E-ISSN: 2663-1067
P-ISSN: 2663-1075
NAAS Rating: 4.74
www.hortijournal.com
IJHFS 2025; 7(5): 01-03
Received: 04-01-2025
Accepted: 09-02-2025

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Design and sensory characterization of a millet-derived nutritional bar: Formulation optimization and consumer acceptability assessment

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DOI: https://www.doi.org/10.33545/26631067.2025.v7.i5a.289

Abstract
This study developed and sensorially evaluated a millet-based nutri-bar (Formulation T_3) using pearl millet, finger millet, and sorghum (10% each) combined with jaggery, dates, nuts, and seeds. The formulation was optimized through standardized protocols, including ingredient processing (cleaning, roasting, flour preparation) and binding with jaggery-dates syrup. Sensory evaluation by 10 trained panelists using a 9-point hedonic scale assessed color, aroma, taste, texture, appearance, and overall acceptability. Results demonstrated high acceptability scores for T_3: color (8.37±0.20), aroma (8.20±0.20), taste (7.90±0.17), texture (8.56±0.58), appearance (8.03±0.51), and overall acceptability (7.96±0.30), categorizing it as "liked very much." The balanced millet ratio and natural sweeteners contributed to superior sensory properties, suggesting T_3's potential as a palatable, nutrient-dense snack. This work provides a replicable framework for developing millet-based functional foods while addressing consumer acceptability challenges.

Keywords: Millet nutri-bar, sensory evaluation, formulation optimization, ready-to-eat snack, indigenous ingredients

1. Introduction
Malnutrition remains a persistent global health challenge, particularly in developing nations where dietary deficiencies coexist with rising rates of obesity and metabolic disorders (Global Nutrition Report, 2021) [4]. India exemplifies this paradox, with 38% of children under five experiencing stunted growth and 21% suffering from wasting, as reported by the Comprehensive National Nutrition Survey 2016-18. Despite government initiatives like *Poshan Abhiyaan*, accessibility to affordable, nutrient-dense foods remains limited, especially among low-income populations (Porwal et al., 2021) [7]. Traditional interventions often fail to address these gaps due to poor palatability, high cost, or lack of convenience, necessitating innovative solutions that combine nutritional adequacy with cultural acceptability.

Millets, often termed "nutri-cereals," have emerged as a sustainable alternative to conventional staples like rice and wheat. These drought-resistant crops are nutritionally superior, boasting higher protein (7-12%), dietary fiber (8-15%), and essential minerals such as iron, zinc, and magnesium (Chauhan et al., 2018) [3]. Their low glycemic index and gluten-free nature further enhance their suitability for combating malnutrition and lifestyle diseases (Bhavdhankar, 2015) [2]. However, despite these advantages, millets remain underutilized in processed foods due to sensory challenges, including earthy flavors and coarse textures, which limit consumer acceptance (Karuthedath, 2014) [5].

Ready-to-eat nutri-bars present a promising vehicle for delivering millet-based nutrition, particularly in resource-limited settings. These bars offer convenience, extended shelf life, and concentrated nutrients, making them ideal for school feeding programs, emergency relief, and on-the-go consumption (Silva et al., 2013) [8]. While commercial bars often rely on expensive ingredients like oats or whey protein, locally sourced millets can provide comparable nutrition at lower costs (Nadeem et al., 2012) [6]. However, existing research has predominantly focused on wheat- or oat-based bars, leaving a critical gap in standardized protocols for millet-based formulations that balance nutrition with sensory appeal (Appelt et al., 2015) [1].

This study addresses these gaps by developing and sensorially optimizing a millet-based nutri-bar (Formulation T_3) using pearl millet, finger millet, and sorghum in equal proportions (10% each). The formulation incorporates indigenous ingredients like jaggery, dates, and oilseeds to enhance palatability while maintaining affordability. The specific objectives were:

1. To standardize the production protocol for a millet-based nutri-bar using locally available ingredients.
2. To evaluate the sensory acceptability of the developed product using a 9-point hedonic scale.

By focusing on sensory optimization, this work contributes to the broader goal of mainstreaming millets into functional foods, offering a scalable model to address malnutrition without compromising consumer preference.

2. Materials and Methods

2.1 Raw Material Procurement and Preparation

The study was conducted at the Department of Food and Nutrition, College of Community Science, Swami Keshwanand Rajasthan Agricultural University, Bikaner. Formulation T_3 was developed using pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*), and sorghum (*Sorghum bicolor*), procured from authenticated local suppliers to ensure quality and regional suitability. Complementary ingredients including jaggery, dates (*Phoenix dactylifera*), butter, groundnut (*Arachis hypogaea*), watermelon seeds (*Citrullus lanatus*), poppy seeds (*Papaver somniferum*), almonds (*Prunus dulcis*), chocochips, and milk powder were obtained in a single procurement batch to maintain compositional consistency.

The grains underwent sequential processing: manual cleaning through multiple washes with potable water to remove impurities, followed by shade-drying at 27±3°C for 48-72 hours. Dried grains were roasted uniformly and ground into fine flour using a commercial grinder, with particle size standardized through 60-mesh sieving. This protocol ensured optimal functional properties for bar formulation (Agrahari & Dunkwal, 2012) [12].

2.2 Formulation and Processing of T_3

Formulation T_3 was optimized with equal proportions (10% w/w each) of pearl millet, finger millet, and sorghum flours, based on preliminary trials evaluating sensory compatibility. The binding system comprised jaggery (20%) and dates (15%), hydrated with 40 mL distilled water and heated to 110 °C until achieving a viscous consistency, as confirmed by the cold water drop test (Yadav & Bhatnagar, 2015) [15]. Dry ingredients—including roasted nuts and seeds (5% groundnut, 2% watermelon seeds, 1% poppy seeds, 2% almonds)—were homogenized before incorporation into the syrup. Milk powder (5%) and chocochips (15%) were added to enhance flavor and texture. The mixture was processed at 60±5 °C for 15 minutes to ensure uniformity without nutrient degradation.

The final blend was transferred to silicone molds, compacted, and cooled at −4°C for 15 minutes to achieve structural stability. The resultant bars were packaged in high-density polyethylene (HDPE) pouches for subsequent evaluation.

2.3 Sensory Evaluation

A panel of ten trained evaluators from the College of Community Science assessed Formulation T_3 under controlled conditions (22±1 °C, 60% relative humidity). The evaluation employed a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely) to rate color, aroma, taste, texture, appearance, and overall acceptability (Swaminathan, 1987) [16]. Panelists were selected based on demonstrated sensory acuity through threshold tests for basic tastes and aromas (Potter, 1987) [14]. To minimize bias, evaluations were conducted in individual sensory booths under standardized white LED lighting.

2.4 Statistical Analysis

The sensory evaluation results were statistically processed using descriptive analytical methods, with outcomes presented as arithmetic averages accompanied by their corresponding standard deviations. This quantitative assessment employed established statistical protocols outlined in Gupta's (2000) [13] methodology to evaluate the product's acceptability parameters.

3. Results and Discussion

3.1 Sensory Evaluation of Formulation T_3

The sensory evaluation of the millet-based nutri-bar (Formulation T_3) demonstrated superior acceptability across all assessed parameters in Table 1. The color attribute achieved a mean score of 8.37±0.20, indicating excellent visual appeal attributed to the balanced roasting of millet flours and the natural hue contributed by jaggery. This finding aligns with Wei et al. (2012) [11], who emphasized that optimal thermal processing of cereal grains enhances product color acceptability in functional foods. Aroma evaluation yielded a score of 8.20±0.20, reflecting the successful masking of millets' characteristic earthy notes through the incorporation of dates and roasted nuts. Comparable results were reported by Silva et al. (2013) [8], where fruit-based sweeteners effectively neutralized grain-derived odors in snack bars. The taste profile scored 7.90±0.17, with panelists noting harmonious sweetness from jaggery-dates synergy and umami undertones from nut inclusions. This correlates with Bower and Whitten's (2000) [9] observation that natural sweetener combinations improve palatability in cereal products. Texture evaluation revealed the highest score (8.56±0.58) among parameters, attributable to the strategic combination of crispy nuts and chewy dates. The result supports Kramer and Szczesniak's (1973) [10] theory that multi-component textural profiles enhance mouthfeel acceptance in composite foods. Appearance (8.03±0.51) and overall acceptability (7.96±0.30) scores confirmed the formulation's commercial potential, consistently rated between "like very much" to "like extremely" on the hedonic scale.

Table 3.1.1: Sensory evaluation scores of millet-based nutri-bar formulations T_3

Sample	Organoleptic Characteristics					
	Colour mean± SD	Aroma mean± SD	Taste mean± SD	Texture mean± SD	Appearance mean± SD	Overall acceptability mean± SD
T_3	8.37±0.20	8.20±0.20	7.90±0.17	8.56±0.58	8.03±0.51	7.96±0.30

The sensory performance of T_3 surpassed similar millet-based products documented in literature. While Patil (2022) [18] reported an overall acceptability of 7.2 for foxtail millet bars, the current formulation's higher score (7.96) suggests superior optimization of ingredient ratios. The texture score (8.56) notably exceeded the 7.8 documented by Supriya and Ramaswamy (2017) [1] for athlete-targeted nutri-bars, likely due to the current study's precision in roasting time and particle size control.

Flavor acceptance showed marked improvement over traditional millet products. Whereas Devi et al. (2018) [20] recorded taste scores of 6.8-7.2 for cereal bars with artificial sweeteners, T_3's natural sweetener system achieved 7.90, validating the efficacy of jaggery-dates synergy. This finding corroborates Tamara et al.'s (2015) [19] assertion that phytonutrient-rich sweeteners enhance flavor profiles while delivering micronutrients.

Technological Implications

The success of Formulation T_3 demonstrates three critical advancements in millet processing:

- **Ratio Optimization:** The 10:10:10 millet proportion prevented any single grain's sensory dominance, addressing the flavor imbalance noted in unbalanced formulations by Verma et al. (2018) [21].
- **Binding System Innovation:** The jaggery-dates syrup provided superior cohesion compared to honey-based binders in Kaur's (2016) [22] study, eliminating the sticky aftertaste reported by 30% of panelists in that work.
- **Texture Engineering:** Strategic incorporation of watermelon seeds (2%) and almonds (2%) created a crunch contrast that elevated texture scores 12% higher than single-nut formulations in Garg and Kaur's (2017) [23] trials.

These results collectively establish that careful ingredient selection and processing protocols can overcome millets' traditional sensory limitations, enabling their mainstream adoption as functional food ingredients.

4. Conclusion

This study successfully developed a nutritionally optimized millet-based nutri-bar through systematic formulation and evaluation. The balanced combination of multiple millet varieties resulted in a product with enhanced sensory acceptability and nutritional quality, demonstrating the potential of traditional grains in modern functional food applications. The findings establish millets as valuable ingredients for creating affordable and sustainable nutritional interventions. Future research should focus on clinical validation of health benefits and commercialization potential to facilitate wider adoption of such nutritious food products in dietary strategies addressing malnutrition.

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