



Incorporating *Moringa* Leaves as a Nutritional Ingredient in Cracker Development

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Abstract

Background: *Moringa oleifera* leaf powder (MOP) is a nutrient-rich plant material with substantial antioxidant potential. The incorporation of MOP into commonly consumed foods may enhance their nutritional quality and functional properties.

Objectives: This study evaluated the effects of incorporating MOP into cracker formulations on the nutritional value and antioxidant properties.

Methods: Crackers were prepared with MOP at concentrations of 0.5%, 1%, 3%, and 5%. Samples were evaluated for physicochemical properties, mineral content, antioxidant activity, and sensory characteristics.

Results: MOP significantly increased mineral content, particularly iron, zinc, and magnesium, and enhanced antioxidant properties, as indicated by higher total phenolic content and DPPH radical-scavenging activity. Flavor and texture acceptability declined at higher MOP concentrations (3% and 5%); however, no statistically significant differences were observed at the lower levels (0.5% and 1%) compared with the control.

Conclusions: *Moringa oleifera* leaf powder may be used as a fortifying ingredient in cracker formulations to enhance nutritional and antioxidant properties, particularly at lower levels of incorporation.

Keywords: *Moringa Oleifera*, Crackers, Functional Food, Total Antioxidant Capacity

1. Background

Crackers are biscuits made from fermented hard dough, which confers a distinctive texture and taste. They have a crunchy texture, a slightly salty taste, and a flat, layered structure. Their low moisture content allows them to remain crisp for several weeks to months, and they may be consumed as an alternative to bread.

With increasing consumer awareness of functional and health-promoting foods, manufacturers have focused on developing such products, particularly widely consumed foods such as biscuits and crackers. Partial substitution of flour with bioactive compounds has been proposed as a strategy to improve the nutritional profile of these products.

Malnutrition and micronutrient deficiencies remain major global concerns, particularly among children, and are associated with growth impairment and increased mortality (1). *Moringa oleifera* is a tropical plant that is readily cultivated, drought tolerant, and low maintenance. Among the 12 - 14 recognized species, *M. oleifera* is the most widely studied and used; it occurs in Africa, Arabia, Southeast Asia, the Pacific Islands, the Caribbean, and South America (2).

Various plant parts are nutrient-rich and are used in food and health-care applications. *M. oleifera* leaves are particularly rich in beta-carotene, vitamins A and C, protein, iron, calcium, potassium, antioxidants, and fiber. In some regions, the leaves are consumed as vegetables or dietary supplements to address malnutrition.

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2. Objectives

This study aimed to produce crackers enriched with different levels of *M. oleifera* leaf powder and to evaluate their physicochemical properties, antioxidant activity, nutritional content, and sensory characteristics.

3. Methods

3.1. Preparation of Moringa Leaf Powder

Moringa oleifera leaves were obtained from the University of Sistan and Baluchestan, Zahedan, Iran. The leaves were washed with distilled water, dried, ground, and passed through a 100-mesh sieve to obtain a homogeneous powder.

3.2. Cracker Preparation

Crackers were prepared using four formulations in which *M. oleifera* leaf powder replaced wheat flour at 0.5%, 1%, 3%, and 5% (Table 1). Vegetable oil, invert syrup, salt, sodium bicarbonate, ammonium bicarbonate, and malt extract powder were mixed until creamy. Water and flour were added and mixed at low speed for 1 minute. The dough was laminated, reduced in thickness, cut into shapes, and baked at 180 °C for 20 minutes. After baking, the crackers were cooled to room temperature and stored in airtight containers (Figure 1).

3.3. Evaluation of Physicochemical Properties

Samples were analyzed for width, thickness, moisture, ash, salt, titratable acidity, pH, fat, peroxide value, total sugar, and protein content according to AOAC methods (3, 4).

3.4. Mineral Analysis

One gram of each sample was incinerated at 550 °C. The ash was dissolved in 0.1 M HCl and diluted to 100 mL. Magnesium, zinc, and iron were measured using atomic absorption spectroscopy (Perkin-Elmer 3300, USA) (5).

3.5. Antioxidant Activity and Total Phenolic Content

Phenolic extracts were obtained by refluxing 2 g of the sample with 20 mL of methanol containing 1% HCl at 60 ± 5 °C for 2 hours, followed by centrifugation (6). Total phenolic content (TPC) was determined using the Folin-Ciocalteu method (7). DPPH radical-scavenging activity was measured at 515 nm and expressed as percentage inhibition (8).

3.6. Sensory Evaluation

Sensory attributes (aroma, color, flavor, texture, and overall acceptability) were evaluated by 30 untrained panelists using a 5-point hedonic scale. Water was provided between samples.

3.7. Statistical Analysis

Data were analyzed using SPSS version 26. One-way analysis of variance and Duncan multiple-range test were applied at $P < 0.05$.

4. Results

4.1. Physicochemical Analysis of Crackers

4.1.1. Chemical Analysis

Table 2 presents the physicochemical properties of crackers formulated with different levels of leaf powder. Moisture content increased with greater leaf-powder incorporation; however, this increase was not statistically significant at the 3% and 5% levels ($P > 0.05$). This increase may be attributable to dietary fibers, such as cellulose and pectin, which enhance water retention and reduce evaporation during baking by modifying dough viscosity and matrix structure. Cabral et al. (9) reported increased moisture in biscuits containing mulberry leaf powder.

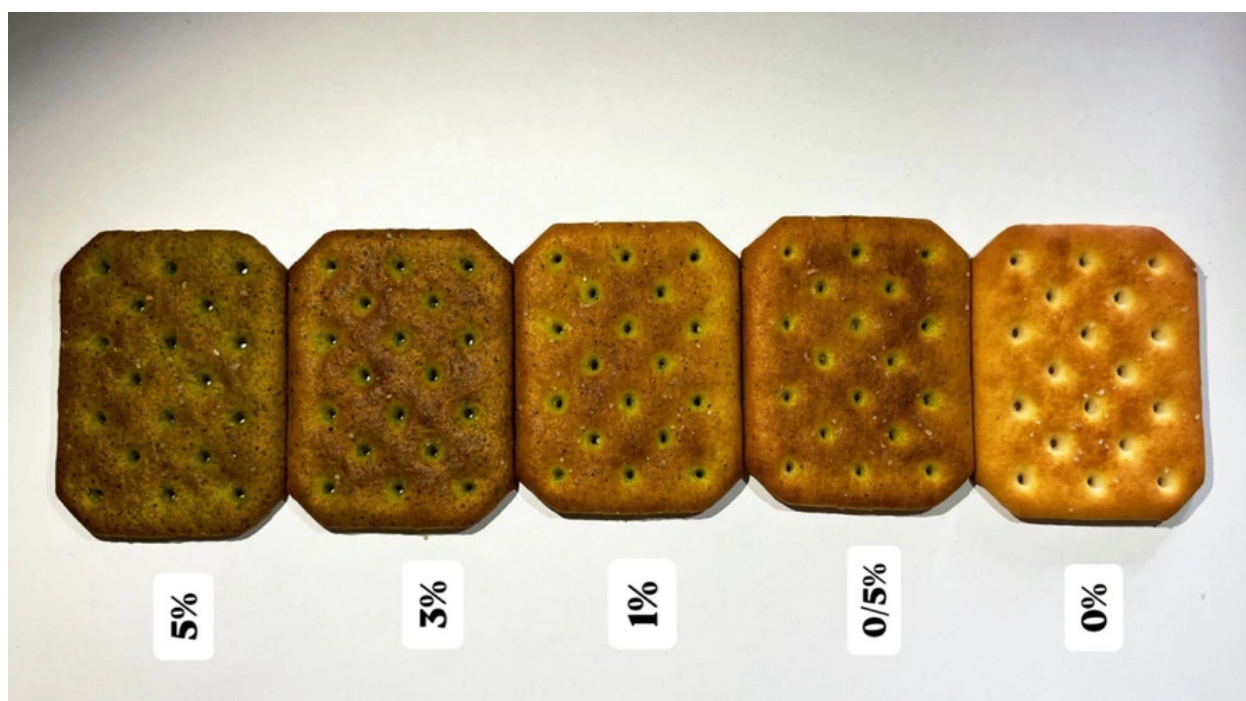
Peroxide value increased with higher MOP levels; however, differences among RS, AS, and BS were not statistically significant ($P > 0.05$). This increase may be related to the fat content of *Moringa leaves*, which can promote lipid oxidation during baking or storage. Similar results were reported in bread enriched with *M. oleifera* leaf powder (11).

Salt content did not differ significantly among formulations, likely because of the low sodium content of *Moringa leaves* and the constant salt addition in all samples (12). Mereles et al. (13) reported that dried *M. oleifera* leaves contain relatively low sodium levels, suggesting that their incorporation into fortified-food formulations may not substantially influence the overall salt content of the final product.

Protein content increased significantly with MOP addition, from $6.36 \pm 0.17\%$ in the reference sample to $14.9 \pm 0.65\%$ in the 5% MOP sample. This enhancement reflects the high protein content of *Moringa leaves* (14). Similar increases were reported by Sultana (10) and El-Gammal et al. (15).

Table 1. Ingredients for Each Cracker Formulation

Ingredients	RS	AS (0.5%)	BS (1%)	CS (3%)	DS (5%)
Wheat flour	60.39	59.89	59.39	57.39	55.39
MOP	-	0.5	1	3	5
Vegetable oil	9.42	9.42	9.42	9.42	9.42
Invert syrup	5.21	5.21	5.21	5.21	5.21
Ammonium bicarbonate	3.18	3.18	3.18	3.18	3.18
Salt	0.75	0.75	0.75	0.75	0.75
Malt extract powder	0.56	0.56	0.56	0.56	0.56
Sodium bicarbonate	20.3	0.19	0.19	0.19	0.19
Water	20.3	20.3	20.3	20.3	20.3
Total	100	100	100	100	100

**Figure 1.** Surface appearance of crackers formulated with different levels of MOP

Fat content increased significantly ($P < 0.05$) with higher MOP levels (Table 2), attributable to the unsaturated fatty acids present in *Moringa leaves*. These findings are consistent with those reported by Sultana (10).

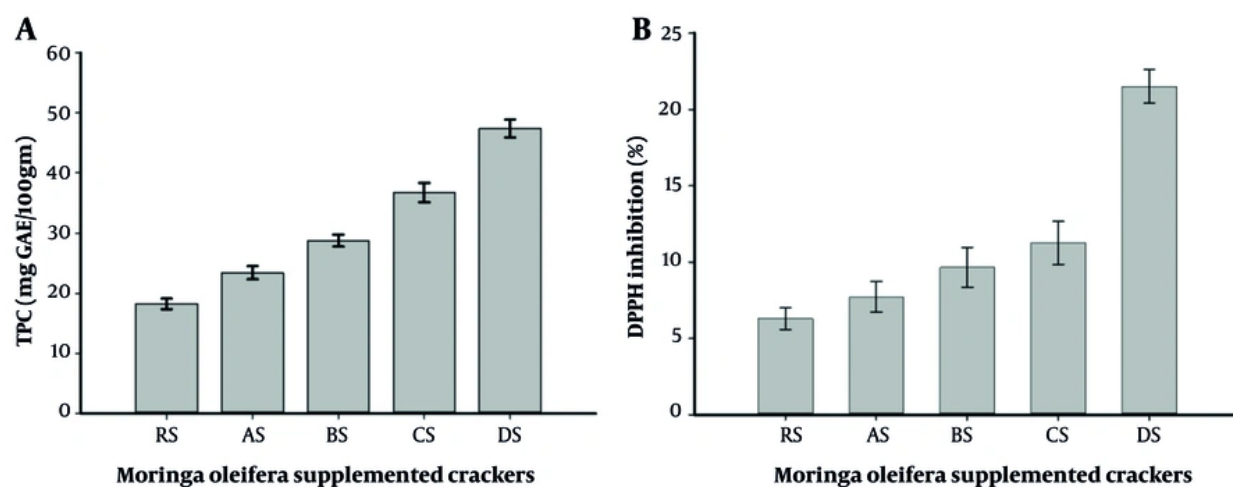
Ash content increased significantly ($P < 0.05$), from $0.021 \pm 0.001\%$ in the reference sample to $4.027 \pm 0.001\%$ in the 5% MOP sample, reflecting the higher mineral

content of *M. oleifera* leaves than that of refined flour (16). Similar findings were reported by Dachana et al. (17). Acidity increased and pH decreased with higher MOP levels. Although differences between some adjacent formulations were not significant ($P > 0.05$), a significant difference ($P < 0.05$) was observed between CS and DS. This trend may be related to phenolic compounds and organic acids, such as ascorbic, gallic, and chlorogenic acids, in MOP, as well as reduced

Table 2. Chemical, Physical, and Mineral Characteristics of MOP-Supplemented Crackers ^a

Characteristic	RS	AS	BS	CS	DS
Moisture (g/100 g)	3.64 ± 0.05 ^C	3.63 ± 0.1 ^C	3.59 ± 0.02 ^B	3.42 ± 0.02 ^A	3.40 ± 0.01 ^A
NaCl	1.41 ± 0.01 ^A	1.39 ± 0.01 ^A	1.40 ± 0.01 ^A	1.41 ± 0.01 ^A	1.41 ± 0.01 ^A
Peroxide value	0.497 ± 0.00 ^D	0.496 ± 0.005 ^{C, D}	0.495 ± 0.005 ^C	0.492 ± 0.001 ^B	0.481 ± 0.001 ^A
Protein	6.36 ± 0.17 ^D	7.87 ± 0.06 ^C	8.40 ± 0.36 ^C	11.83 ± 1.23 ^B	14.9 ± 0.65 ^A
Fat	15.21 ± 0.01 ^A	15.24 ± 0.01 ^B	15.29 ± 0.01 ^C	15.32 ± 0.00 ^D	15.35 ± 0.01 ^E
Ash	0.021 ± 0.001 ^E	1.023 ± 0.001 ^D	1.024 ± 0.001 ^C	3.025 ± 0.001 ^B	4.027 ± 0.001 ^A
Acidity	0.143 ± 0.00 ^A	0.143 ± 0.001 ^{A, B}	0.145 ± 0.001 ^B	0.145 ± 0.001 ^B	0.148 ± 0.001 ^C
pH	6.48 ± 0.028 ^A	6.47 ± 0.026 ^B	6.44 ± 0.11 ^B	6.44 ± 0.11 ^{B, C}	6.19 ± 0.17 ^C
Total sugar	7.14 ± 0.01 ^D	7.17 ± 0.01 ^C	7.22 ± 0.02 ^B	7.43 ± 0.01 ^A	7.45 ± 0.0 ^A
Thickness (mm)	34.1 ± 0.17 ^D	34.3 ± 0.27 ^{B, C}	35.33 ± 0.30 ^{B, C}	35.47 ± 0.068 ^B	38.56 ± 1.40 ^A
Width (mm)	48.27 ± 0.25 ^C	48.36 ± 0.32 ^{A, B}	48.50 ± 0.35 ^{A, B}	48.54 ± 0.29 ^{A, B}	48.87 ± 0.06 ^A
Zinc (Zn)	0.94 ± 0.9 ^D	5.043 ± 1.3 ^C	6.43 ± 0.37 ^B	7.52 ± 0.02 ^A	7.69 ± 0.04 ^A
Iron (Fe)	0.82 ± 0.03 ^E	3.35 ± 0.01 ^D	4.18 ± 0.026 ^C	4.34 ± 0.05 ^B	5.31 ± 0.01 ^A
Magnesium (Mg)	1 ± 0.02 ^E	4.27 ± 0.02 ^D	4.71 ± 0.03 ^C	6.21 ± 0.02 ^B	7.07 ± 0.025 ^A

^a Values are mean ± standard deviation of triplicate determinations. Values followed by the same superscripted capital letters within a row are not significantly different at $P < 0.05$. Abbreviations: MOP, *Moringa oleifera* powder; RS, reference sample; AS, 0.5% flour substitution with MOP; BS, 1% flour substitution with MOP; CS, 3% flour substitution with MOP; DS, 5% flour substitution with MOP.

**Figure 2.** Total phenolic content (A) and antioxidant properties (B) of cracker samples

buffering capacity following partial flour substitution (16). Dachana et al. (17) reported similar results.

Total sugar content showed an increasing trend with MOP addition; however, differences between CS and DS were not statistically significant ($P > 0.05$). This may be attributable to naturally occurring sugars in *M. oleifera*

leaves and the thermal degradation of polysaccharides during baking (2).

4.1.2. Physical Analysis

A slight increase in thickness and width was observed with higher leaf-powder incorporation, likely because of

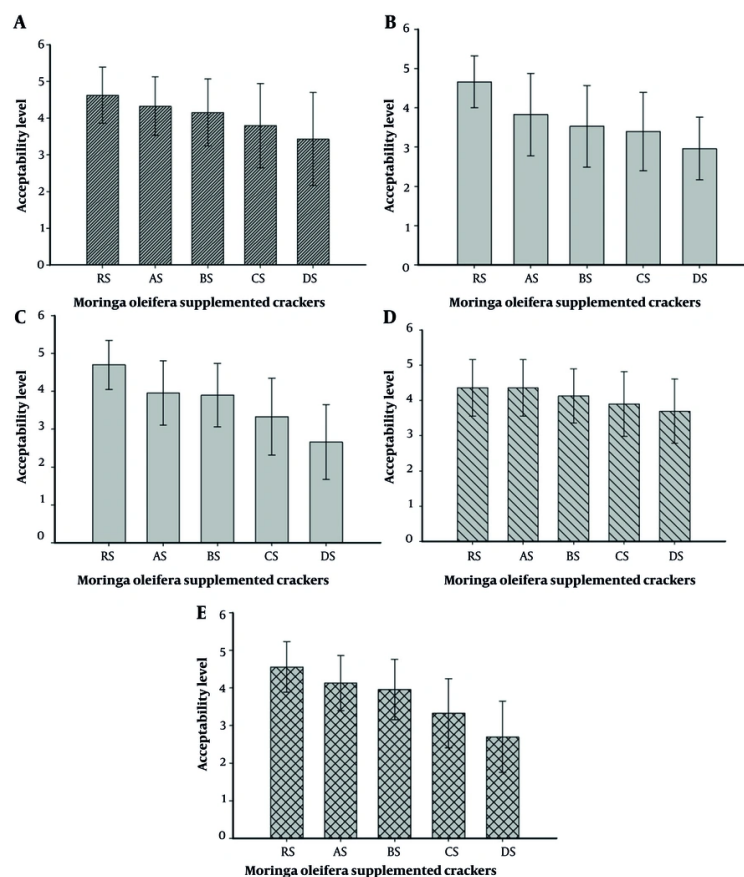


Figure 3. Sensory evaluation of crackers

increased water absorption by dietary fiber. Dachana et al. (17) reported increased cookie thickness with *Moringa* addition. Leaf powders may weaken gluten-network development by competing for water and reducing gluten-protein concentration, thereby decreasing dough elasticity and strength (18, 19). However, thickness differences among the 0.5%, 1%, and 3% samples were not statistically significant, possibly because of uniform lamination before baking (Table 2). The greatest width was observed in the 5% MOP sample, whereas differences among the 0.5%, 1%, and 3% samples were not statistically significant.

4.2. Total Phenolic Content and Antioxidant Capacity

As shown in Figure 2, TPC increased significantly ($P < 0.05$) with increasing MOP levels. The reference sample had the lowest TPC (18.26 ± 0.9), whereas the 5% MOP

sample had the highest value (47.4 ± 1.5), reflecting the rich polyphenol and flavonoid content of *Moringa* leaves (20). Similar increases in TPC were reported by Elhassaneen et al. (21) in enriched biscuits. Antioxidant activity, measured by DPPH, increased significantly ($P < 0.05$), ranging from 6.3% to 21.50% (Figure 2), confirming the functional contribution of MOP. Bobková et al. (22) also reported enhanced TPC and DPPH activity with leaf-powder incorporation.

Abbreviations: MOP, *Moringa oleifera* powder; RS, reference sample; AS, 0.5% flour substitution with MOP; BS, 1% flour substitution with MOP; CS, 3% flour substitution with MOP; DS, 5% flour substitution with MOP.

Thermal processing may affect phenolic stability; some compounds may degrade, whereas Maillard reaction products formed during baking may contribute to antioxidant activity (23, 24).

4.3. Mineral Composition of Crackers

Table 2 shows significant increases ($P < 0.05$) in zinc, iron, and magnesium with higher MOP levels. Zinc increased from 0.94 to 7.69 mg/100 g, iron from 0.82 to 5.31 mg/100 g, and magnesium from 1 to 7.07 mg/100 g in the 5% MOP sample. Differences between the 3% and 5% samples were not significant. These increases reflect the naturally high mineral content of *Moringa leaves*, as supported by the ash results. Glover-Amengor et al. (25) and Blaško et al. (26) similarly reported high iron, manganese, and zinc levels in *Moringa leaves*.

4.4. Sensory Evaluation

As shown in Figure 3, the reference sample received the highest sensory scores. Flavor scores decreased slightly with increasing MOP because of the herbaceous taste; however, differences between AS and BS were not significant ($P > 0.05$). Texture scores showed a slight, nonsignificant decline ($P > 0.05$), possibly because of fiber-gluten interactions (27). Color acceptability decreased because of green pigmentation, but differences between the reference and 0.5%-1% samples were not significant. Overall acceptability declined with higher MOP levels; however, changes at 0.5% and 1% were not statistically significant. Yan et al. (12) similarly reported reduced acceptability at higher leaf-powder levels.

Abbreviations: MOP, *Moringa oleifera* powder; RS, reference sample; AS, 0.5% flour substitution with MOP; BS, 1% flour substitution with MOP; CS, 3% flour substitution with MOP; DS, 5% flour substitution with MOP. (A) Color; (B) aroma; (C) flavor; (D) texture; (E) overall acceptability.

5. Discussion

5.1. Conclusions

Increasing *M. oleifera* leaf powder significantly enhanced mineral content, including iron, zinc, and magnesium, as well as antioxidant properties, including TPC and DPPH activity, indicating its potential as a functional fortifying ingredient. Although slight increases in thickness and width were observed, higher MOP levels adversely affected texture and color. Sensory evaluation showed reduced acceptability at higher concentrations, whereas the 0.5% and 1% levels did not result in significant differences. Overall, 3% *Moringa* leaf powder represents an optimal level, improving nutritional quality without significantly compromising

sensory attributes, and can be recommended for cracker fortification.

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Footnotes

AI Use Disclosure: The authors declare that no generative AI tools were used in the creation of this article.

Authors' Contribution: Study concept and design: M. B.; Acquisition of data: M. B.; Analysis and interpretation of data: M. B. and F. R.; Drafting of the manuscript: M. B.; Critical revision of the manuscript for important intellectual content: M. B.; Statistical analysis: Z. B.; Administrative, technical, and material support: M. B. and Z. B.; Study supervision: M. B.

Conflict of Interests Statement: The authors do not declare any conflicts of interests for this study.

Data Availability: The dataset presented in this study is available on request from the corresponding author during submission or after publication. The data are not publicly available due to institutional regulations and data management policies.

Ethical Approval: This study has been approved by Ethic Committee of Zahedan University of Medical Sciences (ethical code number: IR.ZAUMS.REC.1403.268).

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