1, T_2, T_3) contained significant amounts of protein (14.78 g), fat (16.6 g), fiber (4.1 g), and minerals, including iron (9.67 mg), calcium (269.9 mg), potassium (839.75 mg), phosphorus (565.1 mg), and magnesium (462.92 mg) per 100 g, which were nutritionally superior to the control (groundnut chikki). While there were minor variations across the treatments (T_1, T_2, T_3), the values were comparable, indicating uniformity in nutritional enhancement. The Nutri-chikki showed an overall sensory acceptability score of 8.3, outperforming the control (7.8). Storage studies at ambient (25-30 °C) and cold (4-8 °C) conditions demonstrated that the Nutri-chikki retained acceptable sensory qualities for up to 120 days, as evaluated at 30-day intervals. The findings highlight the potential of Nutri-chikki as a nutritious and shelf-stable alternative to traditional chikki, suitable for wider consumer acceptance.

Key words: Barnyard millet, Soy flour, Fiber, Protein and Mineral enriched nutria chikki

INTRODUCTION

In recent years, there has been a notable shift in consumer preferences towards food products that offer not only great taste but also enhanced nutritional value (Settaluri *et al.,* 2012). Traditional snacks like Nutri-chikki have gained popularity as they fulfill the dual purpose of providing a delightful eating experience while offering essential nutrients necessary for maintaining a balanced diet (Abhirami & Karpagapandi, 2018). Nutri-chikki, a cherished traditional sweet snack in India, has undergone significant evolution with the incorporation of a variety of nutrient-rich ingredients such as pumpkin seeds, flax seeds, groundnuts, almonds, foxtail millet, black sesame seeds, and roasted Bengal gram (Savage & Keenan, 1994; Harsha & Bharti, 2015; Tidke *et al.,* 2017; Komal *et al.,* 2019). These additions have not only augmented the flavor and texture of the chikki but have also significantly enriched its nutritional profile, making it an attractive option for health-conscious consumers. The inclusion of specific ingredients in Nutri-chikki offers a plethora of health benefits. Pumpkin seeds, for instance, are rich in protein and contribute significantly to the daily recommended protein intake (Settaluri *et al.,* 2012). Roasted pumpkin seeds are known to relax nerves and muscles, strengthen bones, and aid in circulation. Flaxseeds, another key ingredient, are renowned for their high alpha-linolenic acid content, making them an excellent alternative to marine products and potentially effective in combating cardiovascular diseases (FAO, 2007; Settaluri *et al.,* 2012). Furthermore, the incorporation of groundnuts provides a good source of vitamin E and magnesium, offering antioxidant properties and supporting muscle function and energy production (Abhirami & Karpagapandi, 2018). Almonds, with their abundance of bioavailable α-tocopherol and polyphenolic constituents, exert antioxidant actions and contribute to overall health and well-being (Coşkuner & Karababa, 2007; Harsha & Bharti, 2015).

Additionally, the inclusion of millets such as foxtail millet and proso millet in Nutri-chikki offers benefits in reducing triacylglycerol levels and inflammation-related indicators, potentially lowering the risk of cardiovascular diseases (Komal *et al.,* 2019). Sesame seeds, widely used in food and nutraceutical industries, are valued for their high oil, protein, and antioxidant contents, offering protective effects against various disorders including hypertension, hypercholesterolemia, and oxidative stress (Chetana & Sunkireddy, 2011). While traditional Nutri-chikki has seen significant advancements in incorporating

nutrient-rich ingredients, there remain research gaps in the development of fiber and protein-rich traditional snacks (Snehal & Shrutika, 2018). Further exploration is warranted to optimize formulations and processing techniques to enhance the nutritional content, sensory attributes, and shelf-life stability of these products. Addressing these gaps will not only contribute to diversifying the snack market but also offer consumers a wider range of healthy and delicious options to incorporate into their diets (Vijaya *et al.,* 2007, 2009). In light of these considerations, this study aims to develop a fiber, protein, and essential nutrient-rich traditional snack by incorporating barnyard millet and soy flour into Nutri-chikki. By leveraging the nutritional benefits of these ingredients, this research endeavors to contribute to the ongoing efforts in promoting healthier snack alternatives and addressing the evolving needs of consumers seeking nutritious and flavorful food options.

MATERIALS AND METHODS

Grains such as barnyard millet (*Echinochloa esculenta* L.), soybean seeds (*Glycine max* L.), black dates (*Phoenix dactylifera* L.), pumpkin seed (*Curcubita* sp.), flax seed (*Linum usitatissium* L.), ground nut (*Arachis hypogea* L.), almond (*Prunus dulcis*), sesame (*Sesamum indicum*) black and white, oats (*Avena sativa*) and sweeteners such as jaggery, corn syrup, sugar were purchased in bulk from local market of Ibrahimpatnam, Rangareddy district of Telangana. Packaging material viz., polyethylene bags (150-gauge thickness), metalized polypropylene pouch, and plastic round container were used for packing multigrain Nutri-chikki. The chemicals and reagents used in the experiments were of Laboratory Reagent (LR), Analytical Reagent (AR) or Guaranteed Reagent (GR) grade. All the reagents and standard stock solutions were prepared using purified deionized water and primary standard solutions. All the glassware used in the present study was cleaned and sterilized according to standard microbiology procedures.

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	Barnyard millets puffed + roasted barnyard millet + finely grounded peanuts + white sesame seeds + jaggery, sugar, black dates powder + barnyard flour + soy flour + desiccated carrot, coconut and sweet potato+pumpkin seeds	25:5:5:10:35:5:5:5:5
T_2	Barnyard millets puffed + roasted barnyard 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	Barnyard millets puffed + roasted barnyard 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

The standardization of multigrain Nutri-chikki was done with pumpkin seed, flax seed, groundnut, oats, almond, black sesame, white sesame, barnyard millet, black dates, jaggery, and little amount of corn syrup and evaluated its consistency through organoleptic evaluation. Based on this evaluation, the three combinations of Nutri-chikkis were prepared with different grains such as pumpkin seed, flax seed, ground nut, almond and barnyard millet as standard ingredients in the ratio of 20:10:20:5:20 (75%) and variations (25%) were made with oats, white sesame, black sesame and roasted Bengal gram (Table 1). A control groundnut chikki prepared by 100% jaggery and roasted and coarsely grounded grounds.

Flow diagram of barnyard millet flour preparation

Barnyard millet
↓
Wash 5-7 times with water to avoid dust, sand and unwanted materials
↓
Soak 5 hours in fresh water
↓
Drain off excess water
↓
Tie in muslin cloth
↓
Keep for 24 hours at room temperature
↓
Dry in shade for 2 days
↓
Grinding
↓
Barnyard millet flour

Flow diagram for puffed barnyard millet preparation

5 kg of barnyard millet
↓
Wash 5-6 times with water to avoid dust, sand and unwanted materials
↓
Soak overnight in just boiled water
↓
Shade dry for 2 days
↓
Conditioning (12 hours in closed stainless steel vessel)
↓
Roasting at 110-160 °C for 3-6 minutes
↓
Sieving
↓
Packing & storage

Flow diagram of black dates powder preparation

5 kg black dates (dry)
↓
Grinding
↓
Sieving
↓
Packing & storage

Flow diagram of Soybean flour preparation

5 kg of soybean
↓
Wash 5-7 times with water to avoid dust, sand and unwanted materials
↓
Soak 5 hours in fresh water
↓
Drain off excess water
↓
Tie in muslin cloth
↓
Keep for 24 hours at room temperature
↓
Dry in shade for 2 days
↓
Roast at low flame until makes aroma and crunch
↓
Grinding
↓
Soy flour

Flow diagram for preparation palm jaggery syrup

Fresh grated palm jaggery
↓
Add water as per require
↓
Heating up to 115 °C
↓
Stirring continuously
↓
Jaggery syrup

Flow diagram for preparation of desiccated carrot

Carrot
↓
Washing, sorting, grading, peeling
↓
Cutting into dices
↓
Blanching
↓
Drying in cabinet dryer at 55-60 °C for 6-8 hours
↓
Cooling at room temperature
↓
Packaging at polypropylene pouches
↓
Storage at ambient temperature for 6-8 months

Flow diagram for preparation of desiccated coconut

Dehusking of coconut
↓
Deshelling
↓
Removal of brown testa
↓
Blanching
↓
Disintegration
↓
Drying
↓
Sieving/grading

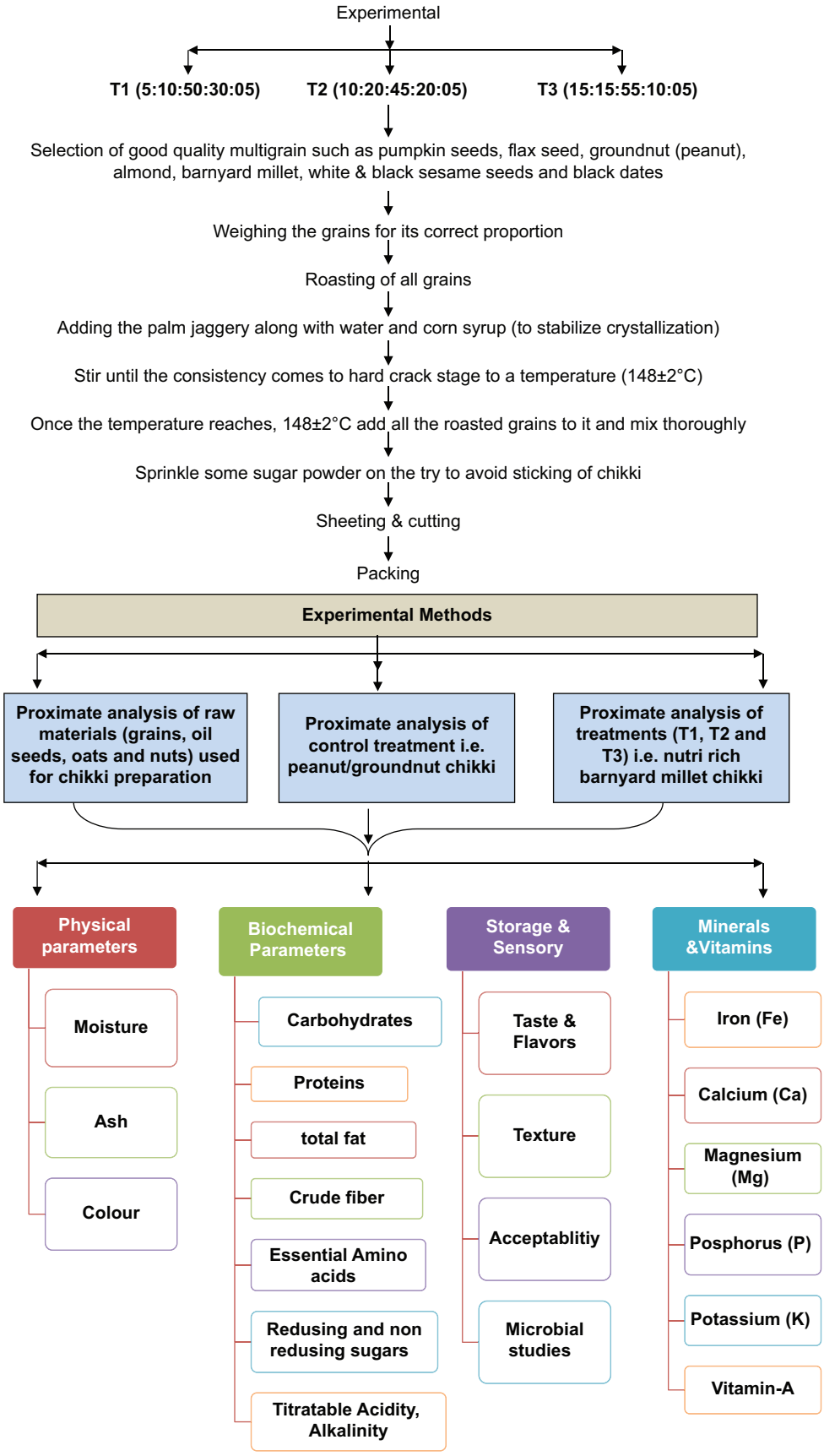
Flowchart for the preparation of desiccated sweet potato

Selection of sweet potato
↓
Washing and peeling of sweet potatoes
↓
Slicing of peeled sweet potato
↓
Tray drying (at 60 °C for 6 hours)
↓
Grinding
↓
Sieving (70 mesh)
↓
Sweet potato flour

Flow diagram adopted for control sample

Peanut seeds
↓
Roasting of peanut seed (at 40 °C for 15 minutes)
↓
Removal of peanut hull and coarsely grind
↓
Preparation of sugarcane jaggery syrup (65%)
↓
Mixing of coarsely grind peanut seed in syrup
↓
Pouring of mixture in previously greased try
↓
Cutting with knife in equal size
↓
Cooling (at 25 °C for 45 min)
↓
Packaging and storage

Flow diagram for experimental samples



Determination of physical parameters

Moisture

Moisture content can be estimation by drying the weighed sample to a steady weight in hot air oven at 70±2 °C. The sample dried later on cooled to room temperature in desiccators before weighing. Formula used for moisture content calculation in percentage is given below (Gandhi *et al.,* 2020a)

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

Total ash

First weigh silica dishes and later weigh each sample by taking 5-10 g of the dried fruit. Samples were heated on a Bunsen burner. Samples were placed in a muffle furnace at 525 °C for 4-6 hours to get ash. Dishes were allowed to cool and then weighed. The fluctuation in weight determines the total ash content and is expressed in percentage (Ranganna, 2007; Gandhi *et al.,* 2020b).

Instrumental analysis of color

The color of Nutri-chikki was assessed using a CIELAB measuring system (Model: LabScan, USA) with a 10° view angle. Three parameters were measured: L*, a*, b*, and ΔE. The L* parameter indicates the lightness of the product, with higher values corresponding to lighter colors. The a* parameter represents the redness (+a*) or greenness (-a*) of the sample, with positive values indicating redness and negative values indicating greenness. Similarly, the b* parameter represents the yellowness (+b*) or blueness (-b*) of the sample, with positive values indicating yellowness and negative values indicating blueness. The ΔE parameter signifies the total color difference between samples, providing a comprehensive measure of color variation (Pallavi *et al.,* 2014; Ramakrishna *et al.,* 2015).

Determination of biochemical parameters

Glycemic carbohydrates

Chikki samples (100 mg) were aliquoted into 16 X 125 mm tubes with screw caps in duplicate. Each tube received 5 milliliters of phosphate buffer (0.08M, pH 6.0) to facilitate matrix hydration and was subsequently stored at 4 °C for 12 hours. Following hydration, the samples underwent enzyme hydrolysis to degrade soluble starch. Specifically, α-amylase solution (50 µL) was added to each tube, and the tubes were then placed in a water bath at 95 °C for 30 minutes using equipment from Daihan Labtech Co., Ltd. (Korea). After incubation, the tubes were cooled to 60 °C and the pH was adjusted to 7.5 with 1 milliliter of 0.275 M NaOH. Protease solution (50 µL) was subsequently added to the tubes, which were then incubated at 60 °C for an additional 30 minutes. The pH was then lowered to 4.5 by adding 1 milliliter of 0.325 M HCl, followed by the addition of amyloglucosidase solution (150 µL). The tubes were once again incubated at 60 °C for 30 minutes.

Following enzymatic treatment, the residue was separated by centrifugation. The liquid supernatant was transferred to a 100 milliliter volumetric flask and diluted to the mark with deionized water. The determination of glycemic sugars in the supernatant was carried out using anthrone reagent. Various volumes of supernatant (ranging from 0.2 to 1 milliliter) were aliquoted into a series of test tubes, each of which was adjusted to a final volume of 1 milliliter with distilled water. To each tube, 4 milliliters of anthrone reagent was added, and the tubes were placed in a boiling water bath for 8 minutes before being rapidly cooled under running tap water. The optical density of the resulting solution, ranging from green to dark green, was measured at 630 nm against a blank. The concentration of glycemic carbohydrate was determined using a standard curve constructed with glucose as the standard (Devindra, 2015).

Total protein content

In accordance with the experimental protocol outlined by Gandhi *et al.* (2017, 2019), a meticulous procedure was followed to assess the biochemical properties of a formulated finished chikki. Initially, a clean test tube was utilized, into which precisely 1 mL of the chikki extract was carefully dispensed. Subsequently, the volume was meticulously adjusted to a total of 2 mL, achieving dilution, by supplementing it with distilled water. Following this, a precise volume of 3 mL of biuret reagent was introduced into the test tube, ensuring accurate measurement. The resultant mixture was then subjected to an incubation period at room temperature, precisely for a duration of 10 minutes, allowing for optimal reaction conditions. Upon completion of the incubation period, the colorimetric assessment was conducted using a spectrophotometer, set to a wavelength of 540 nanometers (nm). Before the measurement, appropriate calibration was ensured by setting the blank reading to zero, as per standard procedure in spectrophotometric analysis. The intensity of color developed in the solution was meticulously recorded at 540 nm wavelength, against the blank, which served as the reference point for adjustment. This meticulous process ensures the accuracy and reliability of the obtained data, conforming to rigorous academic standards in experimental methodology, as outlined by Gandhi *et al.* (2017, 2019).

Total fat content

The method of solvent extraction, as delineated by Pearson (1996) in the utilization of a Soxhlet reflux apparatus, was meticulously employed in this study. Initially, precisely 5 grams (g) of the sample under investigation was meticulously wrapped in a porous material, specifically Whatman filter paper, ensuring uniform distribution within the paper matrix. Subsequently, this prepared sample was delicately placed into the reflux flask of the Soxhlet apparatus, marking the initiation of the extraction process. Furthermore, to ensure

the robustness and reliability of the experimental data, another 5 g sample was meticulously measured and wrapped in a separate Whatman filter paper, forming a replicate. This replicate sample was then placed in another Soxhlet flask, mirroring the setup of the primary sample. This meticulous replication protocol was adopted to validate the consistency and reproducibility of the experimental outcomes.

The prepared flasks, each containing the sample material, were meticulously mounted onto the weighed oil extraction flasks, each containing precisely 200 milliliters (mL) of petroleum ether, the chosen solvent for extraction. Subsequently, all components of the Soxhlet apparatus were methodically coupled, ensuring airtight connections to prevent any leakage or loss of solvent during the extraction process. The heat was then judiciously applied to the apparatus via an electrothermal heating mantle, facilitating the vaporization of the solvent. The heated solvent vaporized and subsequently condensed into the reflux flask containing the sample, initiating the extraction process. This cyclical process continued until the desired extraction duration, with each setup left to operate for a period of 4 hours, ensuring adequate extraction efficiency. Upon completion of the extraction process, the reflux flasks were carefully removed from each setup. Subsequently, the extracted samples were delicately dried for a brief period of 3 minutes in an oven set at a controlled temperature of 60 degrees Celsius, ensuring the removal of any residual solvent and moisture content.

Crude fiber

The Weende method, as elucidated by Pearson (1996), served as the framework for conducting the analysis in this study. Each sample, precisely weighing 5 grams (g), was meticulously divided and wrapped in two-fold muslin cloth. Subsequently, the samples were subjected to boiling in 200 mL of 1.25% sulfuric acid (H_2SO_4) for a duration of 30 minutes under reflux conditions. This step facilitated the breakdown of complex organic compounds present in the samples. Following the acid treatment, each muslin cloth containing the treated sample was thoroughly washed with boiling water to remove any residual acid and solubilized components. The washed cloths were then transferred to boiling flasks containing 1.25% sodium hydroxide (NaOH) solution. Boiling under reflux conditions for 3 minutes facilitated the neutralization of acidic components and the solubilization of the remaining organic matter.

Subsequently, the treated cloths were washed again and carefully transferred to pre-weighed porcelain crucibles. The crucibles were then dried in an oven until a constant weight (w) was achieved, ensuring the removal of any moisture content. Following drying, the samples were subjected to ashing in a furnace at a temperature of 550 degrees Celsius (°C), resulting in the conversion of organic matter to ash. Upon completion of the ashing process, the crucibles containing the ashed samples were allowed to cool in a desiccator to prevent moisture absorption. The final weight (w) of the ashed samples was meticulously recorded for subsequent analysis and interpretation.

Estimation of amino acids

In this experimental procedure for the quantitative determination of amino acids from formulated chikki, the sample preparation involves weighing an appropriate amount of the chikki sample and grinding it into a fine powder. This powdered sample is then stored in a clean, dry container to prevent degradation. Next, the amino acids are hydrolyzed by adding concentrated hydrochloric acid to the powdered sample and heating it in a water bath for a period of 20 min at 80 °C. After hydrolysis, the solution is neutralized using sodium hydroxide (NaOH) and filtered to remove any insoluble particles. The filtrate is then derivatized to make the amino acids suitable for chromatographic analysis, following which it is injected into an HPLC system equipped with an appropriate column. The eluted amino acids are detected using a UV-Vis detector, and their concentrations are quantified by comparing peak areas or heights to those of known standards. Method validation and quality control checks are performed to ensure the accuracy and reliability of the results, and the findings are reported in a clear and concise format, considering the nutritional composition of the chikki sample. Throughout the procedure, adherence to standard protocols and referencing relevant literature sources contribute to the robustness of the analysis, enabling a comprehensive assessment of the amino acid profile (Vijaya *et al.,* 2010) of the formulated chikki.

Reducing and non-reducing sugars

In this experimental procedure, a meticulous approach was employed for the determination of reducing sugars and total sugars in the sample, following the methodology outlined by Lane and Eynon (1923). Initially, a known weight of the sample, precisely 25 grams, was carefully measured and placed into a 250 milliliter (mL) volumetric flask. Subsequently, 100 mL of water was added to the flask to create a solution. The solution was then neutralized with 1 N sodium hydroxide (NaOH), ensuring complete neutralization. Following neutralization, 2 mL of 45% lead acetate solution was added to the mixture, and the resulting solution was allowed to stand for a duration of 10 minutes to facilitate the reaction. To remove excess lead acetate from the sample, 2 mL of 22% potassium oxalate solution was employed. This solution was carefully added to the sample, and the resulting mixture was subsequently diluted up to the mark of the 250 mL volumetric flask. The solution was then filtered to obtain a clear filtrate suitable for further analysis.

For the estimation of reducing sugars, the clear filtrate was titrated against a known quantity of Fehling's A and Fehling's B solutions, employing methylene blue as an indicator. The reducing sugars present in the sample were quantified as a percentage based on the titration results. Additionally, the estimation of total sugars was carried out by adding 5 grams of citric acid to 50 mL of the calibrated sample solution.

The mixture was heated for 10 minutes to ensure complete inversion of sugars. Subsequently, neutralization with NaOH was performed, and the volume was adjusted to 250 mL in a volumetric flask. The total sugars present in the sample were determined as a percentage based on this procedure.

$$\text{Reducing sugars}(\%) = \frac{\text{Factor} \times \text{ dilution}}{\text{Totre value} \times \text{ weight of sample}} \times 100$$

$$\text{Total invert sugars} = \frac{\text{Factor} \times \text{ dilution}}{\text{Totre value} \times \text{ weight of sample}} \times 100$$

Titratable acidity and alkalinity

Titratable acidity was assessed with the method described by AOAC (1995). A measured volume of the sample was titrated with 0.1 N sodium hydroxide (NaOH) solution, employing phenolphthalein as the indicator. The titratable acidity was quantified and expressed as a percentage of malic acid. This standardized procedure ensures the accurate determination of titratable acidity, adhering to established protocols and guidelines outlined by AOAC (1995).

$$\frac{\text{Titre} \times \text{ Normality of alkali} \times \text{ volume made up} \times \text{equivalent weight of acid}}{\text{Volume of sample taken} \times \text{volume of aliquot taken} \times 1000} \times 100$$

Calorific value

Energy value was calculated by using the under mentioned formula:

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

Texture analysis

The breaking strength of Nutra Chikki was determined using the triple beam snap method, also known as the 3-point break method, employing a texture analyzer (Model: LR – 5 K, Lloyds, England, UK). Samples of both the control and Nutra Chikki, each measuring 2.5×5 cm, were subjected to the 3-point breaking test. The test was conducted utilizing a load cell of 1 kN with 6 replicates for each sample. A cross head speed of 50 mm/min and a deflection of 10 mm were maintained throughout the testing procedure. The Peak force at break, indicative of the breaking strength, was recorded for each sample, and the average values were subsequently reported. This methodological approach ensures the precise evaluation of the breaking strength of Nutra Chikki, adhering to standardized testing protocols and utilizing state-of-the-art equipment as per the specifications provided (Lloyds, England, UK).

Fatty acid analysis

The fatty acid composition of the chikki sample oil was determined through a standardized process. Firstly, the fats/oils were converted into fatty acid methyl esters (FAME) following the procedure outlined by the American Oil Chemists' Society (AOCS) method (AOCS, 1997), using 2 N methanolic/KOH. Subsequently, gas chromatography (GC) analysis was conducted using a Varian GC-450 instrument equipped with a Flame Ionization Detector (FID). Separation was achieved using an SP 2380 fused silica capillary column (0.25 mm × 30 m × 0.2 µm film thickness) from Supelco, Bellefonte, PA, USA. The GC was programmed to ramp from 100 to 220 °C at a rate of 5 °C/min and maintained at 220 °C for 5 minutes. Injection temperature was set at 220 °C, with a split ratio of 1:20. The detector temperature was maintained at 250 °C, and a nitrogen flow rate of 1 mL/min was utilized. Fatty acids were identified by comparison with authentic standards and reported as relative percentages.

Microbial examination of fortified barnyard millet brittle (chikki)

The processed millet and peanut chikki samples were tested for microbial contamination observed at a regular interval of 1 month up to 4 months. To determine the microbial contamination pour plate method was followed by preparing nutrient agar medium (for bacterial count), EMB (eosin methylene blue) agar medium (for entero bacteriaceae and related coliforms), LB (Luria Bertoni's) agar (for *E. coli*), Mac-conkey's agar (for differential growth of gram positive bacteria), czapackdox medium (for mould count), Sabaraud's agar (for pathogenic fungi isolation), PDA (potato dextrose agar) for isolation of spore, fungal and mushroom spores and yeast malt agar. 5 gm of fortified millet chikki and peanut chikki samples were soaked in to 10 mL distilled water and grounded into fine paste and 1mL of liquid solution taken in to various agar medium and yeast malt agar separately and transferred in to sterilized Petri dishes aseptically under laminar air flow chamber. The inoculated Petri dishes were incubated in an incubator in an inverted position at 24 °C for 24 to 48 hours for bacterial growth and 4 to 5 days for moulds growth (Gandhi *et al.,* 2018).

Determination of minerals (Ca, Fe, Mg and K)

Iron, calcium, magnesium, and potassium levels in formulated barnyard millet chikki were determined via atomic absorption spectrophotometry. Samples were digested and diluted for analysis alongside calibration standards. The spectrophotometer quantified each element's concentration based on absorbance measurements at optimized wavelengths. Quality control measures ensured precision, with results reported in standardized units (Parvez & Vijaya, 2020).

Determination of phosphorus

To determine the phosphorus content in formulated barnyard millet chikki using the Fiske Subbarow method, representative samples were finely ground and digested with concentrated nitric acid. After cooling, aliquots of the digested solution were diluted and prepared for analysis. Standard phosphate solutions of known concentrations were also prepared. Following the addition of reagents, including ammonium molybdate and stannous chloride, to both the

standard solutions and sample aliquots, color development was allowed. Absorbance measurements were then taken using a spectrophotometer at a suitable wavelength. A calibration curve was constructed using absorbance values of standard solutions, enabling the interpolation of phosphorus concentrations in the sample solution.

Determination of Vitamin-A

The analysis of Vitamin A in chikki involved a digestion process using ethanolic pyrogallol and ethanolic KOH for 18 hours at a temperature of 37 °C. Following digestion, Vitamin A was extracted into a hexane solvent layer, subsequently separated and quantified using High-Performance Liquid Chromatography (HPLC). The HPLC system utilized was a Shimadzu LC-10AS, manufactured by Shimadzu Corp., Tokyo, Japan. A C-18 (ODS) column with dimensions of 25 cm × 4.6 mm id, supplied by Supelco, Bellefonte, USA, was employed for chromatographic separation. Detection of Vitamin A was performed using an ultraviolet detector set at a wavelength (λ) of 320 nm. The mobile phase composition comprised 65% acetonitrile, 25% methanol, and 10% chloroform, with a flow rate of 1 mL/min, as outlined by Chase *et al.* (2004).

Storage and stability studies of control treatment and nutri rich barnyard millet Brittle (chikki)

Chikki were packed in polypropylene pouches and kept at ambient temperatures (~27 °C) and cold temperatures (4±2 °C) for 120 days. The storage stability was determined by estimating all physico-chemical parameters and sensory evaluation by 50 panel members.

Sensory evaluation of nutri rich barnyard millet brittle (chikki)

To assess the quality, acceptability, the products were presented to a panel of ten judges and the evaluation for sensory parameters such as color, taste, flavor, texture and overall acceptability characteristics was carried out using a 9-point hedonic scale. Chikki samples with code numbers were served one at a time for evaluation. Sensory evaluation was carried out for freshly prepared Chikki products and those stored for 30, 60, 90 and 120 days at 27±2 °C and 4±2 °C.

Statistical analysis

Data was statistically analyzed using one-way ANOVA on graph pad prism 6.01 software (Gandhi *et al.,* 2018). The results were presented as mean±S.D. (Standard deviation) and data from different treatments and controls were compared by Duncan's multiple –range test at $p<0.05$.

Principal component analysis (PCA)

Principal Component Analysis (PCA) is a powerful statistical technique widely used in food product development and stability studies. PCA enables researchers to analyse complex datasets and identify patterns or trends within the data by reducing its dimensionality while preserving most of the variability present in the original dataset. In food product development, PCA is employed to explore the relationships between various ingredients, processing parameters, and sensory attributes of food products. By examining these relationships, researchers can optimize formulations, enhance product quality, and tailor food products to meet consumer preferences. PCA helps identify key ingredients or processing conditions that contribute most significantly to desired product characteristics, facilitating the creation of innovative and appealing food products.

Stability studies, PCA aids in assessing the effects of storage conditions, packaging materials, and formulation changes on the quality and shelf-life of food products. By analysing changes in key parameters such as sensory attributes, chemical composition, and microbial activity over time, PCA helps identify factors influencing product stability and predict potential deterioration mechanisms (Gandhi *et al.,* 2024; Gandhi & Vijaya, 2024a, b). This allows food manufacturers to make informed decisions regarding product formulation, packaging, and storage practices to ensure product quality and safety throughout its shelf-life. In the present study, the observed proximate changes of Nutri-chikki during stability studies at different storage conditions were subjected to Principal Component Analysis (PCA). Additionally, PCA was conducted in conjunction with sensory studies to comprehensively evaluate the changes in the sensory attributes of the Nutri-chikki over time. This integrated approach allowed for a thorough examination of the relationships between proximate composition changes, sensory characteristics, and storage conditions, providing valuable insights into the stability and quality of the Nutri-chikki product.

RESULTS

Table 2, presents the proximate composition and selected mineral content of various food ingredients, including peanuts, palm jaggery, black dates powder, puffed barnyard millet, barnyard millet flour, soy flour, white sesame, black sesame, pumpkin seeds, flax seeds, and oats. The values are expressed per 100 g of the edible portion of each ingredient. Among the constituents analysed, peanuts exhibited relatively high levels of protein (31.61%) and fat (42.7%), making them a significant source of energy and essential nutrients. Palm jaggery and black dates powder were rich in carbohydrates, with values of 64.82% and 87.6%, respectively, making them suitable sweetening agents and energy sources. Puffed barnyard millet and barnyard millet flour contained moderate levels of protein, carbohydrates, and fat, contributing to their nutritional value as alternative grains. Soy flour stood out for its exceptionally high protein content (49.3%) and significant fat content (24.9%), making it a valuable plant-based protein source for vegetarians and vegans. White sesame and black sesame seeds were notable for their high fat content, with values of 83.14% and 74.8%, respectively, along with appreciable levels of protein and minerals such as calcium and iron. Pumpkin

Table 2: Proximate composition of peanuts, palm jaggery, black dates powder, puffed barnyard millet and barnyard millet flour (all values are expressed per 100 g edible portion)

Constituents	Peanuts	Palm jaggery	Black dates powder	Puffed barnyard millet	barnyard millet flour	Soy flour	White sesame	Black sesame	Pumpkin seeds	Flax seeds	Oats
Moisture %	5.36	3.4	5.48	2.4	3.2	1.4	5.93	6.21	5.66	8.50	9.96
Ash %	3.62	1.02	2.88	4.1	6.15	2.8	3.5	8.46	7.46	1.96	2.15
Carbohydrates %	1.68	64.82	87.6	60.5	65.5	18.6	71.41	86.14	22.16	5.14	69.4
Proteins %	31.61	2.16	1.82	8.6	11.6	49.3	14.70	9.32	43.4	32.8	13.62
Fat %	42.7	0.11	1.93	4.6	5.8	24.9	83.14	74.8	63.2	21.79	8.92
Crude Fiber	3.63	-	3.26	12.2	14.07	3.0	6.12	5.4	2.57	20.28	8.57
Iron (mg)	1.79	7.63	1.02	152	163	1.8	1.02	0.82	14.24	17.23	63.50
Calcium	8.7	84.4	15.4	13	14	32.8	0.44	0.52	11.98	14.6	469
Potassium	6.54	926	165	47.6	52.3	21.6	1.12	1.62	16.43	350	362
Phosphorus	152	46	15.3	115	121	72.2	0.8	0.93	1040	462	472
Magnesium	80	74	12	3.9	7.2	28.1	0.29	0.44	344	118	42

seeds and flax seeds exhibited moderate levels of protein, fat, and minerals such as iron, calcium, potassium, and phosphorus, highlighting their potential as nutritious snacks or additions to various dishes. Oats showed a balanced composition of carbohydrates, proteins, and fats, along with significant levels of iron, calcium, potassium, and phosphorus, making them a popular breakfast cereal choice for their health benefits.

Table 3, presents the physicochemical analysis of control and fortified Barnyard millet brittle (chikki) across various parameters. The treatments include the control group and three different fortification levels labelled as T_1, T_2, and T_3. In terms of moisture content, the control group exhibited the lowest value at 2.02%, while the fortified samples showed slightly higher moisture levels ranging from 5.27% to 5.36%. Ash content remained relatively consistent across all treatments, with values ranging from 3.16% to 3.42%. Carbohydrate content increased notably in the fortified samples compared to the control, with values ranging from 73.2% to 76.4%, indicating successful fortification with additional carbohydrates. Similarly, protein content showed a significant increase in the fortified samples, with values ranging from 43.3% to 52%, highlighting the effectiveness of fortification in enhancing the protein content of Barnyard millet brittle. Crude fiber content showed slight variations among the treatments, with values ranging from 2.72% to 3.12%. Fat content also increased in the fortified samples compared to the control, with values ranging from 32% to 34%. Regarding the Brix: Total Soluble Solids (TSS) ratio, there were variations across the treatments, indicating differences in sweetness levels. Acidity and alkalinity levels showed slight fluctuations among the treatments, reflecting variations in pH levels. Reducing sugars, non-reducing sugars, and total sugars exhibited some variability among the treatments, with different levels of fortification leading to differences in sugar content. Table 4, presents the microbial and coliform count of processed control and fortified Barnyard millet brittle (chikki) using various agar media and pour plate methods. The treatments include the control group and three different fortification levels labelled as T_1, T_2, and T_3. Microbial counts for all treatments were reported as NIL across the different agar media and pour plate methods. This indicates that no microbial growth was observed in any of the samples tested, including the control and fortified Barnyard millet brittle.

Table 3: Physicochemical analysis of control and fortified barnyard millet brittle (chikki)

Parameter	Treatment			
	Control	T_1	T_2	T_3
Moisture	2.02	5.36	5.27	5.270
Ash	3.16	3.42	3.22	3.36
Carbohydrates	61.5	74.3	73.2	76.4
Proteins	10.3	47.9	52	43.3
Crude fiber	2.4	3.12	2.84	2.72
Fat	23.0	32	34	32
Acidity	0.026	0.082	0.30	0.33
Alkalinity	1.06	1.11	1.10	1.13
Reducing sugars	0.5	0.3	0.3	0.4
Non reducing sugars	0.7	0.5	0.6	0.3
Total sugars	1.6	1.8	1.10	1.9
Energy (Calorific value)	494.2	776.8	806.8	766.8

Table 4: Microbial and coliform count of processed control and fortified barnyard millet brittle (chikki)

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

Table 5, summarizes the physico-chemical changes observed during storage of the samples at ambient and cool temperatures over different durations. The parameters analysed include percentage of moisture, ash content, carbohydrates, and protein content. For the control group (C), there were slight fluctuations in the percentage moisture, ash content, carbohydrates, and protein content over the storage period of 120 days. However, these changes were minimal and remained within a narrow range. For treatment T_1, which represents one of the fortified samples, similar trends were observed with slight variations in the percentage of moisture, ash content, carbohydrates, and protein content over the storage period. These fluctuations were relatively small and did not deviate significantly from the initial values. Treatment T_2, another fortified sample, exhibited comparable patterns of physico-chemical changes during storage. The percentage of moisture, ash content, carbohydrates, and protein content showed minor fluctuations within a consistent range over the 120-day storage period. Treatment T_3, the third fortified sample, also displayed consistent trends in physico-chemical changes during storage. The percentage of moisture, ash content, carbohydrates, and protein content remained relatively stable over the duration of the study, with only slight variations observed. Tables 6 and 7 present the physico-chemical changes observed during storage of the samples at both ambient and cool temperatures over various durations. The parameters analysed include crude fiber, acidity, alkalinity, reducing sugars, non-reducing sugars, and energy content. For the control group (C), there were

Table 5: Physicochemical changes during storage at ambient and cool temperatures

S. No.	Duration (Days)	% Moisture		% Ash		Carbohydrates		Protein	
		Ambient	Cold	Ambient	Cold	Ambient	Cold	Ambient	Cold
C	30	2.01	2.02	3.16	3.16	61.5	61.5	10.3	10.3
	60	1.88	2.0	3.16	3.16	61.5	61.55	10.3	10.3
	90	1.86	2.0	3.15	3.16	61.5	61.5	10.2	10.2
	120	1.80	1.99	3.15	3.16	61.5	61.5	9.93	9.97
T_1	30	5.34	5.35	3.42	3.42	74.3	74.2	47.5	47.6
	60	5.30	5.35	3.42	3.42	74.3	74.2	47.5	47.6
	90	5.27	5.32	3.42	3.42	74.0	74.2	47.2	47.5
	120	5.25	5.30	3.42	3.42	74.0	74.2	47.1	47.3
T_2	30	5.27	5.27	3.22	3.22	73.2	73.2	52	52
	60	5.25	5.27	3.22	3.22	73.2	73.2	50	52
	90	5.24	5.26	3.20	3.21	73.2	73.2	50	50
	120	5.24	5.25	3.20	3.21	73.2	73.2	50	50
T_3	30	5.27	5.27	3.36	3.36	76.4	76.4	43.3	43.3
	60	5.25	5.26	3.36	3.36	76.4	76.4	42.8	43.1
	90	5.24	5.26	3.34	3.36	76.4	76.4	42.7	43.1
	120	5.22	5.25	3.34	3.35	76.4	76.4	42.5	42.8

Table 6: Physicochemical 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	3.12	3.12	0.034	0.034	2.01	2.01	82.23	82.25
	60	3.10	3.12	0.032	0.032	2.01	2.01	82.20	82.19
	90	3.7	3.11	0.031	0.032	1.99	1.98	82.19	82.12
	120	3.7	3.10	0.031	0.031	1.94	1.98	82.19	82.12
T_1	30	2.42	2.45	0.023	0.024	1.04	1.06	98.71	98.18
	60	2.40	2.44	0.020	0.022	1.01	1.04	98.15	98.15
	90	2.40	2.44	0.020	0.022	1.01	1.01	98.12	98.13
	120	2.40	2.44	0.020	0.022	1.01	1.01	98.10	98.13
T_2	30	2.84	2.84	0.015	0.015	0.85	0.85	92.19	92.20
	60	2.82	2.84	0.015	0.015	0.85	0.84	92.15	92.15
	90	2.80	2.82	0.013	0.015	0.85	0.83	92.14	92.15
	120	2.80	2.82	0.013	0.015	0.85	0.82	92.12	92.12
T_3	30	2.72	2.72	0.010	0.010	0.73	0.75	92.03	92.01
	60	2.72	2.70	0.010	0.009	0.69	0.73	92.0	92.01
	90	2.70	2.70	0.010	0.009	0.68	0.71	91.97	92.01
	120	2.68	2.69	0.008	0.009	0.65	0.70	91.91	91.89

fluctuations in some parameters over the storage period of 120 days. However, these changes were generally minimal and remained within a narrow range for most parameters, whether stored at ambient or cool temperatures. For treatments T_1, T_2, and T_3, which represent fortified samples, similar trends were observed with minor fluctuations in the analysed parameters over the storage duration of 120 days. These changes were relatively small and did not deviate significantly from the initial values.

Table 8 presents the changes in mineral values during storage at both ambient and cool temperatures for different durations. The minerals analysed include iron, calcium, magnesium, phosphorus, and potassium. For the control group (C), the levels of iron, calcium, magnesium, phosphorus, and potassium remained relatively stable throughout the storage period of 120 days, regardless of whether the samples were stored at ambient or cool temperatures. Similarly, for treatment groups T_1, T_2, and T_3, which represent fortified samples, there were minimal fluctuations in the levels of iron, calcium, magnesium, phosphorus, and potassium over the storage duration of 120 days, irrespective of the storage temperature. These results indicate that both the control and fortified samples maintained consistent levels of essential minerals throughout the storage period, suggesting that the processing and storage conditions did not significantly affect the mineral content of the samples. The stability observed in

Table 7: Physicochemical changes during storage at ambient and cool temperatures

S. No.	Storage duration (Days)	Reducing sugar		Non reducing sugar		Energy	
		Ambient	Cold	Ambient	Cold	Ambient	Cold
C	30	0.5	0.5	0.05	0.05	494.2	494.2
	60	0.5	0.5	0.05	0.05	494.2	494.2
	90	0.5	0.5	0.05	0.05	493.8	493.8
	120	0.5	0.5	0.05	0.05	492.72	492.88
T_1	30	0.5	0.5	0.05	0.05	606.45	606.45
	60	0.5	0.5	0.05	0.05	606.27	606.36
	90	0.5	0.5	0.05	0.05	603.69	605.87
	120	0.5	0.5	0.06	0.06	603.2	605.07
T_2	30	0.4	0.4	0.03	0.03	637.51	637.42
	60	0.4	0.4	0.03	0.03	629.51	637.42
	90	0.4	0.4	0.02	0.02	629.15	629.42
	120	0.3	0.4	0.02	0.02	629.15	605.07
T_3	30	0.2	0.3	0.03	0.04	478.8	594.09
	60	0.3	0.3	0.03	0.03	592	594.09
	90	0.3	0.1	0.02	0.02	591.51	593.29
	120	0.1	0.1	0.02	0.02	590.53	592

Table 8: Mineral value changes during storage at ambient and cool temperatures

S. No.	Storage duration (Days)	Iron		Calcium		Magnesium		Phosphorus		Potassium	
		Ambient	Cold	Ambient	Cold	Ambient	Cold	Ambient	Cold	Ambient	Cold
C	30	4.4±0.086	4.4±0.086	147.6±0.00	147.6±0.00	225.2±0.29	225.2±0.29	378±0.34	378±0.34	798.6±0.53	798.6±0.53
	60	4.4±0.086	4.4±0.086	147.6±0.00	147.6±0.00	225.2±0.29	225.2±0.28	378±0.34	378±0.34	798.6±0.53	798.6±0.53
	90	4.4±0.086	4.4±0.085	147.6±0.00	147.6±0.00	225.2±0.28	225.2±0.28	377±0.034	377±0.034	798.6±0.53	798.6±0.53
	120	4.4±0.085	4.4±0.085	147.6±0.00	147.6±0.00	225.2±0.28	225.2±0.28	377±0.34	377±0.34	798.6±0.53	798.6±0.53
T_1	30	4.5±0.092	4.5±0.092	269.9±0.97	269.9±0.97	462.95±0.77	462.95±0.77	565.1±0.07	565±0.07	839.7±0.71	839.75±0.71
	60	4.5±0.092	4.5±0.091	269.9±0.97	269.9±0.97	462.95±0.77	462.95±0.77	565.1±0.07	565±0.07	839.7±0.71	839.75±0.71
	90	4.5±0.092	4.5±0.091	269.9±0.97	269.9±0.97	462.95±0.77	462.95±0.77	565.1±0.07	565±0.07	839.7±0.71	839.75±0.71
	120	4.5±0.090	4.5±0.090	269.9±0.07	269.9±0.97	462.95±0.77	462.95±0.77	565.1±0.07	565±0.07	839.7±0.71	839.75±0.71
T_2	30	4.3±0.082	4.3±0.082	258.3±0.06	258.3±0.06	433.82±0.66	433.82±0.66	520.3±0.02	520±0.02	653.7±0.70	653.7±0.70
	60	4.3±0.080	4.3±0.081	258.3±0.06	258.3±0.06	433.82±0.66	433.82±0.66	520.1±0.02	520±0.02	653.7±0.70	653.7±0.70
	90	4.3±0.079	4.3±0.080	258.3±0.06	258.3±0.06	433.82±0.66	433.82±0.66	520.1±0.02	520±0.02	653.7±0.70	653.7±0.70
	120	4.3±0.078	4.3±0.079	258.3±0.06	258.3±0.06	433.82±0.66	433.82±0.66	520.1±0.02	520±0.02	653.7±0.70	653.7±0.70
T_3	30	4.4±0.072	4.4±0.072	269.2±0.00	269.2±0.00	452.16±0.52	452.16±0.52	386.19±0.06	386±0.06	723.6±0.30	723.6±0 0.30
	60	4.3±0.071	4.3±0.071	269.2±0.00	269.2±0.00	452.16±0.52	452.16±0.52	386.19±0.06	386±0.05	723.6±0.30	723.6±0.30
	90	4.3±0.070	4.3±0.070	268.2±0.00	268.2±0.00	452.16±0.52	452.16±0.52	386.19±0.05	386±0.05	723.6±0.30	723.6±0.30
	120	4.3±0.070	4.3±0.070	268.2±0.00	268.2±0.00	452.16±0.52	452.16±0.52	386.18±0.05	386±0.05	723.6±0.29	723.6±0.29

the mineral values of the samples is essential for maintaining their nutritional quality and ensuring that consumers receive adequate levels of essential nutrients. The minimal fluctuations in mineral levels indicate that the samples are suitable for long-term storage without significant degradation of their nutritional value. The findings of this study suggest that the fortified samples can serve as a good source of essential minerals, contributing to the dietary intake of these nutrients. Furthermore, the stability of mineral levels during storage enhances the suitability of these products for consumption over an extended period.

Table 9, displays the amino acid composition of both control and nutria-rich barnyard millet chikki stored under

Table 9: Amino acid constitutes of control and nutria rich barnyard millet chikki

S. No.	Storage period	T_1		T_2		T_3	
		Ambient	Cold	Ambient	Cold	Ambient	Cold
Histidine	0	0.025	0.025	0.020	0.021	0.022	0.022
	30	0.023	0.024	0.019	0.021	0.021	0.022
	60	0.020	0.022	0.018	0.020	0.021	0.022
	90	0.020	0.022	0.018	0.019	0.020	0.021
	120	0.020	0.022	0.018	0.019	0.020	0.021
Isoleucine	0	0.019	0.020	0.008	0.007	0.015	0.014
	30	0.019	0.020	0.008	0.007	0.014	0.014
	60	0.018	0.020	0.007	0.006	0.014	0.014
	90	0.018	0.018	0.007	0.005	0.013	0.014
	120	0.018	0.018	0.007	0.005	0.013	0.014
Leucine	0	0.015	0.015	0.011	0.011	0.012	0.012
	30	0.014	0.015	0.010	0.010	0.012	0.011
	60	0.014	0.015	0.010	0.010	0.011	0.011
	90	0.014	0.015	0.009	0.009	0.011	0.011
	120	0.014	0.015	0.008	0.009	0.009	0.009
Lysine	0	0.009	0.009	0.003	0.003	0.007	0.007
	30	0.008	0.009	0.002	0.001	0.008	0.006
	60	0.008	0.007	0.002	0.001	0.006	0.005
	90	0.006	0.007	0.002	0.001	0.006	0.004
	120	0.006	0.006	0.002	0.001	0.004	0.003
Methionine	0	0.008	0.008	0.002	0.002	0.006	0.006
	30	0.007	0.008	0.002	0.002	0.005	0.006
	60	0.007	0.007	0.002	0.002	0.004	0.005
	90	0.007	0.006	0.002	0.002	0.004	0.005
	120	0.007	0.006	0.002	0.001	0.004	0.004
Phenylalanine	0	0.011	0.011	0.009	0.008	0.007	0.007
	30	0.010	0.010	0.008	0.007	0.006	0.006
	60	0.010	0.009	0.006	0.007	0.005	0.003
	90	0.010	0.008	0.006	0.005	0.004	0.003
	120	0.008	0.008	0.006	0.004	0.002	0.002
Threonine	0	0.004	0.004	0.003	0.003	0.003	0.004
	30	0.004	0.004	0.003	0.003	0.003	0.003
	60	0.003	0.003	0.003	0.002	0.002	0.003
	90	0.002	0.002	0.002	0.001	0.002	0.002
	120	0.002	0.002	0.001	0.001	0.001	0.002
Tryptophan	0	0.013	0.013	0.005	0.005	0.007	0.007
	30	0.012	0.012	0.005	0.005	0.007	0.006
	60	0.011	0.012	0.004	0.004	0.006	0.006
	90	0.011	0.011	0.003	0.003	0.005	0.005
	120	0.011	0.010	0.003	0.003	0.005	0.004
Valine	0	0.008	0.008	0.004	0.004	0.003	0.005
	30	0.008	0.007	0.003	0.003	0.003	0.005
	60	0.007	0.007	0.003	0.002	0.003	0.002
	90	0.006	0.006	0.003	0.002	0.003	0.001
	120	0.005	0.005	0.003	0.002	0.001	0.001

different conditions (ambient and cold) for varying durations. For all amino acids analysed (histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine), there were observable changes in their concentrations over the storage period and with different storage conditions. For instance, in the control group (T1), the concentration of amino acids generally decreased over time, irrespective of storage temperature. However, the extent of decrease varied among amino acids. The observed changes in amino acid concentrations can be attributed to various factors such as storage temperature, duration, and the inherent stability of amino acids. The decrease in amino acid concentration over time may be due to factors such as enzymatic degradation, oxidation, and Maillard reactions, which are known to occur during storage, especially under ambient conditions where the rate of chemical reactions is generally higher compared to cold storage. Additionally, the differences in amino acid degradation between ambient and cold storage conditions suggest that temperature plays a crucial role in preserving the stability of amino acids. Cold storage slows down enzymatic and chemical reactions, thereby reducing the rate of amino acid degradation. These findings underscore the importance of proper storage conditions in maintaining the nutritional quality of food products, particularly those rich in amino acids. Proper packaging and storage at lower temperatures can help minimize nutrient losses and preserve the overall quality of the product over an extended period.

Table 10, presents the fatty acid composition of both control and nutri-rich barnyard millet chikki stored under different conditions (ambient and cold) for various durations. The fatty acid composition is expressed as a percentage of total fatty acids and includes different fatty acids such as saturated, monounsaturated, and polyunsaturated fatty acids. The fatty acid composition remained relatively stable throughout the storage period and under different storage conditions (ambient and cold). There were no significant differences in the fatty acid composition between the control group and the nutri-rich barnyard millet chikki (T_1, T_2, T_3). This indicates that the fortification of barnyard millet chikki did not alter the fatty acid profile significantly. The minor fluctuations observed in the fatty acid composition over the storage period are likely due to factors such as exposure to oxygen, light, and temperature variations, which can lead to oxidation of fatty acids. However, these changes were minimal and did not affect the overall fatty acid profile of the product. The maintenance of fatty acid stability is crucial for the nutritional quality and shelf life of the product. Stable fatty acids contribute to the sensory attributes and overall acceptability of the product by preventing rancidity and off-flavours.

Sensory analysis

The sensory evaluation of barnyard chikki under ambient and cold storage conditions revealed significant differences in the retention of quality attributes over time (Figures 1 and 2).

Appearance

In terms of appearance, the control group under ambient conditions saw a decline from a score of 9 at day 0 to 7 by day 120. Comparatively, under cold storage, the control group started with a slightly lower score of 8, which decreased to 7 over the same period. For T_1, the appearance score dropped more dramatically under ambient conditions, from 9 to 5, whereas under cold conditions, the decline was less severe, from 8 to 6. T_2 maintained a high appearance score of 9 until day 60 under ambient conditions, dropping to 6 by day 120. Under cold storage, T_2's appearance was better preserved, maintaining a score of 9 until day 90 and only decreasing to 7 by day 120. T_3 showed a similar trend, with scores declining from 9 to 6 under ambient conditions, but a more stable score of 7 under cold storage until day 60, then decreasing to 6 by day 120. Overall, cold storage effectively preserved the visual quality of all treatments better than ambient conditions, particularly for T_2.

Texture

The control group's texture remained stable at 8 until day 90 under ambient conditions, then declined to 6 by day 120. Under cold storage, the control group's texture was consistent at 7 throughout the storage period. T_1 showed a significant drop in texture from 8 to 4 by day 120 under ambient conditions, while under cold conditions, it maintained a score of 8 for the first 60 days before decreasing to 5 by day 120. T_2 consistently had high texture scores of 9 until day 90 under ambient conditions, slightly decreasing to 7 by day 120. Under cold storage, T_2 maintained a score of 8 until day 120. T_3's texture score under ambient conditions decreased from 6 to 5 by day 120, while under cold storage, it showed a notable decline from 5 at day 0 to 4 by day 120. Cold storage clearly helped in maintaining the texture better across all treatments, especially for T_2.

Table 10: Fatty acid constitutes of control and nutri rich barnyard millet chikki

	Storage period	T_1		T_2		T_3	
		Ambient	Cold	Ambient	Cold	Ambient	Cold
Fatty acid	0	13.29	13.29	15.19	15.19	12.82	12.82
	30	13.25	13.25	15.19	15.18	12.80	12.81
	60	13.23	13.24	15.19	15.18	12.80	12.81
	90	13.21	13.23	15.15	15.18	12.79	12.81
	120	13.2	13.23	15.15	15.17	12.77	12.8

Taste

For taste, the control sample's score under ambient conditions was stable at 8 for the first 60 days, then declined to 7 by day 120. Under cold storage, the control group's taste score decreased more significantly from 8 to 4 by day 120. T_1 remained consistent at 7 until day 90 under ambient conditions, but dropped sharply to 3 by day 120. Under cold storage, T_1's taste also decreased from 8 to 4. T_2 had the highest initial taste score of 9, maintaining good taste quality until day 60 under ambient conditions, then decreasing to 5 by day 120. Under cold storage, T_2 maintained a high score of 9 until day 90, before dropping to 4 by day 120. T_3's taste score under ambient conditions decreased from 7 to 5, while under cold storage, it decreased from 7 to 6. These findings indicate that T_2 provided the best taste retention under both storage conditions, although cold storage generally resulted in more significant drops in taste quality by day 120.

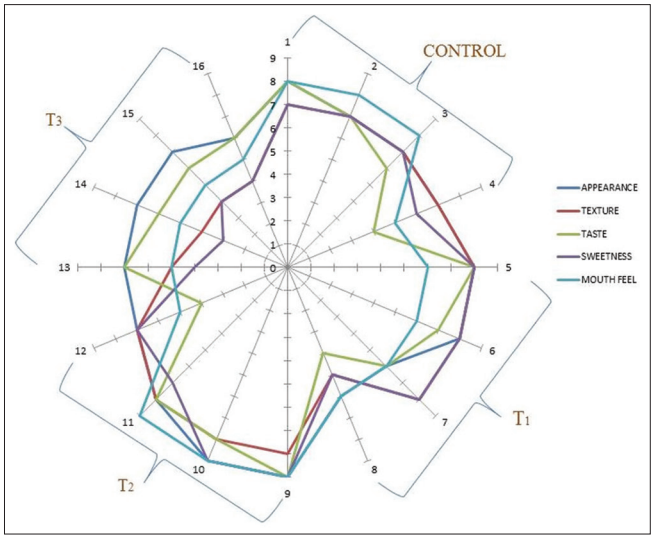


Figure 1: Sensory analysis of fortified barnyard millet brittle (chikki) prepared with different ratios stored at cold (4-16 °C) atmospheric conditions

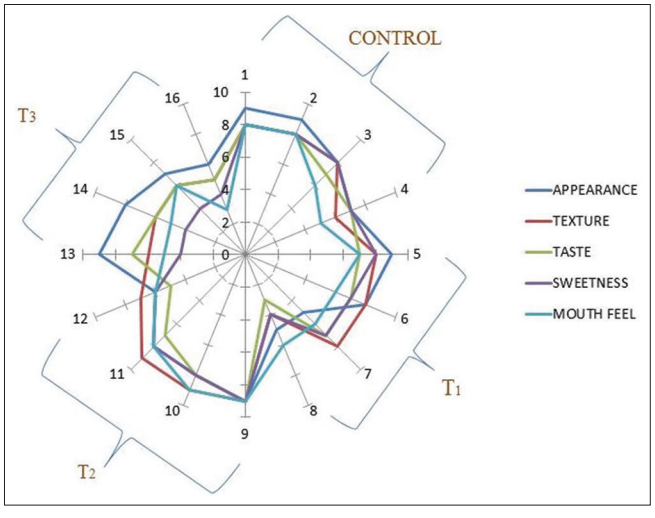


Figure 2: Sensory analysis of fortified barnyard millet brittle (chikki) prepared with different ratios stored at ambient atmospheric conditions

Mouth feel

The mouth feels of the control group decreased from 8 to 5 by day 120 under ambient conditions. Under cold storage, the control group's mouth feel remained stable at 8 for the first 60 days before decreasing to 5 by day 120. T_1 showed a decline from 7 at day 0 to 6 by day 120 under ambient conditions, and remained constant at 6 under cold storage. T_2 had the highest initial score of 9 under ambient conditions, which remained high until day 90 before dropping to 6 by day 120. Under cold storage, T_2 exhibited high stability, with scores of 9 until day 90, decreasing to 5 by day 120. T_3 showed the most significant decline in mouth feel from 5 at day 0 to 3 by day 120 under ambient conditions, and a stable score of 5 under cold storage. This indicates that T_2's formulation better preserved the mouth feel of barnyard chikki under both storage conditions, particularly under cold storage.

Economic analysis

The economic analysis of nutri-rich barnyard millet chikki was calculated and presented in Table 11. From the table it is concluded that the processed chikki available at affordable price to common people.

Principal Component Analysis (PCA)

Principal Component Analysis (PCA) was conducted on the physico-chemical parameters of formulated barnyard millet chikki during storage at ambient (Figures 3 & 4) and

Table 11: Economic analysis for the processing of nutri-rich barnyard millet chikki

Name of the ingredient	Quantity (g)	Price/kg	Amount (Rs)
Barnyard 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
Packing & labelling	1000	600	1200
Profit (20%)	-	-	483.36
Sale price/10 kg	-	-	4116
Sale price/1 kg			411.6
Sale price/100 gm	-	-	42 INR

cold temperatures (Figures 5 & 6). The data encompassed variations in moisture, ash content, carbohydrates, proteins, crude fiber, fat content, acidity, alkalinity, reducing sugars, non-reducing sugars, total sugars, and microbial counts over storage durations ranging from 30 to 120 days. Additionally, mineral values including iron, calcium, magnesium, phosphorus, and potassium, as well as amino acid and fatty acid compositions, were analysed.

PCA elucidated relationships among these variables, revealing patterns of variation and providing insights into the impact of storage conditions on the chikki's nutritional profile and microbial stability. In the analysis, parameters with positive loadings with PC1 at both ambient and cold storage included carbohydrates, proteins, and fat content, indicating a significant contribution of these variables to the overall variance in the chikki samples. Parameters with positive loadings with PC2 varied between ambient and cold storage conditions. At ambient storage, parameters such as moisture, acidity, and alkalinity showed positive loadings with PC2, suggesting their influence on the secondary sources of variation. In contrast, at cold storage, parameters like crude fibre and certain mineral values exhibited positive loadings with PC2, implying their role in shaping the variation observed in the chikki samples under colder conditions (Figures 5 & 6).

DISCUSSION

The proximate composition and mineral content of the analyzed food ingredients offer valuable insights into their

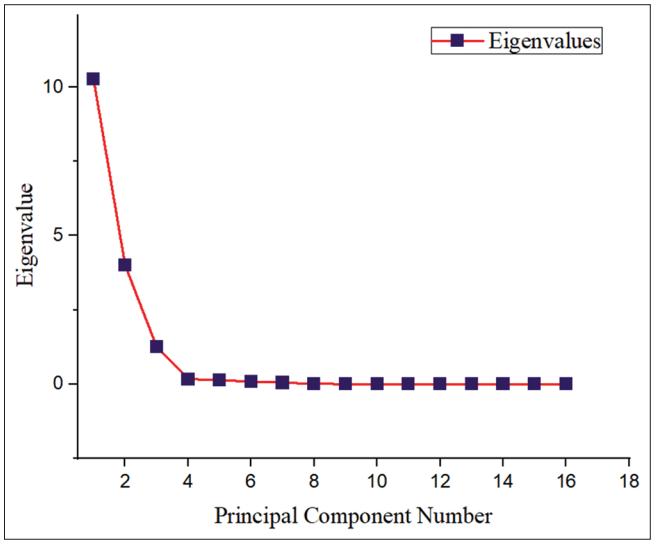


Figure 3: Scree plot of PCA for formulated barnyard millet chikki stored at ambient storage condition

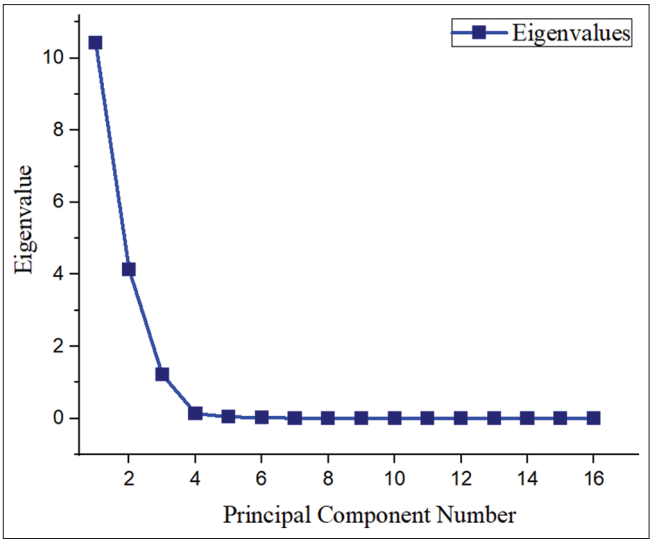


Figure 5: Scree plot of PCA for formulated barnyard millet chikki stored at cold (4-16°C) storage condition

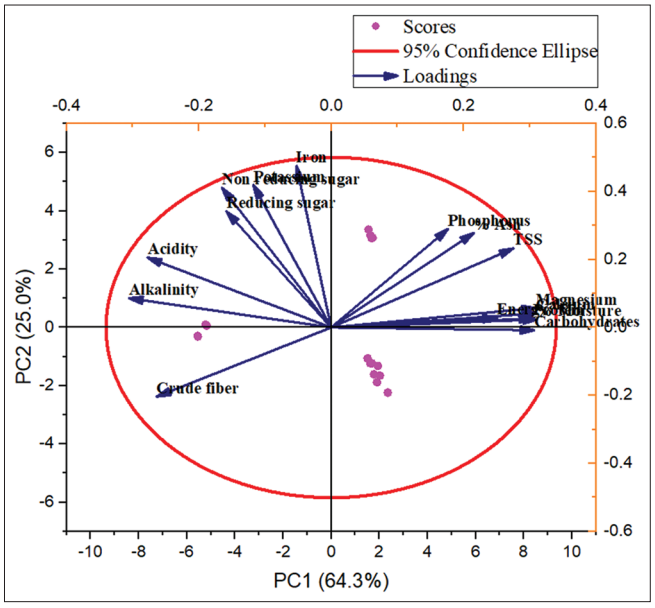


Figure 4: Biplot of PCA for formulated barnyard millet chikki stored at ambient storage condition

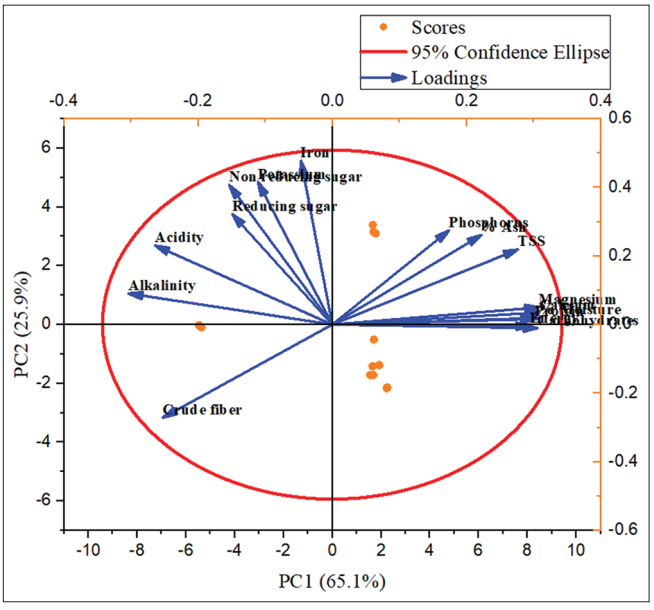


Figure 6: Biplot of PCA for formulated barnyard millet chikki stored at cold (4-16°C) storage condition

nutritional profiles and potential health benefits. Peanuts emerge as a rich source of both protein and fat, making them a valuable dietary component for individuals seeking to meet their energy and nutrient requirements (Win *et al.,* 2011). Similarly, soy flour stands out for its exceptional protein content, offering a plant-based alternative to animal-derived protein sources. Palm jaggery and black dates powder are identified as carbohydrate-rich ingredients, suitable for providing energy and sweetness in various culinary applications. These natural sweeteners may offer advantages over refined sugar due to their higher mineral content, including iron and calcium. However, consumption should be moderated to avoid excessive calorie intake (Sugihara *et al.,* 1999). The high-fat content of sesame seeds, particularly white and black varieties, underscores their potential as sources of healthy fats, including essential fatty acids. Incorporating these seeds into the diet can contribute to overall lipid balance and cardiovascular health. Pumpkin seeds and flax seeds are highlighted for their moderate levels of protein, fat, and essential minerals, making them versatile additions to salads, baked goods, or as standalone snacks. These seeds are also recognized for their potential health benefits, including anti-inflammatory and antioxidant properties (Singh *et al.,* 2007).

The physicochemical analysis of control and fortified Barnyard millet brittle (chikki) provides insights into the impact of fortification on its nutritional and sensory properties. Fortification resulted in increased carbohydrate and protein content in the fortified samples compared to the control, indicating successful enhancement of nutritional value through fortification (Pallavi *et al.,* 2014). This is particularly beneficial for individuals seeking higher protein and energy intake from snack foods. The increase in fat content in the fortified samples suggests the addition of fat-rich ingredients during fortification, potentially contributing to the texture and mouthfeel of the product. Further investigation into the source and type of fat added would provide valuable information regarding the nutritional implications of fortification. Variations in moisture content among the treatments may influence the shelf stability and sensory attributes of the product. Higher moisture levels could affect the texture and crispness of the brittle, potentially impacting consumer acceptance (Bukya *et al.,* 2018).

Differences in acidity, alkalinity, and sugar content among the treatments reflect variations in the formulation and processing methods used for fortification. These parameters play a crucial role in determining sensory attributes such as taste, flavor, and overall palatability of the fortified product (Sidel & Stone, 1993). The absence of microbial growth in all samples, including both the control and fortified Barnyard millet brittle, suggests that the processing methods employed were effective in maintaining microbial safety and preventing contamination. The microbial count results indicate that the production process, which likely includes steps such as heating, drying, and packaging, was successful in controlling microbial growth and ensuring product safety. These steps are crucial for inhibiting the growth of pathogenic microorganisms and spoilage organisms that could compromise the safety and quality of the brittle (Mehta *et al.,* 1994). The results indicate that both the control and fortified samples maintained overall stability in their physicochemical properties during storage at both ambient and cool temperatures. The fluctuations observed in moisture content, ash content, carbohydrates, and protein content were minimal and did not indicate significant degradation or spoilage of the samples. These slight variations are typical in food products and can be attributed to factors such as moisture migration, enzymatic activity, and minor chemical reactions. However, these changes were within an acceptable range and did not raise concerns regarding the safety or quality of the samples. The consistent stability observed in the physicochemical properties suggests that the processing and packaging methods employed were effective in preserving the integrity of the products during storage. The use of cool temperatures may have contributed to slowing down the rate of deterioration and extending the shelf life of the samples (Muttagi *et al.,* 2014). The stability of other parameters, such as crude fiber, acidity, alkalinity, reducing sugars, non-reducing sugars, and energy content, was generally maintained, with minimal fluctuations over the storage period. These variations are typical and do not indicate significant degradation or spoilage. The effective processing and packaging methods are evidenced by the consistent stability of these physicochemical properties, suggesting successful preservation during storage, especially at cool temperatures (Ramakrishna *et al.,* 2015).

CONCLUSION

The development of a multigrain Nutri-chikki enriched with Barnyard millet, soy flour, and various nutrient-dense ingredients successfully enhanced the nutritional profile of the traditional chikki. The inclusion of sesame seeds, puffed Barnyard millet, dry black dates powder, desiccated carrot, coconut, sweet potato, and seeds of pumpkin and flax contributed to significant increases in protein, fiber, and essential minerals such as iron, calcium, potassium, phosphorus, and magnesium. The nutritional analysis of the multigrain Nutri-chikki showed superior values compared to the conventional groundnut chikki, with protein content at 14.78 g, fat at 16.6 g, fiber at 4.1 g, and noteworthy mineral content across three compositions (T_1, T_2 and T_3).

The organoleptic evaluation indicated high consumer acceptance, with an overall sensory score of 8.3 compared to 7.8 for the groundnut chikki. Furthermore, the storage stability assessment revealed that the Nutri-chikki maintained acceptable sensory qualities for up to 120 days under both ambient and cold storage conditions. The findings of the current study suggest that the fortified Nutri-chikki is not only nutritionally superior but also palatable and stable over extended storage periods. Thus, it presents a viable option for a nutritious snack that caters to a broad consumer base, providing enhanced health benefits while maintaining the traditional appeal of chikki. Future studies could explore

further optimization of the formulation and investigate the bioavailability of the nutrients to maximize the health benefits of this innovative snack.

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