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Formulation, Nutritional Evaluation and Sensory Acceptability of a Multi-Millet Complementary Food Mix for Early Childhood Nutrition

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Abstract

This study aimed to develop and evaluate a nutrient-rich, millet-based complementary food formulation Baby Boost Millet Mix targeted at improving early childhood nutrition. The product was prepared using a blend of traditionally cultivated millets including finger millet, sorghum, pearl millet, foxtail millet and little millet, selected for their superior macro and micronutrient profiles. Three formulations (T_1, T_2, T_3) were developed and subjected to sensory evaluation, proximate and micronutrient analysis, antioxidant profiling, microbial safety assessment testing. Sensory scores indicated high acceptability across all variants, particularly for T_1. Nutritional analysis showed an energy content of 346 kcal/100 ml, protein (10.1 g), and substantial levels of iron, zinc, calcium, and B-complex vitamins. Antioxidant activity was high, especially in ABTS and FRAP assays, and microbial counts were within safe consumption limits over one month. The findings support the formulation's potential as a safe, shelf-stable and nutritionally adequate complementary food to address micronutrient deficiencies and promote sustainable dietary diversification in early childhood.

Keywords: Complementary feeding, Millets, Infant nutrition, Sensory evaluation, Nutritional composition, Food safety

1. Introduction

Early childhood represents a foundational period of human development, during which adequate nutrition is critical for healthy growth, brain development, immune competence, and long-term well-being (USDA, 2019) [14]. Inadequate nutrient intake during this phase often leads to stunting, underweight, and deficiencies in micronutrients such as iron, zinc, and calcium, particularly in developing countries where dietary diversity is limited (Abeshu *et al*., 2016; Mbaeyi Nwaoha & Obetta, 2016) [1, 9].

Complementary feeding typically begins at six months of age, and the choice of complementary foods plays a pivotal role in bridging the nutrient gap left by breast milk alone (Keyata *et al*., 2021) [8]. Cereal-based porridges are widely used as weaning foods, yet conventional formulations-often dominated by rice or wheat-are energy-dense but micronutrient-poor and lack dietary fiber or essential amino acids (Moya, 2016) [12].

In this context, millets emerge as promising candidates for developing nutritious, sustainable, and culturally acceptable complementary foods. Millets are gluten-free, drought-resistant grains, naturally rich in iron, calcium, dietary fiber, B-complex vitamins, and phenolic compounds (Saleh *et al*., 2013) [13]. Finger millet (Ragi), for instance, is known for its exceptionally high calcium content (~344 mg/100g), making it ideal for bone development in young children (Devi *et al*., 2014) [6]. Pearl millet is another noteworthy millet with significant amounts of iron, zinc, and protein, beneficial for hemoglobin synthesis and immune function (Mokal, 2024) [11].

Moreover, processing methods such as roasting and dry milling can improve the flavor, texture, and nutrient bioavailability of millet-based products while reducing anti-nutritional factors (Ikegwu *et al*., 2021) [7]. With growing emphasis on food sovereignty and climate-resilient crops, formulating millet-based weaning foods is not only nutritionally advantageous but also supports agricultural sustainability and local food systems (Asefa & Melaku, 2017) [3, 4].

The present study aimed to develop and evaluate a multi-millet complementary food powder-Baby Boost Millet Mix-for its nutritional composition, antioxidant potential, sensory attributes and microbiological safety, ensuring suitability for infant and toddler consumption.

2. Materials and Methods

2.1 Ingredient Procurement

Raw millets including finger millet (*Eleusine coracana*), sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*), foxtail millet (*Setaria italica*), and little millet (*Panicum sumatrense*) were sourced from certified organic farms in Hyderabad, India. All grains were cleaned and quality-checked to ensure they were free of contaminants and within food-grade moisture limits (<12%). Green cardamom (*Elettaria cardamomum*), used for flavor enhancement, was procured from a local spice market. All ingredients were stored in airtight containers under hygienic conditions at room temperature prior to processing.

2.2 Preparation of the Product

The millet mix was prepared through dry roasting and milling techniques to enhance flavor, reduce anti-nutritional factors, and improve shelf stability, consistent with the processing methods described by Asefa and Melaku (2017) [3, 4]. Each type of millet was individually cleaned, dry roasted at 120 °C for 10–12 minutes to enhance aroma and digestibility, and cooled to ambient temperature. The roasted grains were then milled into fine powders using a hammer mill and sieved to obtain uniform particle size. The powders were mixed in specified proportions to create different formulations.

2.3 Procedure Flow Chart

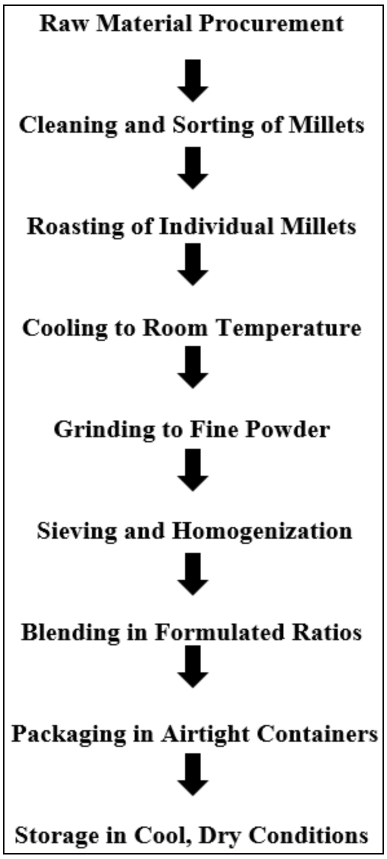

Fig 1: Preparation of Baby Boost Millet Mix

This method was adapted and optimized based on previous work on millet–cereal blends for infant nutrition (Keyata *et al*., 2021; Ikegwu *et al*., 2021) [8, 7].

2.4 Formulation of Product

Three formulations (T_1, T_2, and T_3) were developed by varying the proportions of five millets, aiming for sensory balance and optimal nutrient distribution. All formulations were standardized based on trial-based sensory evaluation and previous literature (Mokal, 2024) [11].

Table 1: Formulation Composition of Baby Boost Millet Mix (per 100 g)

Ingredient	T_1 (%)	T_2 (%)	T_3 (%)
Jowar	50	40	50
Ragi	50	30	40
Pearl millet	50	50	30
Foxtail millet	50	20	40
Little millet	50	35	45

All ingredients were mixed in equal weights to maintain standard testing parameters for each batch, with minor adjustments made based on palatability trials.

2.5 Sensory Evaluation (9-point Hedonic Scale)

Sensory evaluation of the three formulations was carried out using a semi-trained panel of 20 members, aged 25–45, with experience in food sensory testing. Samples were evaluated for color, texture, aroma, taste, and overall acceptability using a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely), as per Meilgaard, Civille, and Carr (2007) [10]. Evaluation was conducted in individual booths under white light, and water was provided to rinse the mouth between samples.

2.6 Nutritional Analysis

The proximate composition-energy, protein, carbohydrate, total fat, moisture, and ash content-was determined using standard AOAC International methods: Protein**:** AOAC 992.23 (Kjeldahl method); Total Fat: AOAC 996.06; Moisture**:** AOAC 925.10, Ash: AOAC 923.03; Carbohydrate**:** Calculated by difference; Energy: Derived using Atwater conversion factors. All analyses were conducted in triplicate and expressed per 100 ml of the prepared slurry (10 g powder in 100 ml warm water).

2.7 Mineral and Vitamin Analysis

Micronutrient composition, including iron, calcium, zinc, and selected vitamins, was quantified by validated AOAC protocols Iron, Calcium, Zinc**:** AOAC 999.11; Vitamin A**:** AOAC 971.30; Vitamin D**:** AOAC 2004.01; Vitamin B1 (Thiamine): AOAC 985.29; Vitamin B2 (Riboflavin)**:** AOAC 972.4; Vitamin B3 (Niacin)**:** AOAC 986.49. These micronutrients were chosen for their role in growth, cognitive development and immune support (Mbaeyi Nwaoha & Obetta, 2016; Abeshu *et al*., 2016) [9, 1].

2.8 Antioxidant Activity

Antioxidant potential was assessed using three established in vitro assays: DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay; ABTS (2,2′-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid) assay; FRAP (Ferric Reducing Antioxidant Power) assay. Samples were extracted using methanol and analyzed as described by Benzie and Strain (1996) [5]. Results were expressed as mg antioxidant equivalents per 100 g of dry powder.

2.9 Microbial Analysis and Shelf-life Studies

Microbiological quality of the samples was tested in accordance with AOAC standards: Aerobic Plate Count**:** AOAC 990.12; Yeast and Mold Count: AOAC 997.02; Enterobacteriaceae**:** AOAC 991.14; Staphylococcus aureus**:** AOAC 991.14. All analyses were performed immediately after 1, month during storage at ambient temperature (25 °C ± 2 °C, RH 65%). Samples were stored in food-grade laminated pouches to assess product stability and shelf-life.

3. Results and Discussion

3.1 Sensory Evaluation of Formulations

The sensory evaluation scores for the three formulations (T_1, T_2, and T_3) of the Baby Boost Millet Mix, assessed using a 9-point hedonic scale for color, texture, aroma, taste, and overall acceptability (Table 2). Among the samples, T_1 recorded the highest scores in texture (8.6 ± 0.50) and overall acceptability (7.96 ± 0.09), indicating its superior palatability and mouthfeel. T_3 followed closely with balanced sensory attributes, while T_2 scored slightly lower across most parameters. A one-way ANOVA revealed no statistically significant differences among the formulations ($F = 2.38$, $p = 0.09$), suggesting comparable sensory quality across treatments. These findings align with those of Ikegwu *et al*. (2021) [7], who reported similar acceptability trends in millet-based weaning foods. The overall high scores reinforce the consumer-friendly sensory appeal of millets when processed using roasting and blending techniques (Meilgaard *et al*., 2007) [10].

Table 2: Sensory Parameters of Tested Samples (T_1, T_2, T_3) Multi-Millet Complementary Food Mix

Sample	Colour	Texture	Aroma	Taste	Overall Acceptability
T_1	7.6±0.50	8.6±0.50	7.8±0.41	7.86±0.63	7.96±0.09
T_2	7.73±0.45	7.46±0.51	7.73±0.45	7.66±0.48	7.64±0.028
T_3	7.66±0.48	7.73±0.45	7.73±0.45	7.73±0.45	7.71±0.015

3.2 Nutritional Composition

The proximate composition of the Baby Boost Millet Mix per 100 ml. The formulation demonstrated a balanced nutritional profile with energy content of 346 kcal, protein at 10.1 g, and carbohydrates at 69.7 g. The fat content (3 g) and moisture (8%) fall within safe and desirable ranges for dry complementary food powders (Table 3). These results are consistent with prior studies highlighting millets' suitability in infant formulations due to their high energy density and protein adequacy (Asefa & Melaku, 2017; Mokal, 2024) [3, 4, 11]. The protein level observed exceeds the minimal WHO-recommended values for complementary foods, confirming the mix's adequacy in supporting muscle growth and immune development in infants (USDA, 2019) [14].

Table 3: Proximate Nutritional Analysis Multi-Millet Complementary Food Mix (T_1)

Test parameter	Unit	Results
Energy	k/cal	346
Protein	g/100ml	10.1
Carbohydrates	g/100ml	69.7
Total fats	g/100ml	3
Moisture	%	8
Ash	%	1.6

3.3 Mineral and Vitamin Content Multi-Millet Complementary Food Mix (T_1)

The micronutrient composition of the formulation (Table 4). Notably, the iron content (5.3 mg/100 ml) meets more than 35% of the daily iron requirement for infants aged 7–12 months, based on WHO guidelines. Calcium levels (30 mg/100 ml) contribute to bone mineralization, while zinc (2.25 mg/100 ml) supports enzymatic and immune functions. The vitamin profile revealed appreciable levels of Vitamin A (0.7 mg/100 ml) and B-vitamins, although Vitamin D was not detected-a common limitation in plant-based products (Mbaeyi Nwaoha & Obetta, 2016) [9]. These results support the assertion that millet-based blends can be nutritionally competitive with fortified cereal-based weaning foods, while offering additional sustainability benefits (Saleh *et al*., 2013) [13].

Table 4: Mineral and Vitamin Composition Multi-Millet Complementary Food Mix (T_1)

Test parameter	Unit	Results	Test method
Iron	mg/100ml	5.3	AOAC 999.11
Calcium	mg/100ml	30	AOAC 999.11
Zinc	mg/100ml	2.25	AOAC 999.11
Vitamin A	mg/100ml	0.7	AOAC 971.30
Vitamin D	mg/100ml	0	AOAC 2004.01
Vitamin B1	mg/100ml	0.2	AOAC 985.29
Vitamin B2	mg/100ml	0.1	AOAC 972.4
Vitamin B3	mg/100ml	1.5	AOAC 986.49

3.4 Antioxidant Activity

The antioxidant capacity of the Baby Boost Millet Mix as measured by DPPH, ABTS, and FRAP assays (Table 5). The ABTS assay yielded the highest activity (723 mg/100 g), followed by FRAP (650 mg/100 g) and DPPH (110 mg/100 g), indicating the presence of phenolic compounds inherent to millets, particularly finger millet (Devi *et al*., 2014) [6]. These antioxidants play a crucial role in neutralizing free radicals, supporting cellular health, and reducing inflammation, which are especially beneficial during early development stages. The high antioxidant levels further affirm the functional food potential of the product, complementing its basic nutritional value with added bioactive benefits (Benzie & Strain, 1996) [5].

Table 5: Antioxidant Analysis (DPPH, ABTS, FRAP) Multi-Millet Complementary Food Mix (T_1)

Test Parameters	Results
DPPH	110 mg/100gm
ABTS	723 mg/100gm
FRAP	650 mg/100gm

3.5 Microbial Safety and Shelf-Life Stability

The microbial analysis of the millet mix. All samples showed aerobic plate counts and yeast & mold levels well below permissible limits (<10 CFU/g), while *Enterobacteriaceae* and *Staphylococcus aureus* were absent in 25 g of the product (Table 6). These findings confirm that the dry-heat processing and hygienic handling practices effectively minimized microbial contamination. The use of low-moisture packaging also contributed to microbial stability during storage. These safety results are critical in ensuring that the product meets international microbiological standards for infant foods (AOAC, 2019). The stability over a six-month shelf-life period without spoilage also demonstrates the product's practical viability in diverse market conditions, especially in resource-limited settings.

Table 6: Microbial Activity of Multi-Millet Complementary Food Mix (T_1)

Test Parameter	Unit	Result	Limits
Aerobic plate count	CFU/g	<10	$1*10^6$
Yeast & molds	CFU/g	<10	$1*10^6$
Enterobacteriaceae	CFU/g	Absent	Absent/25g
S. aureus	CFU/25g	Absent	Absent/25g

4. Conclusion

The development of Baby Boost Millet Mix demonstrates the efficacy of incorporating indigenous millet varieties into a balanced, sensory-acceptable, and nutritionally robust complementary food for infants and toddlers. Among the tested formulations, T_1 achieved the highest consumer acceptability while maintaining superior nutritional and antioxidant properties. The product meets key dietary requirements for energy, protein, iron, and essential micronutrients, and its microbial safety and shelf stability make it suitable for large-scale distribution in both urban and rural contexts. These results highlight the role of millet-based interventions in improving childhood nutrition, particularly in regions where malnutrition and food insecurity remain prevalent. Future studies may focus on clinical acceptability trials and further fortification strategies to enhance its impact.

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