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Development and Quality Evaluation of Iron Rich Megh-Laddoo

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ABSTRACT

Background: Iron deficiency anemia (IDA) remain highly prevalent among tribal girls and women in remote regions of India more than others. This issue arises from limited access to iron rich foods, low dietary variety and poor nutrient absorption. The present study aimed to develop and evaluate a culturally acceptable, iron rich functional food called “Megh Laddoo”.

Method: Ragi (finger millet), bay berry (*Myrica esculenta*), sesame seeds and Bengal gram were used to formulate three variants (VRI, VR-II and VR-III). The formulations were prepared with ragi to sesame seeds ratios of 1:1, 2:1 and 3:1, respectively. Sensory evaluation (9 point hedonic scale) identified VR-III as the most acceptable variant (8.6/10). The selected variant was named ‘Megh Ladoo’ and was subjected to further nutrient analysis, shelf-life assessment and cost evaluation.

Result: Megh Laddoo (VR-III) provides 367.52 kcal energy, 10.52 g protein, 8.96 g dietary fibre, 204 mg calcium and 18.10 mg of iron, per 100 g, meeting about one-third (57%) of the ICMR daily iron requirement for adolescent girls. Microbial analysis confirmed that Megh Laddo is safe for consumption for up to two weeks. At Rs.9 for 30 g serving, it is accessible to economically disadvantaged sections of the population. Thus, Megh Laddoo could increase iron intake and improve health outcomes for tribal girls and women, highlighting culturally relevant food based solutions to tackle IDA in hilly areas with limited resources.

Key words: Iron deficiency anaemia, Laddoo, Microbial analysis, Nutrient analysis, Organoleptic, Tribal nutrition.

INTRODUCTION

Iron deficiency anemia (IDA) is a hematological condition characterized by a reduction in haemoglobin levels due to insufficient iron availability, which is vital for haemoglobin synthesis and biological functions such as cellular respiration, energy production, DNA synthesis and cell proliferation (Longo and Camaschella 2015).

IDA remains one of the most prevalent global health challenges, particularly affecting adolescent girls and women in lower socioeconomic strata. Common physical symptoms include fatigue, weakness and shortness of breath, which can contribute to development of depression, anxiety and reduced quality of life, thereby impeding women’s ability to perform daily activities and work effectively (Chauhan *et al.,* 2022). Among pregnant women, anemia increases the risk of maternal mortality, preterm delivery, low birth weight and developmental delays in infants. Cognitive decline, including memory loss, has also been linked to iron deficiency (Chakrabarty *et al.,* 2023).

Although global efforts has led to a reduction in anaemia among women aged 15-49 from 2000 to 2013 a reappearance has been observed from 2013 to 2019, especially in regions with Human Development Index (HDI). Recent data from National Family Health Survey (NFHS) 2019-21 revealed a further rise in prevalence compared to 2015-16. Poor dietary diversity remains a key contributor to this persistent burden (Givens *et al.,* 2024). Meghalaya, along Sikkim, West Bengal, Kerala and Goa have a significantly higher prevalence of Minimum Dietary Diversity (MDD) among Children. In contrast, states like Uttar Pradesh and Gujarat showed lower rates. Alarmingly, 77.54% of Indian Children consume fewer than the minimum required food groups, jeopar- dizing their growth and development (Padigapati *et al*., 2024).

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Ragi, or finger millet *(Eleusine coracana),* is an ancient cereal grain cultivated primarily in Asia and Africa, valued for its nutritional benefits and health advantages. Recently, its popularity has surged globally due to its impressive nutritional profile and versatility in cooking (Shivakumara *et al*., 2023). Ragi has best quality protein along with the presence of essential amino acids, vitamin A, B, iron and particularly calcium (Sundareswari, 2024) Thus, ragi found to be a good diet for growing children, women, old age people and patients (Shobha and Ravishankar, 2017).

Sesame seeds (*Sesamum indicum L.*) are a powerhouse of phytochemicals and nutrient dense bioactive compounds. offering key micronutrients like iron (Mostashari and Mousavi, 2024). As a plant based iron source, sesame seeds may serve as a natural and safe dietary option with potential use as an iron supplement in the management of anemia (Tangko *et al*., 2020).

Dates are a rich source of nutrients, providing substantial energy along with balanced composition of carbohydrates, essential amino acids such as tryptophan, omega-3 fatty acids, vitamin C, vitamin B6 and important minerals including calcium, zinc and magnesium. Dates are also particularly rich in dietary fiber. In addition, dates are recognized as an excellent source of antioxidants, mainly carotenoids and phenolics compounds, which contribute to their anti - inflammatory, anti - carcinogenic and antimicrobial properties. Evidence from the literature further indicates that the consumption of dates can increase haemoglobin level (Saputri *et al.,* 2021). There is a quest for regional and inexpensive, iron rich food ingredients common in local dietaries.

Bay berry fruit (*Myrica* L.) is a wild fruit found in the Himalayan regions of India, including Meghalaya and Himachal Pradesh. Myrica species is widely used in traditional Chinese medicine owing to their attractive colour, unique sweet/ sour flavour and significant medicinal properties such as anti-bacterial, anti-cancer, anti-oxidants and anti- inflammatory. The fruit extracts are rich in bioactive compounds, including flavanols, phenolic acids, organic acids, proteins and vitamins, particularly Vitamin C. Himalayan bay berry is considered a valuable medicinal plant, as its root, bark, leaves and fruits possess therapeutic properties and are used as active ingredient in several ayurvedic formulations for the treatment of various ailments and disorders including ulcers, anemia, fever, diarrhoea etc (Lily *et al.,* 2022) (Banerjee and Sen 2023).

Given the nutritional potential of these ingredients, targeted food-based interventions are urgently required to address micronutrient deficiencies in tribal adolescent girls in Meghalaya. The study, therefore, aimed to develop and evaluate Megh Laddoo, an iron functional food supplement developed by incorporating finger millet and vitamin C- rich bay berry fruit, as a culturally acceptable strategy to combat anaemia.

MATERIALS AND METHODS

Procurement and processing of raw materials

The ingredients used to preparation for Megh Laddoo included ragi (*Eleusine coracana*) also known as finger millet, bengal gram (*Cicer arietinum*), sesame seeds (*Sesamum indicum*), perilla seeds (*Perilla frutescens* L), sunflower seeds (*Helianthus annuus* L*),* dates (*Phoenix dactylifera*), turmeric (*Curcuma longa*), jaggery (*Saccharum officinarum*) and bay berry fruit (*Phyllanthus emblica* L*).* All raw ingredients were procured from a local market in Shillong, East Khasi Hills district, Meghalaya.

Preparation of base mix

All raw ingredients were inspected for quality prior to use. Ragi, sesame seeds, bay berry fruits and dates were hand cleaned to remove impurities. Bay berry fruit were dried and ground into fine powder. Ragi, bengal gram, sesame seeds, perilla seeds and sunflower seeds were roasted individually at 130±2°C for 10 minutes to enhance both flavor and nutritional value (Sruthi *et al.,* 2021). After roasting ragi, bengal gram, sesame seeds and perilla seeds were ground into fine powder while sunflower seeds were chopped into smaller pieces. Jaggery syrup was prepared separately, ghee was melted and dates were ground into paste to facilitate binding (Ahmad *et al*., 2018), (Ekal and Kumbamoorthy, 2024). The cooled ingredients were mixed, coarsely ground and shaped into round balls. A small quantity of jaggery syrup and ghee was added, as needed to aid binding. Finished laddoos were stored in airtight containers after setting.

Formulation of megh laddoo

Table 1 presents the three formulated variations (I. II, III) of Megh Laddoo (each standardized to 100 g total weight). All variations contained fixed quantities of roasted bengal gram (15 g), perilla seeds (10 g), sunflower seeds (8 g), dried dates (7 g), turmeric (1 g), bay berry powder (10g), jaggery (5 g) and ghee (5 g).

Variations differed in whole ragi and sesame seeds.

- Variation I: 19.5 g ragi + 19.5 g of sesame seeds (1:1 ratio).
- Variation II had 26 g ragi +13 g of sesame seeds (2:1 ratio).
- Variation III 29.25 g ragi + 9.75 g sesame seeds (3:1 ratio).

These proportions optimized nutritional profile and sensory characteristics while maintaining consistent total of 100 g across all variations.

Organoleptic evaluation of megh laddoo

A quasi experimental design was employed to evaluate the sensory attributes of the newly developed laddoo (Singh and Kushwaha 2022). Organoleptic evaluation was conducted at the Food Sensory Evaluation Centre, Avinashilingam Institute of Home science and Higher education for Women, Coimbatore, using 30 semi-trained panelists and a 9-point hedonic scale (Amerine *et al*., 2013).

Prior to participation, panelists were informed about the study purpose and written informed consent were obtained. Ethical clearance was secured from the Avinashilingam Institute of Home science and Higher education for Women, Coimbatore (IHEC No. 785IHEC/21-22/FSN-26).

Table 1: Different variations of Megh laddoo.

Ingredients	Variations (weight in gm)		
	I	II	III
Whole ragi (roasted)	19.5	26	29.25
Bengal gram whole (roasted)	15	15	15
Sesame seed (roasted)	19.5	13	9.75
Perilla seeds	10	10	10
Sunflower seed (roasted)	8	8	8
Dates (dried)	7	7	7
Turmeric	1	1	1
Bay berry powder	10	10	10
Jaggery	5	5	5
Ghee	5	5	5
Total	100	100	100

The panelists evaluated the three variations for colour, appearance, flavour, texture, taste and overall acceptability. Average score were recorded to identify the best accepted formulation (Tomar *et al*., 2026).

Nutrient analysis

The laddoo samples that fulfilled the organoleptic characteristics, including colour appearance, flavour, texture, taste and overall acceptance, were selected for further nutrient analysis.

Assessment of nutrient composition

Food analysis and quality control are used to gather information about the characteristics of products from the time raw ingredients are received to the finished product in order to make sure they meet set standards (Falko, 2023). This procedure also determines the acceptability of the product (Nielsen 2024). The macronutrients and micronutrients in the supplements were thoroughly examined. The Association of Official Analytical procedures (A.O.A.C. 2023) standard operating procedures were followed in the conduct of this analysis. Table 2 provides a summary of the nutrient analysis techniques.

Shelf life analysis

Shelf life of the developed product was assessed over 15 days under refrigerated storage (4±1°C), monitoring key quality parameters including pH level, total plate count (TPC) and mold count at of 7, 15 days following standard microbiological method APHA Compendium of Methods for Microbiological Examination (APHA 2017) Acceptance criteria were: pH 4.0-6.5, TPC $<10^6$ CFU/g, yeast/mold $<10^3$ CFU/g (Da Silva *et al.,* 2018). Table 3 provides detailed methodology employed in this analysis.

Total fungal count

The total fungal count was determined using the Colony Count Technique at 25±1°C following the IS 5403:2012 (method for Yeast and Mould Count of Foodstuffs). Count were performed on days 7th and 15th using a colony counter, with results expressed as CFU/g.

Total plate count

The total plate count was enumeration using the Colony Count Technique at 30±1°C in according to IS 5402: 2012 (Method for General Enumeration of Microorganism). Analysis was conducted on days 7th and 15th with colonies counted using colony counter and reported as CFU/g (Table 3).

Cost effectiveness

The development of the product was designed to ensure economic viability, making it accessible across socio-economic strata. This consideration is particularly important as micronutrient deficiency related malnutrition is more prevalent among economically weaker sections due to food insecurity and limited dietary diversity (Burns *et al.,* 2020).

The selected ingredients were chosen for their regular availability in households and affordability. This ensures that the product can serve as a practical and sustainable dietary intervention for malnourished and anaemic populations.

Statistical methods

The data were analyzed using descriptive statistics to determine means and standard deviations. Sensory analysis results were evaluated with one-way ANOVA, followed by Turkey's test for mean separation at $p<0.05$. An independent t-test ($p<0.05$) examine relationship among hedonic scale metrics. IBM SPSS Version 25.0 was used for all analyses.

RESULTS AND DISCUSSION

Organoleptic evaluation of the prepared megh laddoo

As shown in Table 4, the mean score and standard deviation of three variations were evaluated based on appearance, flavour, taste, texture, colour and overall acceptability**.** The

Table 2: Analytical methods of nutrient analysis.

Nutrients	Analytical method	Reference/standard method
Total carbohydrate	Anthrone reagent method	FSSAI Manual 2016-
Energy	Bomb calorimeter	FAO Manual, 2003-
Protein	Kjeldahl method	AOAC - (981.10)
Fat	Soxhlet extraction method	AOAC - (954.02)
Calcium	Calcium method	AOAC - (927.02)
Iron	Atomic absorption spectrometry	AOAC - (980.01)
Folic Acid	UV-Visible spectrometry	Standard UV- Vis Method
Fibre	Fibroton method	AOAC - (2011.25)
Vitamin A	High-performance liquid chromatography (HPLC) with fluorescence detection	
Riboflavin	UV - Visible spectrometry	BIS 1969-2005
Thiamine	HPLC method	BIS 1969-2005
Folate	HPLC with UV	
Zinc	Flame AAS = Atomic absorption spectroscopy	AOAC - 1990 (Method 969.32)
Ascorbic acid	High-performance liquid chromatography (HPLC)	IS 5838 - 1970

three formulations referred as VR-I, VR-II and VR-III, respectively used different proportions of ragi and sesame seeds: 1:1, 2:1 and 3:1. Among the three variations, VR-III received the highest overall acceptability score of 8.6±0.62 followed by VR-II (8.0±0.45) and VR-I (7.86±0.57). In terms of specific attributes, VR-III scored 8.53±0.57 for appearance, 8.43±0.679 for colour, flavour, 8.6 for taste and 8.3 for texture. VR-II achieved scores of 8.3±0.68, 8.1± 0.76, 8.17±0.70, 8±0.59 and 8.07±0.52 in colour, flavour, taste and texture. VR-I showed the lowest scores overall 7.9±0.71, 7.98±0.81, 7.8±0.55, 8.03±0.67 and 7.767±0.504 in Colour, 8.467±0.681 for flavour, 8.63±0.556 taste and 8.3±0.75 texture. Based on the highest sensory evaluation scores, the most preferred formulation VR-III was selected and named 'Megh-Ladoo' in honour of the name of the state of Meghalaya. The variation was further analysed for its nutrient composition, including energy, protein, Iron Calcium, Zinc, folate, vitamin C and Dietary fibre content (Civille *et al*., 2024).

The study is supported by various studies focusing on millet based food development. For instance, Selvaprakash *et al.* (2021) utilized conjoint analysis to optimize ingredient levels in millet and pulse based ready-to-eat products. Their methodology involved panelists ranking sensory attributes on a 9 point hedonic scale to determine the most preferred combinations, directly aligning with the approach of assessing different proportions to select an optimal product based on high sensory scores.

Similarly, a study by Ibrahim *et al.* (2021) on pearl millet based found that the sensory evaluation was crucial in determining the most preferred blend, with an 80;20% millet Bambara nut flour combination achieving the highest score. Furthermore, Bhavya *et al.* (2020) conducted sensory evaluations for millet based pizza bases with varying proportions of proso millet flour, observing that attributes such as texture, taste, crust, colour and overall acceptability were significantly impacted by the flour ratios, leading to the selection of the best formulation. These studies collectively reinforce the importance of sensory evaluation in optimizing ingredient formulations for consumer acceptance in millet derived foods.

A study by Ilangovan (2024) corroborate this finding, reporting that micronutrients dense adai formulation the highest ragi concentration (Type I) received an average rating of 36.85, underscoring the impact of ingredient ratios on palatability. These finding reinforce the current results, suggesting that optimal adjustments in recipe formulation can significantly enhance both taste and nutritional quality. Conversely, the findings by Chaturvedi (2014) differ from the present study. That study examined recipes incorporating varying levels of malted flour (50%, 70% and 100%) and reported that composite flour products were most acceptable at 50%, followed by 75% and 100%. The author recommended blends containing foxtail millet, wheat and chickpea flour to produce nutritious and sensory-acceptable extrudates for underprivilege children.

Millet consumption in India declined from 15.89 kg per capita in 1960 to 8.54 kg in 2022, at a compound growth rate at -1.30% per annum (Singh and Singh, 2024).

Through the development of Megh laddoo, this study aims to promote the consumption of ragi by demonstrating its nutritional and sensory appeal in a locally relevant and accessible format.

Table 3: Procedures of shelf life analysis.

Analysis	Procedure
Appearance	Sensory evaluation
Colour	Sensory evaluation
Odour	Sensory evaluation
pH	FSSAI - electrometric method
Total bacterial count	Colony count technique
Total fungal count	Colony count technique

Nutritional composition of value megh ladoo

The nutrients analysis of Megh laddoo reveals that it provides 367.52 kcal of energy per 100 g, with 5.55 g fat, 10.52 g protein 68.87 g carbohydrate, 8.96 g dietary fibre and is rich in calcium (204 mg/100g), iron (18.10 mg/100 g), vitamin C (28.5 mg/100 g) and zinc (4.85 mg/100 g), riboflavin (0.23 mg/100), thiamine (0.22 mg/100 g) and folate (38 mg/100 g). When compared with the recommended dietary allowances (RDA, ICMR) for adolescent girls, protein is 46 grams, the dietary fibre is 38 grams, iron is 32 milligrams/ day, zinc is 14.2 milligrams/day. Based on this result, iron meets 50% of the RDA protein meets 23% of the RDA for adolescent girls. Detailed on nutrient values are presented in Table 5.

The high calcium and iron content of Megh laddoo is supported by earlier work showing that finger millet flor contributed substantial calcium (194.3 mg/100 g), Similarly, the use of jaggery and peanuts has been shown to enhance

Table 4: Organoleptic evaluation of different variations of Megh laddoo.

Variations	Appearance	Colour	Flavour	Taste	Texture	Overall acceptability	VR III vs VR I	VR III vs VR II	VR II vs VR I
VR I	7.9±0.712	7.967±0.809	7.8±0.551	8.033±0.669	7.767±0.504	7.86±0.57	<0.001*	0.002*	0.802^{NS}
VR II	8.233±0.679	8.1±0.759	8.167±0.699	8±0.587	8.067±0.521	8.0±0.45			
VR III	8.533±0.571	8.433±0.679	8.467±0.681	8.633±0.556	8.3±0.750	8.6±0.62			

- Abbreviation VR-Variations.
- Values are presented as means±standard deviation.
- Turkey test ($p<0.05$) *significant at 0.05%.

the iron density of traditional laddoos, contributing approximately 44.3 mg/kg of iron (Kazi and Auti 2017).

The nutrient rich Megh laddoo is consistent with previous research on seed enriched laddoos. A study by Kame and Ghumre (2025) on chia seeds incorporated laddoo reported high levels of protein (11.99), Calcium (891.25 mg) and Iron (6.26 mg), demonstrating that laddoos formulated with nutrient dense ingredients can serve as concentrated sources of essential minerals and macronutrients.

Findings from an earlier study on Marayoor jaggery show that it contains higher levels of iron, B - Vitamins, simple sugars and notable antioxidant activity and that product prepared with it are well accepted by consumers. These results suggest that jaggery is not only a traditional sweetener nut also a meaningful source of micronutrients (Jacob *et al.,* 2024).

A recent study by Anitha *et al.* (2024), reported that an intervention group consuming millets showed a statistically significant increase in haemoglobin concentration of 13.6% ($p<0.0005$), whereas the control group showed a non-significant change of 4.8% ($p= 0.1362$). Furthermore, four studies reported that children in the intervention group transitioned from mild anemia to normal haemoglobin levels, providing compelling evidence that millet consumption can positively influence hematological health. Iron deficiency remains one of the leading causes of anemia among adolescent girls and their children (Givens *et al.,* 2024). Similar studies have shown that the consumption of whole grains contributes to reduce the risk of chronic diseases such as type 2 diabetes and certain cancer as well as improved gut microbiota and enhanced insulin sensitively (Khan *et al.,* 2024). Since ragi is the primary ingredient in Megh-laddoo, the product holds a potential as an affordable and nutritious intervention to address micronutrient deficiencies.

Table 5: Nutrient analysis of Megh Laddu.

Nutrients	Mean ± SD
Energy (kcal/100 g)	367.52±2.43
Fat (g)	5.55±0.87
Protein (g)	10.52±0.9
Carbohydrate (g)	68.87±0.13
Dietary Fibre (g)	8.96±0.9
Calcium (mg/100 g)	204.00±0.52
Iron (mg/100 g)	18.10±0.5
Zinc (mg/100 g)	4.85±0.11
ß-carotene (mg/kg)	1.5±0.1
Riboflavin (mg/kg)	0.23±0.01
Thiamine (mg/kg)	0.22±0.01
Folate (µg/kg)	38±0.55
Vitamin C (mg)	28.5±1.42

o Values are presented as means±standard deviation.

Shelf life study of developed product

The shelf life study of the Megh Laddoo was conducted to assess its chemical and microbiological stability of the product. Evaluations were carried out on the 7th day and 15th day post production, as presented in Table 6. The pH remained constant at 7.0 on both days, indicating that neutral pH was maintained throughout the study period (FSSAI 2023).

Progressive increased in microbial load was observed between day 7 and day 15. While the bacterial count on day 7 remained within the acceptable safety limits, a marked increase was recorded by day 15, (Table 6) suggesting a potential risks of spoilage with extended storage. Similarly, the total fungal count increased nearly threefold between day 7 and day 15. Although both bacterial and fungal count counts remained below the critical threshold, the rise in fungal colonies over time warrants particular attention. Plate 1 and 2 present the total plate counts for the 7th day and 15th day, respectively.

Studies on millet based weaning foods have shown that microbial counts and water activity change over storage, especially under non-vacuum ambient packaging, underscoring the need for appropriate storage conditions to maintain stability (Sihag *et al.,* 2015).

Similar storage changes have been reported in traditional Indian sweets such as rava burfi, where microbial counts and sensory quality deteriorated significantly during ambient storage, limiting the product's shelf life to about nine days at room temperature. This aligns with the present study, in which Megh laddoo also showed a progressive rise in bacterial and fungal counts by 15 days, indicating restricted stability under room temperature conditions (Shrivas *et al*., 2018).

A study by Geetha *et al.* (2020) showed that millet based products are nutritionally rich and can remain stable during storage. Their millet based diabetic mix was tested for 90 days and although moisture, free fatty acids and peroxide values increased over time, all remained within safe limits. Microbial counts were also safe with no mold or *E. coli*

Table 6: Shelf life analysis.

Shelf life study	Specification	7th day	15th day
Chemical analysis			
pH	6.5- 8.0	7.0	7.0
Micro-biological analysis			
Total bacterial count	Max 10×10^3cfu/g	25×10^1cfu/g	60×10^1cfu/g
Total fungal count	$<10\times10^1$cfu/g	2×10^1cfu/g	4×10^1cfu/g

#FSSAI Microbiological standard 2023 *cfu/g-colony forming unit per gram.

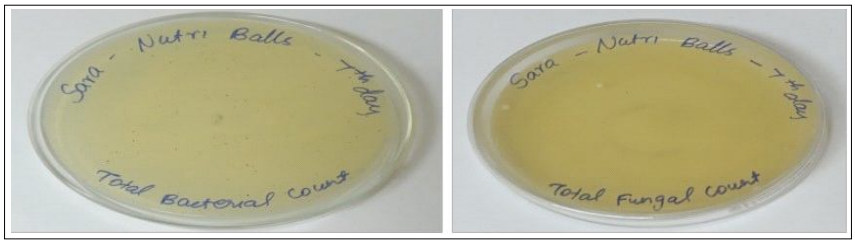


Plate 1: Total plate count analysis using colony count technique for 7th day.

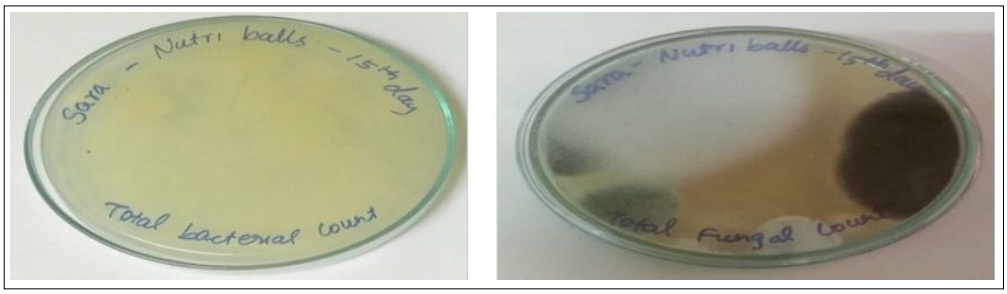


Plate 2: Total plate count analysis using colony count technique 15th day.

Table 7: Costing economics of product.

Proportion	Quantity	Cost (in rupees)
Ragi	29.25 g	5.5
Bengal gram	15 g	3
Sesame seeds	9.75 g	5
Sunflower seeds	10 g	10
Perilla seeds	8 g	10
Bay berry fruit	10 g	30
Dates	7 g	10
Jaggery	5 g	0.30
Ghee	5 g	3.00
Turmeric	1	0.20
	Total : 100 g	Total: 29.73 Rs = Rs. 9per/pieces

detected. The study concluded that millets in healthy, long lasting food products.

A study by Tiwari *et al.* (2018) reported similar findings, showing a gradual increase in the total viable count, reaching 5×10^3 CFU/g in malted ragi flour during storage. Despite of increase, the microbial levels, the product remained within the maximum permissible limit indicating acceptable microbial stability. A comparable study on Calpro ladoos using similar ingredients observed 3-4 fungal colonies on the 7th day, increasing to 6-7 colonies by the 14th day, further supporting the extended shelf life of such products (Shekhar 2019).

The findings are aligns with the study by Sai and Devi (2023) on shelf life, which reported that the pH and microbial counts remained within acceptable limits up to 7th day of storage. However, both fungal and bacterial loads increased significantly by the 10th day, exceeding permissible safety standards.

Similar results were observed in a study by Singh *et al.* (2022) on nutri cereals based Mahua laddoo prepared with jaggery, where microbiological analysis indicated a standard plate count of 2041 cfu/g, which coliform, yeast and mold counts were below detectable limits (<10 cfu/g). These results highlight that traditional cereals products generally maintain acceptable microbial safety at early stages of storage. This aligns with the present study, where the microbial load of the developed product remained within safe limits during the initial storage period.

Costing economics of product

The cost analysis for the Megh-laddoo formulation (Table 7) outlines the individual cost contribution of each ingredient used in the preparing 100 g of the product. The total production cost was Rs. 29.25 for 100 g which equates to approximately 9 rupees per 30 g serving making it highly affordable for economically disadvantaged tribal communities.

This compares favourable with similar millet based functional foods. For instance, finger millet flour based edible dessert cups were priced at Rs. 20.28/piece (Molu *et al.,* 2024). Megh Laddoo demonstrate superior cost effectiveness at less than half the price of comparable millet based products while delivering higher iron content (18.10 mg/ 100 g) and cultural acceptability for tribal populations.

A study from Andhra Pradesh showed that finger millet undergoes multiple marketing stages, causing its price to rise from about Rs. 3300 at the farm level to Rs. 5000 - 6500 at retail, with high marketing margins at each step. The authors noted low net returns for farmers, highlighting the importance of value addition to improve economic viability. This supports our costing results, as processing finger millet into Megh laddoo makes the product more affordable while increasing its market value compared to

selling the raw grain (Beera *et al.,* 2024). This claim supports our costing results, as processing finger millet into Megh laddoo makes the product more affordable while increasing its market value compared to selling the raw grain.

The finding indicate that the cost Megh Laddoo is found to be lesser than the cost of (Sai and Devi 2023) for Nutri ball (NB3), where the ingredient cost for 100 g of the product was calculated at Rs. 17.45. in developed nutri - ball. This comparison highlights the cost-effectiveness of Megh-Laddu, making it a feasible option for households seeking affordable nutritional supplementation. By incorporating nutritious yet low cost ingredients, Megh Laddoo can serve as an accessible dietary intervention for addressing nutritional deficiencies, particularly in economically disadvantaged communities. The cost breakdown further emphasises the importance of strategic ingredient selection in achieving both nutritional quality and economic viability. Megh laddoo can be used as a cost effective food based supplement in regional and national feeding programmes.

CONCLUSION

The developed iron rich Megh-laddoo demonstrated high acceptability, with a mean overall acceptability score of 8.6/ 10. It provides 367.52 kcal, 10.52 g protein, 8.96 g dietary fibre, 204 mg calcium, 28 mg Vitamin C and 18.10 mg / 100 g iron, contributing to one-third (57%) of the ICMR recommended dietary allowance for iron among sedentary adolescent girls. Shelf life studies confirm product stability is up to the 15th days under refrigeration, with microbial counts within FSSAI permissible limits. Costing only Rs 9 per 30 g serving. Thus, Megh laddoo offers an affordable, nutrient rich functional food to combat iron deficiency anaemia among adolescent girls.

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Informed consent

The study was conducted in accordance with ethical standards. The experimental protocols were approved by Institutional Human Ethical Committee (IHEC) of Avinashilingam Institute for Home Science and Higher Education for Women under clearance No. IHEC/21-22/FSN-26.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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