

Sustainable Utilization of Mulberry Leaf Waste in High-Fiber Cookies and Crackers

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Abstract

Mulberry leaf waste (MLP), generated in large quantities during sericulture pruning, harvesting, and leaf grading, is a nutrient-dense by-product with significant potential for value addition in functional food applications. It comes to be very high in crude fiber (10–18%) and plant protein (15–25%), thus it is the best reference for high-fiber and high-protein bakery products. On top of that, mulberry leaves waste has an ash content of 5–12%, fat of 2–5%, and very important minerals like calcium (1,500–2,500 mg/100 g) and iron (20–40 mg/100 g), which together make a very nutritious product. The bioactive compounds such as phenolics (150–350 mg GAE/100 g), flavonoids (50–120 mg QE/100 g), and GABA (20–50 mg/100 g) are responsible for strong antioxidant, anti-diabetic, hypolipidemic, and anti-inflammatory activities. This summarizes the work done in the area of MLP usage in the production of cookies and crackers enriched with fiber and proteins. The use of MLP at 2–10% substitution levels have a positive impact on the overall dietary fiber, protein, mineral, and antioxidant capacity of the baked goods and decreases their glycemic response. Each specific product has advantages such as better crispness, higher browning stability, and nutraceutical value improvement as a result of polyphenols being retained during baking. Still, greater substitution rates might cause changes in sensory properties such as hardness increase, and the greenish hue and a mild herbal taste might come into existence. The application of processing methods such as low temperature drying, ultrafine milling, and mixing MLP with wheat or multigrain flours can help preserve bioactive compounds while keeping desirable sensory qualities. Overall, the valorisation of mulberry leaf waste provides a sustainable, circular-economy approach for producing nutritionally enriched cookies and crackers, supporting agro-waste reduction and enhancing functional food development within the sericulture sector.

Keywords: Mulberry leaf waste, Dietary fiber, Plant-based protein, Sustainable, Cookies and Crackers

1. Introduction

Bakery products such as crackers and cookies are widely consumed due to their convenience, extended shelf life, and desirable sensory characteristics. However, traditional formulations are predominantly based on refined wheat flour and are often deficient in dietary fiber, micronutrients, and

bioactive compounds. Increasing awareness of lifestyle-related disorders has shifted consumer preference toward functional bakery products enriched with natural ingredients (Ujong et al., 2023). The agricultural sector faces two main problems which include its need for proper nutrition and its problem of producing waste through agro-industrial processes. The sericulture industry produces significant quantities of mulberry leaf waste during pruning, harvesting, and grading operations. Major silk-producing areas such as Karnataka produce excessive leaf waste because their silk farmers discard leaves that have reached maturity or become damaged by pests or because they have produced too much silk. Approximately 10–20% of harvested leaves may remain unused, representing a considerable biomass resource (Krajewska & Dziki, 2023).

Mulberry leaves offer high nutritional value because they have been used in traditional herbal medicine. The plant contains high levels of fiber and protein and minerals and phytochemicals which make it suitable for developing functional food products. The use of mulberry leaf waste (MLP) in crackers enables manufacturers to improve product nutrition while meeting environmental sustainability requirements. The review presents a complete assessment of the scientific advancements made in developing crackers from MLP.

2. Generation and Current Utilization of Mulberry Leaf Waste

The process of mulberry cultivation requires regular pruning which helps create fresh leaf growth needed for silkworm feed. The workers discard leaves which do not meet feeding standards during their work. The process of sorting and grading post-harvest crops produces leaf waste material. The existing disposal methods used today involve multiple approaches to waste management (Shilpa et al., 2024).

- Composting
- Animal feeding
- Field decomposition
- Limited use in herbal tea production

Despite its nutritional richness, systematic food-based valorization remains limited. Expanding its use into functional bakery products offers a higher-value application pathway.

3. Nutritional and Phytochemical Composition of Mulberry Leaf Waste

MLP is an agro-residue that contains high nutritional value because its composition includes essential macronutrients and vital minerals and bioactive compounds. The product shows potential as a functional ingredient in cereal-based food products because it contains substantial dietary fiber and plant protein content. The high fiber content delivers three benefits because it improves digestive health and increases feelings of fullness and helps control blood sugar levels. The protein fraction from MLP enhances the nutritional value of bakery goods because it works together with cereal proteins to create a more nutritious product. MLP contains important minerals with calcium and iron as its main components and smaller quantities of magnesium and potassium (Weenuttranon et al., 2023). The minerals establish essential functions for maintaining bone health, supporting oxygen transport, enabling enzymatic reactions and maintaining electrolyte equilibrium. The presence of these micronutrients enhances the fortification potential of MLP when incorporated into baked goods.

The nutritional composition of mulberry leaf waste goes beyond its fundamental elements because it contains bioactive compounds which include phenolic compounds and flavonoids and γ -aminobutyric acid and alkaloids that contain 1-deoxynojirimycin as their main component. The phytochemicals display powerful antioxidant capabilities while they also demonstrate effects which reduce diabetes symptoms and lower blood lipids and fight inflammation (Thaipitakwong et al., 2018). DNJ, in particular, contributes to glycemic control through inhibition of carbohydrate-digesting enzymes. The overall nutritional and phytochemical profile of MLP is illustrated in Figure 1.

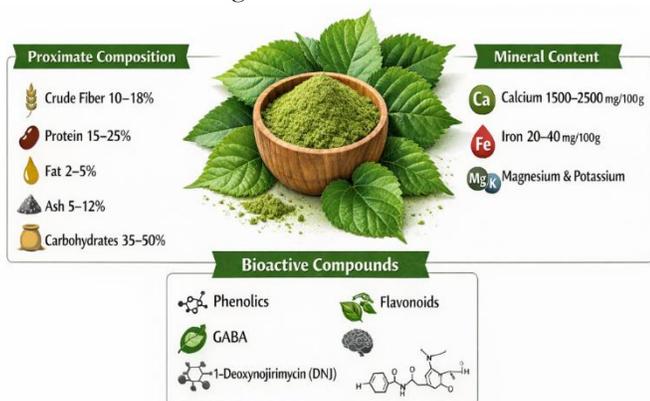


Figure 1. Nutritional and phytochemical composition of mulberry leaf waste (MLP).

4. Functional Properties of Mulberry Leaf Waste in Cracker Formulation

The incorporation of mulberry leaf waste (MLP) into cracker formulations requires evaluation of its functional and technological properties, as these directly influence dough

behavior and final product quality. Due to its high fiber content, MLP exhibits strong water absorption capacity, which affects dough hydration and consistency. Increased water binding enhances structural integrity but may also increase dough stiffness if used at higher substitution levels (Levickienė et al., 2024). Therefore, optimization of water addition is essential when formulating MLP-enriched crackers.

The presence of dietary fiber also influences oil absorption capacity, contributing to improved mouthfeel and flavor retention. Fiber particles interact with gluten proteins, potentially weakening the gluten network at higher inclusion levels. This interaction may reduce dough extensibility and spread ratio, leading to slightly denser cracker structures. However, controlled incorporation levels can maintain desirable crispness and texture (Zhou et al., 2025). Particle size plays a critical role in product quality. Ultrafine milling of mulberry leaf powder improves dispersion within wheat flour matrices, resulting in better texture, reduced grittiness, and uniform colour distribution. Smaller particle sizes also enhance bioactive compound retention and functional performance in baked products.

5. Application of Mulberry Leaf Waste in Crackers

5.1 Substitution Levels and Formulation

Research studies show that the best substitution rate for cracker recipes exists between 2% and 10% range. The sensory characteristics of food products maintain their quality when 2 to 5 percent level is used, which also improves their nutritional value. The inclusion of 6 to 8 percent moderate levels results to improved fiber and antioxidant content, which changes color and texture to some extent. The sensory characteristics of food products become less acceptable to consumers when the substitution rate exceeds 10 percent because it produces harder texture and darker color and mild herbal flavor.

5.2 Effect on Nutritional Enhancement

Incorporation of MLP significantly increases dietary fiber, protein, and mineral content of crackers. The antioxidant capacity of enriched crackers improves due to the retention of phenolic compounds during baking. Additionally, the presence of DNJ and fiber may contribute to reduced predicted glycemic index, making these crackers suitable for health-conscious consumers.

5.3 Effect on Physical and Textural Properties

MLP-enriched crackers generally show:

- Increased hardness with higher substitution levels
- Reduced spread ratio
- Enhanced crispness at optimal inclusion
- Improved structural stability

Although fiber may dilute gluten strength, optimized formulations maintain acceptable textural properties.

5.4 Sensory Characteristics

Sensory evaluation studies reveal that crackers with up to 5% MLP substitution receive high acceptability scores for taste, texture, and overall quality. Higher levels may impart a greenish hue and mild herbal taste due to chlorophyll and phytochemicals. However, blending with multigrain flours or adjusting seasoning can improve flavor balance.

6. Health Benefits of MLP-Enriched Crackers

The inclusion of mulberry leaf waste (MLP) in crackers brings operational advantages because its dietary fiber and bioactive elements increase their functional properties. The high fiber content promotes digestive health through its ability to enhance bowel movements and support gut microbiota, while phenolic compounds and flavonoids deliver antioxidant defense against oxidative damage (Ma et al., 2021). The bioactive alkaloid 1-deoxynojirimycin (DNJ) improves blood sugar control through its ability to inhibit α -glucosidase, which results in decreased blood glucose levels after meals. The combination of fiber and phytochemicals produces a combined effect that helps with lipid metabolism and protects cardiovascular health. The compositional and in vitro studies provide evidence for these benefits, but researchers need to conduct additional human clinical studies to verify them (Deng et al., 2024). The potential health benefits of MLP-enriched crackers are illustrated in Figure 2.



Figure 2. Potential health benefits of mulberry leaf waste (MLP)-enriched crackers.

7. Sustainability and Circular Economy Perspective

The valorization of mulberry leaf waste (MLP) strongly aligns with sustainable food production systems and circular economy principles. The sericulture industry generates substantial waste through its pruning and harvesting and grading activities because it discards large amounts of mulberry leaves which remain unused as biomass (Jadhav et al., 2020). The transformation of agro-residue into a functional food ingredient leads to reduced environmental impacts while increasing resource efficiency and creating additional value. The MLP integration into cracker recipes functions as an

effective method for converting low-value waste materials into high-value nutraceutical products. The approach leads to waste reduction while supporting sustainable agro-processing operations and providing sericulture industry stakeholders with new business prospects. The mulberry leaf waste transformation process provides a link between environmental protection and the development of new nutritional solutions.

8. Challenges

- **Sensory constraints at higher incorporation levels**, including increased hardness, darker coloration, and a characteristic herbal aftertaste that may affect consumer acceptability.
- **Alteration of dough rheology and gluten network structure**, potentially compromising texture, spread ratio, and overall product quality.
- **Variability in nutritional and phytochemical composition** due to differences in leaf maturity, seasonal variation, and agronomic practices.
- **Lack of standardized processing protocols** for drying, milling, and storage, leading to inconsistencies in functional performance.
- **Limited evidence from large-scale industrial trials**, restricting commercial scalability assessment.
- **Insufficient data on long-term shelf life and stability of bioactive compounds** during storage and distribution.

9. Conclusion

The waste materials from mulberry leaves serve as a valuable ingredient that can create nutritional value and functional benefits for the production of crackers. The high content of dietary fiber and protein together with minerals and bioactive compounds in the product boosts the nutritional value and functional capabilities of standard bakery items. The implementation of MLP not only enhances health benefits but also enables the sericulture industry to practice environmentally friendly waste disposal methods through circular economy systems. The combination of proper processing methods with optimized substitution rates enables the achievement of preferred sensory attributes together with maximum nutritional advantages. The use of mulberry leaf waste to produce crackers creates an environmentally friendly and creative method for developing functional foods while transforming agricultural waste into valuable resources.

7. References

Deng, L., Zhong, G., Wang, Q., Zhu, Z., & Peng, Y. (2024). Mulberry leaf and konjac flour compound dietary fiber improves digestion and metabolism in elderly mice with high-fish-protein diet by regulating gut microbiota structure and intestinal tissue repair. *Food*

- Chemistry*, X, 22, 101295.
<https://doi.org/10.1016/j.fochx.2024.101295>
- Jadhav, Y. T., Babu, B. K. K., Chavan, A. D., & Tambave, K. N. (2020). Mulberry and its waste utilization an important socio-economic status in sericulture. *International Journal of Plant Protection*, 13(1), 119–124. <https://doi.org/10.15740/has/ijpp/13.1/119-124>
- Krajewska, A., & Dziki, D. (2023). *Enrichment of Cookies with Fruits and Their By-Products: Chemical Composition, Antioxidant Properties, and Sensory Changes*.
- Levickienė, D., Kulaitienė, J., Vaitkevičienė, N., & Rakauskaitė, L. (2024). Influence of Mulberry Leaf Powder Additive on Chemical and Physical Characteristics of Wheat and Rice Flour Butter Cookies. *Foods*, 13(11). <https://doi.org/10.3390/foods13111737>
- Ma, G., Chai, X., Hou, G.-G., Zhao, F., & Meng, Q. (2021). Phytochemistry, bioactivities and future prospects of mulberry leaves: A review. *Food Chemistry*, 372, 131335. <https://doi.org/10.1016/j.foodchem.2021.131335>
- Shilpa, Shukla, P., & Singh, S. (2024). Development and Analysis of Multigrain Functional Bakery Products. *Journal of Basic and Applied Research International*, 30(4), 13–24. <https://doi.org/10.56557/jobari/2024/v30i48814>
- Thaipitakwong, T., Numhom, S., & Aramwit, P. (2018). Mulberry leaves and their potential effects against cardiometabolic risks: A review of chemical compositions, biological properties and clinical efficacy. *Pharmaceutical Biology*, 56(1), 109–118. <https://doi.org/10.1080/13880209.2018.1424210>
- Ujong, A. E., Emelike, N. J. T., Woka, F. I., & Otekeiwebia JNR, F. (2023). Formulation of fiber enriched crackers biscuit: Effect on nutritional composition, physical and sensory properties. *Heliyon*, 9(5), e15941. <https://doi.org/https://doi.org/10.1016/j.heliyon.2023.e15941>
- Weenuttranon, J., Pathanibul, P., & Hongkulsup, C. (2023). *Effect of mulberry (Morus alba L.) leaf enrichment on antioxidant, textural, and sensory properties of cassava pasta*. <https://doi.org/10.17170/kobra-202307218413>
- Zhou, X., Wu, S., & Sun, X. (2025). The Combination of Enzymes in the Enhancement of Fibre-Enriched Product Quality: Effects of the Interactions of Dietary Fibre, Gluten Proteins, and Starch Granules on Dough Rheological Properties and Bubble Dynamics. *Foods*, 14(22). <https://doi.org/10.3390/foods14223963>
