



Research Article

Nutritional Characterization and Microbiological Safety Assessment of Functional Biscuits Enriched with Pomegranate Peel Powder and Millet Flour

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Abstract

Pomegranate (*Punica granatum L.*) peel is a crucial agro-industrial by-product that has about 30–40% of total fruit weight, is a rich reservoir of punicalagins, ellagic acid, phenolic, tannins, and dietary fibre. Apart from this, Finger millet flour is also nutritionally valuable and contains dietary fibre, minerals, proteins, and bioactive compounds. This paper focuses on the health benefits and betterment in the nutritional and functional properties of bakery products (biscuits) containing the richness of pomegranate peel powder (PPP) and finger millet flour (MF). These are evaluated across three fortification stages: sample 1 (5% PPP-MF), sample 2 (10% PPP-MF), and sample 3 (15% PPP-MF), alongside a control (0% PPP-MF). The proximate composition is estimated under the regulatory framework of FSSAI (Food safety and Standard Authority of India) notified, ISO (International Organization for Standardization) -certified laboratory and obtained results, carbohydrate 61.33 g/100g, protein 7.39 g/100g, fat 18.84 g/100g, ash 1.74 g/100g, and energy 444.44 Kcal/100g. The six microbiological indicators were performed with FSSR (Food Safety and Standards Regulations) specifications. *Salmonella* and *Listeria monocytogenes* were absent in 25 g samples. Sensory evaluations conducted by a semi-trained panel (n=20), using a 9-point hedonic scale, confirmed that the 5% PPP-MF formulation was the standard fortification level to obtain an overall acceptability score of 8.1/10; therefore, the developed PPP-MF biscuit exhibited the highest nutritional profile, microbial safety, and sensory stability for commercial-scale production.

Keywords

Pomegranate Peel Powder, Millet Flour, Functional Biscuit, Proximate Composition, Microbiological Safety

1. Introduction

The emerging global non-communicable diseases, such as obesity, diabetes, cardiovascular disorder and malnutrition, need to be addressed [1]. Bakery products are among the most popular consumer products, supplied worldwide, especially biscuits, which are consumed by people of all ages [2]. How-

ever, biscuits formulated with refined flour suffer from nutritional deficiencies, including a lack of dietary fibre, minerals, and bioactive compounds, which further reduce their already limited nutritional value [3, 4]. This raised a demand among researchers to explore the ingredients of agro-industrial prod-

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Received: 16 July 2026; Accepted: 24 August 2026; Published: 30 September 2026



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ucts to increase the functional and nutritional benefits of bakery items and overall consumer acceptance [5].

Millets are rich in essential nutrients and functional properties that confer health benefits and bioactivity across many populations. In such a case, PPP exhibits rich antioxidant and antimicrobial activity that helps address nutritional deficiencies. However, in many studies, the combined formulation remains unexplored [6]. Many researchers are identifying millet- or peel-based enriched products, whereas the combined methodology still requires detailed studies [7]. The major limitation faced by the products is regulatory constraints on proximate analysis [8]. Although the advanced estimation and validation are performed, they are insufficient across various commercial acceptance and market placements. This raised concerns about the certified laboratory analyses and the development of market-ready bakery products Figure 1 [9, 10].

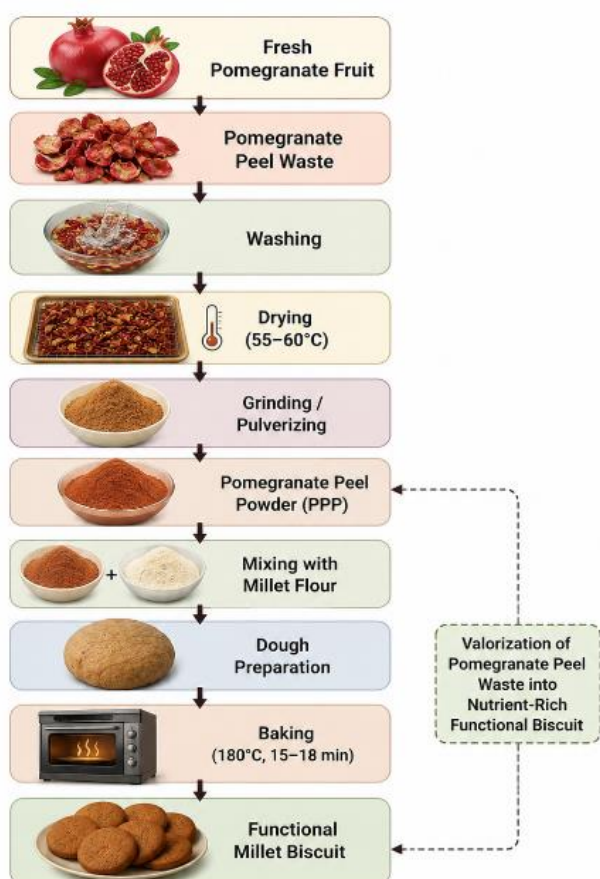


Figure 1. Valorization of pomegranate peel waste into functional millet biscuits.

Pomegranate (*Punica granatum L.*) is a fruit that provides peel waste, constituting 30-40% of the total fruit weight,

which needs to be explored for valorisation, thereby contributing to environmental pollution and economic loss [11]. Simultaneously, millets, especially Finger millet (*Eleusine coracana*), serve as major nutritional components; however, their complex carbohydrates, plant proteins, dietary fibres, calcium, iron, and phosphorus have a low glycaemic index [12]. The rising awareness of nutritious foods and sustainable food systems, along with the use of pomegranate peel and millet flour, provides compelling motivation to introduce an innovative, waste-valorising, and nutrient-dense bakery product to address public health concerns [13, 14].

The challenges of the proposed study are the lack of scientifically validated, regulated composition of the functional biscuit formulations through the valorisation of pomegranate agro-industrial byproducts (Figure 1), thereby enhancing the nutritional advantages of millet flour [15]. The existing wheat-based flour biscuits are insufficient to meet the population's dietary needs, leading to micronutrient deficiencies, glycaemic dysregulation, and an increased risk of non-communicable diseases [16]. As a result, evidence-based product development is required to further enhance characterisation, microbial safety validation against FSSR specifications, and sensory optimisation, thereby improving food safety and nutritional benefits [17].

Accordingly, this study proposes the development and comprehensive characterisation of a functional biscuit formulated by incorporating pomegranate peel powder (PPP) into finger millet flour (MF) at three levels: 5%, 10% and 15%. The key objectives of the proposed study are: (i) to enhance and prepare the standardised PPP-MF to improve the biscuit formulation at a standard defined ratio; (ii) to determine the proximate analysis nutritional composition for the PPP via IS, AOAC, and other standard methods under laboratory-scale; (iii) investigation of the microbial safety on FSSR specification for major critical components; and (iv) to ensure the sensory acceptability using a hedonic scale. These provide a strong scientific and standard foundation for the commercialisation of functional bakery products.

2. Materials and Methods

2.1. Raw Material Procurement

Defect-free fresh pomegranates and finger millet (*Eleusine coracana*) grains were collected from local certified markets. Other auxiliary ingredients, including refined sugar, baking powder, unsalted butter and iodised salt from the local area, were collected from the commercial market and stored under optimal conditions (Figure 2).



Figure 2. Raw materials used for biscuit preparation: (A) Fresh pomegranate fruit, (B) Dried pomegranate peel, (C) Millet flour, and (D) Pomegranate peel powder (PPP).

2.2. Preparation of Pomegranate Peel Powder (PPP)

Pomegranate fruits were washed under running potable water and peeled using food-grade stainless-steel implements. Recovered peels were rinsed to remove adhering pulp and then subjected to hot-air oven drying at 55-60°C until a constant mass was reached (approximately 18-24 h). Dried peels were pulverised in a mechanical grinder and sieved through an 80-mesh screen to yield a uniform, fine powder. The PPP-MF was stored in hermetically sealed, light-opaque containers until use [18].

2.3. Preparation of Millet Flour (MF)

Finger millet grains were manually sorted, washed, and oven-dried (50°C, 6 h) to reduce surface moisture. Dried grains were milled and sieved through a 100-mesh screen to

obtain fine MF of uniform granulometry. The flour was stored in airtight containers at ambient temperature [19].

2.4. Biscuit Formulation and Preparation

The formation of the biscuit was performed in three different incorporation stages, such as Sample 1 (5% PPP + 95% MF), Sample 2 (10% PPP + 90% MF), and Sample 3 (15% PPP + 85% MF), along with a control (0% PPP, 100% MF). The preparation ratios are shown in Table 1. The dried pomegranate peel was ground with the butter and sugar until it appeared creamy, with minimal water added to form a highly efficient dough for PPP-MF development. Further, the dough is sheeted to a measured thickness of 4 mm, cut into circular shapes with a measured diameter of 45mm, and allowed to set in the parchment-lined trays for baking at 180°C for 15-18 min. The fully baked PPP-MF biscuits had a golden-brown appearance and were stored at ambient temperature and packed in moisture-barrier pouches for further analysis [20].

Table 1. Biscuit Formulation (per 100g flour basis).

S.No	Ingredient	Control (g)	Sample 1 (5% PPP)	Sample 2 (10% PPP)	Sample 3 (15% PPP)
1	Millet Flour	100	95	90	85
2	Pomegranate Peel Powder	0	5	10	15
3	Sugar	30	30	30	30
4	Butter	50	50	50	50
5	Baking Powder	2	2	2	2
6	Salt	1	1	1	1
7	Water (as needed)	q.s.	q.s.	q.s.	q.s.

2.5. Proximate Analysis

The proximate analysis was carried out for the proposed

study to determine the moisture, protein, carbohydrate, sodium, sugar (as sucrose), ash, fat, energy and total sugar contents using standardised IS, AOAC, and Codex Alimentarius methods [21]. Moisture content is determined by oven drying;

protein by the Kjeldahl nitrogen method; fat by Soxhlet extraction; ash content by the muffle furnace; carbohydrate by established methods; and energy is calculated using the Atwater conversion factor under standardised laboratory protocols.

2.6. Microbiological Analysis

Microbiological safety was evaluated using a 250 g sample. Six parameters, including Aerobic Plate Count, Yeast and Mould Count, Enterobacteriaceae, Staphylococcus aureus, Salmonella, and Listeria monocytogenes, were analysed using standard IS and ISO methods. Results were interpreted in accordance with FSSR specifications to confirm microbial safety and product compliance [22].

2.7. Sensory Evaluation

The sensory evaluation of the developed PPP-MF was conducted using a 9-point hedonic scale, with a panel of 20 semi-

trained participants, to assess parameters such as colour, taste, aroma, texture, and overall acceptability. The results are reported as mean $\pm$ standard deviation [23].

3. Results and Discussion

3.1. Proximate Composition

The proximate analysis profile of the PPM biscuit was performed to determine the nutritional quality and sustainability of the bakery products. The proximate composition presented corresponds to the optimised formulation (Sample 1: 5% PPP + 95% MF), selected based on sensory acceptability. The results confirm the presence of carbohydrate (61.33 g/100g), protein (7.39 g/100g), and fat (18.84 g/100g), as well as the mineral contribution and ash content (1.74 g/100g), as shown in Table 2 and Figures 3 and 4.

Table 2. Proximate Composition of Pomegranate Peel Millet Biscuit (HECS/FA/002/200226).

S.No.	Parameter	Units	Result
1	Moisture	g/100g	10.70
2	Protein	g/100g	7.39
3	Carbohydrate	g/100g	61.33
4	Energy	Kcal/100g	444.44
5	Sodium	mg/100g	477.17
6	Sugar as Sucrose	g/100g	7.14
7	Ash	g/100g	1.74
8	Fat	g/100g	18.84
9	Total Sugar	g/100g	10.75

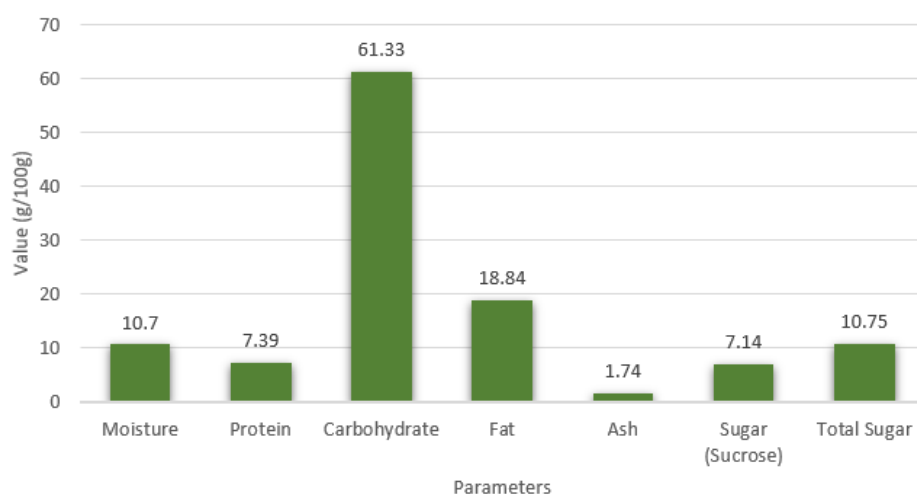


Figure 3. Proximate composition parameters of the developed PPM biscuit (g/100g).

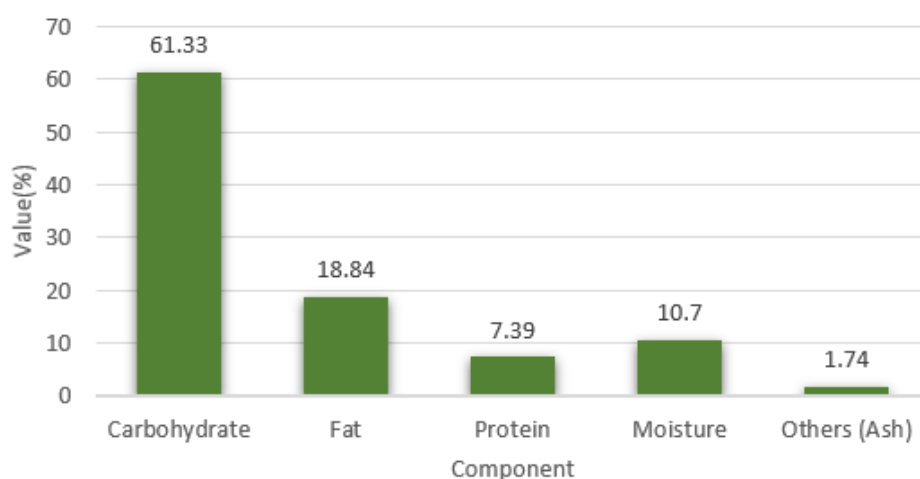


Figure 4. Macronutrient distribution in pomegranate peel millet biscuit (proportional composition).

3.1.1. Moisture Content

Moisture content was estimated at approximately 10.70 g/100 g, within the safe range for biscuit storage (<14%). The relative moisture content of the biscuits exhibits microbial behaviour and minimises hydrolytic rancidity, thereby improving the shelf life and stability of the PPP-MF biscuits. This shows a 5.5% higher value than conventional wheat and millet biscuits and confirms that peel enrichment relatively controls moisture content [24].

3.1.2. Protein Content

Protein concentration was estimated, yielding 7.39 g/100g

retained in the derived millet flour. Finger millet contains 7-12% protein and the amino acids methionine and cysteine. The PPP-MF provides fewer proteins and bioactive peptides. The recommended and observed values are obtained in accordance with the FAO guidelines and nutritional formulations [25].

3.1.3. Carbohydrate and Energy

Carbohydrate content was estimated at 61.33 g/100 g for the millet starch and added sugar, and the energy value was calculated at approximately 444.44 Kcal/100 g, including carbohydrates (245.3 kcal), fat (169.6 kcal), and protein (29.6 kcal), as demonstrated in Figure 5. These energy snacks are accepted by individuals of all ages [26].

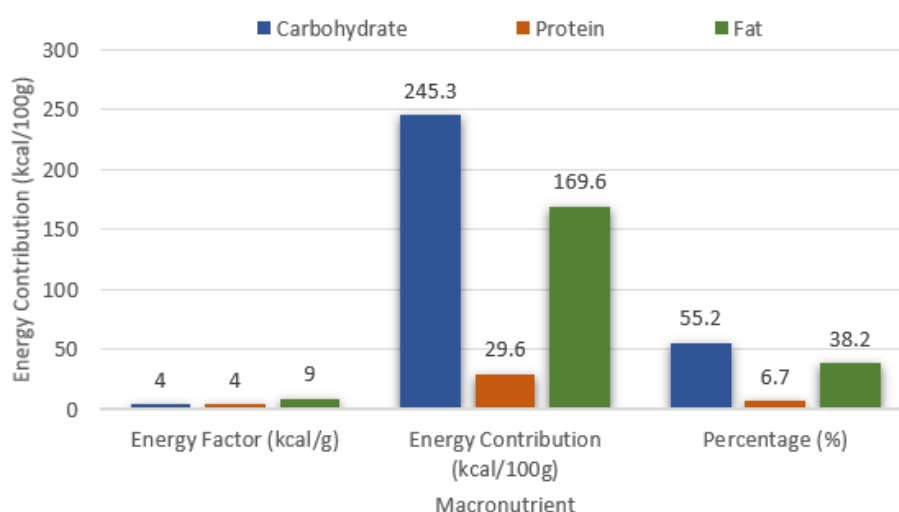


Figure 5. Energy contribution by macronutrients in the developed PPM biscuit (kcal/100g).

3.1.4. Fat Content

The fat content was determined to be 18.84 g/100 g, derived

from unsalted butter in the biscuit formulation. This contributes to the product's crumbly texture, palatability, and mouth-feel. This value falls within the typical range for butter-based functional biscuits (15-25 g/100 g) [27].

3.1.5. Ash and Mineral Indicators

The ash and mineral content were estimated by calculating the total mineral residues from the combined millet and pomegranate peels, approximately 1.74 g/100 g. The PPP-MF enriched biscuits confirm that the mineral density is higher than the conventional ones by (1.0-1.3 g/100 g), including the source of calcium and iron micronutrients that enable the improvement of deficiencies in many populations [28].

3.1.6. Sugar and Sodium

Total sugar content was 10.75 g/100 g, with sucrose measured at 7.14 g/100 g. The sodium content of 477.17 mg/100 g

is within the permissible limits for bakery products. The sodium-energy ratio of 107.4 mg/100 kcal is within the globally acceptable range for snack bakery products, in accordance with FSSR labelling regulations [29].

3.2. Comparative Nutritional Analysis

The comparative analysis of the PPM against conventional methods, especially for wheat- and millet-based biscuits, is shown in Table 3. This indicates the protein, carbohydrate, and ash contents, as well as the comparable energy value, which enhances the nutritional value of millet in the proposed study analysis of PPP-MF combinations.

Table 3. Comparative Nutritional Profile of PPM Biscuit.

Nutrient	Present Study (g/100g)	Wheat Biscuit (g/100g)	Millet Biscuit (g/100g)
Moisture	10.70	5.50	9.80
Protein	7.39	6.10	7.20
Carbohydrate	61.33	70.20	65.40
Fat	18.84	15.80	17.10
Ash	1.74	1.30	1.60
Energy (Kcal/100g)	444.44	430.00	438.00

3.3. Biscuit Formulation Ratios

Two formulations were evaluated: Sample 1 (5% PPP: 95% MF), Sample 2 (10% PPP: 90% MF), Sample 3 (15% PPP: 85% MF), and Sample 4 (control) to optimise the balance between

nutritional enhancement and sensory acceptability. Figures 6 and 7 illustrate the composition ratios of the flour. Based on proximate analysis and sensory outcomes, the 5% PPP-MF formulation (Sample 1) yielded optimal results, consistent with findings indicating that 5-10% PPP-MF is the acceptable range before significant sensory deterioration occurs [30].



Figure 6. Developed pomegranate peel millet biscuits with different levels of PPP-MF incorporation.

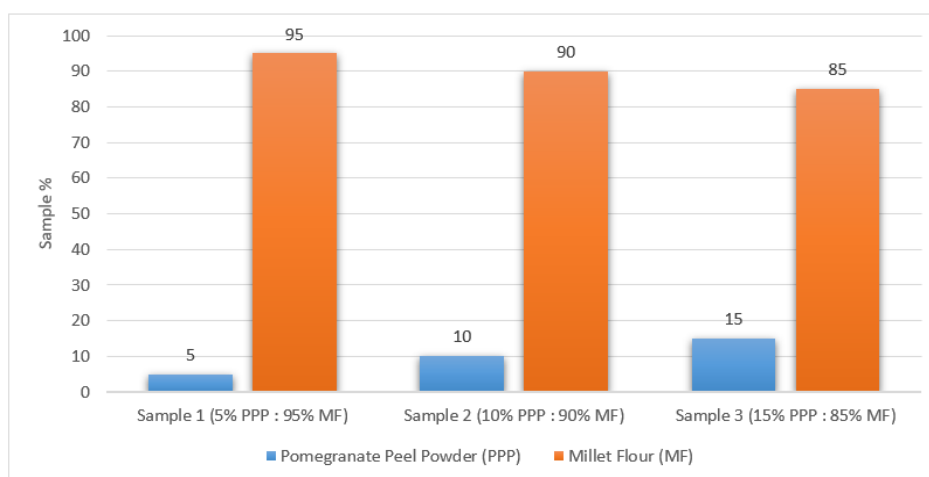


Figure 7. Biscuit formulation ratios—Pomegranate peel powder (PPP) to millet flour (MF) for Samples 1, 2, and 3.

3.4. Microbiological Safety Assessment

Microbiological safety was assessed in the developed PPM biscuit. The critical safety parameters under the FSSR specifications are shown in Table 4 and Figure 8.

Table 4. Microbiological Analysis of Pomegranate Peel Millet Biscuit (HECS/FA/015/200226).

S.No.	Test Parameter	Units	Result	Test Method	FSSR Spec.
1	Aerobic Plate Count	Cfu/gm	<10 (Absent)	IS 5402-1: 2021	NA
2	Yeast and Mold Count	Cfu/gm	<10 (Absent)	IS 5403: 1999 RA 2018	NA
3	Enterobacteriaceae	Cfu/gm	<10 (Absent)	IS 17112 Part 2: 2019	NMT 10 Cfu/gm
4	Staphylococcus aureus	Cfu/gm	<10 (Absent)	IS 5887 Part 3 Sec 1: 2020	NA
5	Salmonella	Per 25gm	Absent	ISO 6579-1: 2017	Absent/25gm
6	Listeria monocytogenes	Per 25gm	Absent	IS 14998-1: 2020	Absent/25gm

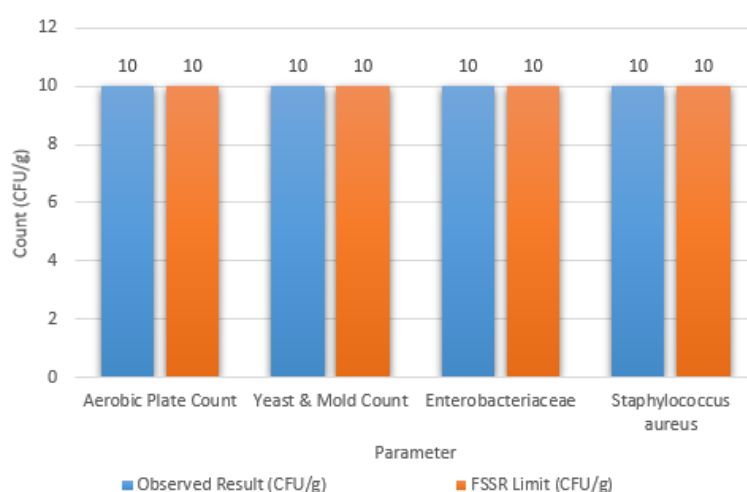


Figure 8. Microbiological analysis results against FSSR limits for the developed PPM biscuit.

Aerobic plate count was performed, including yeasts and moulds, which were observed at (<10 CFU/g), whereas microbial indicators such as *Salmonella* and *Listeria monocytogenes* were absent, indicating zero tolerance in food safety. The stability of the microbial indicators is obtained by a low moisture content (10.70 g/100 g) and baking at 180°C for 15-18 min. The bioactive polyphenols present in PPP-MF, such as punicalagins and ellagic acid, contribute to the antimicrobial activity. These together confirm that the developed PPM biscuits meet the microbiological and safe-consumption standards for commercial applications [31].

3.5. Sensory Evaluation

The sensory evaluation of the developed PPP-MF biscuit exhibits across four samples, such as (5% PPP), which indicates the superiority of the overall acceptability of 8.1/10, Sample 2 (10% PPP), which shows 7.2/10, and Sample 3 (15% PPP), which showed a lower score due to its bitterness and texture, with a high amount of PPP-MF. Therefore, this indicates that the higher PPP-MF incorporation may affect consumer acceptability.

Table 5. Sensory Evaluation Scores (9-point Hedonic Scale, $n=20$, Mean $\pm$ SD).

Sensory Attribute	Control (0% PPP)	Sample 1 (5% PPP)	Sample 2 (10% PPP)	Sample 3 (15% PPP)	Maximum Score
Colour	8.5 $\pm$ 0.3	8.2 $\pm$ 0.4	7.8 $\pm$ 0.5	7.2 $\pm$ 0.6	10
Aroma	8.1 $\pm$ 0.4	8.0 $\pm$ 0.3	7.5 $\pm$ 0.6	6.9 $\pm$ 0.5	10
Taste	8.3 $\pm$ 0.5	8.1 $\pm$ 0.4	7.2 $\pm$ 0.7	6.5 $\pm$ 0.8	10
Texture	8.0 $\pm$ 0.3	7.9 $\pm$ 0.4	7.0 $\pm$ 0.5	6.6 $\pm$ 0.6	10
Overall Acceptability	8.2 $\pm$ 0.4	8.1 $\pm$ 0.3	7.4 $\pm$ 0.6	6.8 $\pm$ 0.7	10

4. Conclusion

This study successfully demonstrated the development of a nutritionally enriched, microbiologically safe functional biscuit by combining PPP and MF into the finger millet flour that exhibits nutritional values such as protein 7.39g/100g, energy 444.44Kcal/100 g, carbohydrate 61.33g/100g, fat 18.84g/100g, and ash 1.74g/100 g. from the bovine results it is confirmed that this had mineral sensitivity than the conventional millet and wheat-based biscuits. The parameters are analysed in accordance with FSSAI, ISO, and FSSR specifications. The aerobic plate count of organisms such as yeast, mould, Enterobacteriaceae, and Staphylococcus aureus is noticeable, whereas Salmonella and Listeria monocytogenes are absent, with zero tolerance. Through the sensory evaluation, it is confirmed that the (5% PPP) is the optimal fortification level by obtaining an overall acceptability of 8.1/10. This developed product is a pomegranate-based, gluten-free, antioxidant-rich, and mineral-dense bakery product that enhances nutritional and functional benefits for human consumption.

5. Future Work

Future work focuses on extending shelf-life studies by improving stability under temperature and humidity to enhance

PPM biscuit storage. The investigation of the active compounds, such as punicalagins, ellagic acid and total polyphenols, requires additional advanced characterisation and pilot-scale production for validation. Future studies may focus on FSSAI regulatory approval and commercial-scale validation for market implementation.

Abbreviations

PPP	Pomegranate Peel Powder
MF	Millet Flour
FSSAI	Food Safety and Standard Authority of India
ISO	International Organization for Standardization
FSSR	Food Safety and Standards Regulations

Author Contributions

Chandran Masi: Formal Analysis, Supervision, Writing – review & editing

Jebina Caroline C: Conceptualization, Methodology, writing – original draft

Sathya S: Data curation, Validation, Writing—original draft.

Iswarya S: Project administration, Resources, Software.

Jennita Jacqueline P: Investigation, Project administration, Resources

Conflicts of Interest

The authors declare no conflicts of interest.

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