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Crispy Brownie Responses to Young And Mature Moringa Oleifera Leaf Powder Concentrations**Yoakhim Yafet Engelhard
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Abstract. Crispy brownies offer a low-moisture bakery matrix for incorporating plant-derived ingredients, but moringa leaf powder may affect texture and consumer acceptance. This study described physicochemical and sensory responses to different concentrations of young or mature *Moringa oleifera* leaf powder in two separately analyzed experiments. Each experiment used four nominal concentrations (0, 1.5, 3.0, and 4.5% relative to wheat-flour weight) with three reported replicates per treatment. Brownies were evaluated for moisture content, instrumental hardness, and five hedonic attributes using 25 consumer panelists. Total phenolic content and DPPH radical-scavenging activity were measured only in the selected 3% young-leaf formulation (A2). In the young-leaf series, mean moisture increased from 0.92 to 1.32%, while hardness increased from 5.30 to 9.57 N as powder concentration increased. Fortified mature-leaf treatments had moisture values of 0.64–0.65%, and their hardness values ranged from 3.72 to 9.05 N. The reported overall-acceptance means for the young-leaf control and A2 were 5.92 and 5.72, respectively; consequently, A2 did not have the highest overall mean. For A2, total phenolics were 243.08 ± 0.01 mg gallic acid equivalents per 100 g and the DPPH IC₅₀ was 8.33 ± 0.07 ppm. These findings describe product-level responses and identify A2 as a candidate moringa-containing formulation, but do not establish a statistically tested maturity effect or antioxidant improvement relative to a control.

Keywords: Antioxidant activity; Crispy brownies; *Moringa oleifera*; Sensory acceptance; Texture.

INTRODUCTION

Crispy brownies are thin-baked chocolate products in which low moisture content and mechanical texture contribute to product quality. Their composition makes them a potential vehicle for agricultural ingredients obtained from locally available plant materials. However, ingredient addition may alter moisture retention, fracture properties, flavor, and liking. Work on cocoa-derived ingredients in crispy brownies illustrates the need to evaluate physical and sensory attributes together rather than interpreting individual measurements in isolation

(Permana et al., 2023; Dwiani & Yuniartini, 2022).

Moringa oleifera leaves contain nutrients and phytochemicals of interest for food development, although their composition depends on plant material and processing conditions (Peñalver et al., 2022). Reviews of moringa applications in bakery products and studies on moringa-enriched cookies and bread indicate that incorporating its leaf powder may affect product composition, texture, and acceptability (Milla et al., 2021; Fapetu et al., 2022; Govender & Siwela, 2020). Research on moringa snack crackers



likewise reports changes in product characteristics after fortification (Cervera-Chiner *et al.*, 2024). These observations support studying the ingredient within a specific brownie matrix rather than assuming that effects will be identical across bakery products.

The growth stage of moringa leaves may be relevant because leaf composition and certain antinutritional constituents vary with maturity (Qadir *et al.*, 2022; Perveen *et al.*, 2025). At the same time, drying conditions can influence the properties of the resulting powder (Koriyama *et al.*, 2023; Paramita, 2023). Thus, products prepared with younger or more mature leaves may display different descriptive profiles. However, an inference that maturity itself causes a difference requires a design and analysis that directly compare maturity groups.

Food texture and sensory perception cannot be inferred from leaf composition alone. Fiber incorporation may change the structure of baked products, while phenolic compounds can influence sensory responses in complex formulations (Sempio *et al.*, 2024; Czajkowska-González *et al.*, 2021). Volatile and nonvolatile compounds in moringa products have also been examined in relation to flavor and consumer perceptions (Rodrigues *et al.*, 2023; Zhang *et al.*, 2024). Because chocolate contributes its own flavor and phenolics, the interpretation of moringa-containing brownies must also consider the cocoa-based matrix (Palma-Morales *et al.*, 2023).

Previous bakery research documents the feasibility and limitations of moringa incorporation, but data for thin, crisp brownies prepared using young-leaf and mature-leaf powders at

matched nominal concentrations remain limited. The present work contributes product-specific descriptive information from two separately analyzed concentration series. Its scope is deliberately restricted to the measured physical and sensory responses and the phenolic and DPPH measurements performed on one selected formulation.

Therefore, this study aimed to describe the effects of increasing young- or mature-moringa-leaf powder concentrations on the moisture content, instrumental hardness, and consumer hedonic responses of crispy brownies within each experimental series. Total phenolic content and DPPH radical-scavenging activity were additionally characterized for the selected 3% young-leaf formulation; a direct statistical maturity comparison and an across-formulation antioxidant comparison were not part of the reported analyses.

MATERIAL AND METHODS

Study Area and Materials

The work was carried out in March–April 2026 at the Food Technology and Nutrition Laboratory, Faculty of Agriculture, Sam Ratulangi University, Manado, Indonesia. Total phenolic content and DPPH assays were reported as conducted at the Center for Standardization and Industrial Services (BSPJI), Manado. Young and mature moringa leaves were sourced from Manado. Other reported ingredients were dark chocolate (Colatta), margarine (Blue Band), medium-protein wheat flour (Segitiga Biru), powdered sugar, eggs, vanilla powder, and salt. Chemicals listed for the analytical work included water, ethanol, analytical-grade methanol, Folin–Ciocalteu reagent, sodium carbonate, and DPPH.

Experimental Design and Treatment Coding

Two separate completely randomized concentration experiments were described. Experiment A comprised young-leaf powder: A0 = 0% (control), A1 = 1.5%, A2 = 3.0%, and A3 = 4.5%. Experiment B comprised mature-leaf powder: B0 = 0% (control), B1 = 1.5%, B2 = 3.0%, and B3 = 4.5%. Percentages were reported relative to wheat-flour weight (w/w). Three replicates were reported for each of the eight nominal treatments (24 nominal experimental units). The original record does not clarify whether A0 and B0 were independently produced or represent the same control observations; therefore, the two experiments must not be treated as independent evidence for maturity effects until this is verified.

Leaf-Powder and Brownie Preparation

Fresh leaves were sorted, washed, drained, and oven-dried at 50 °C for 6–8 h until constant mass, following the processing description attributed to Paramita (2023). Dried leaves were ground and passed through an 80-mesh sieve. For brownies, chocolate and margarine were melted using a double boiler. Eggs and powdered sugar were mixed, followed by melted chocolate and dry ingredients (flour, vanilla, salt, and the assigned moringa powder). The batter was spread to a thickness of approximately 2–3 mm and baked at 150 °C for 20 min, then cooled. The ingredient amounts, operational maturity criteria, and independent batch-preparation scheme were not specified in the source manuscript and require confirmation from the laboratory record for reproducibility.

Physicochemical and Sensory Measurements

Moisture content was measured gravimetrically with reference to SNI 01-2891-1992 (Badan Standardisasi Nasional, 1992). Instrumental hardness was measured with a texture analyzer and expressed in newtons (N). Additional instrumental settings, including probe type and test speed, were not reported. Sensory liking was evaluated by 25 consumer panelists using a seven-point hedonic scale (1, extremely dislike; 7, extremely like) for aroma, taste, sensory texture, flavor, and overall acceptance (Addo-Preko *et al.*, 2023; Soekarto, 1985). Taste and flavor were retained as separate recorded attributes, but their operational definitions and panel-serving procedure are not documented in the source.

Total Phenolics, Antioxidant Activity, and Statistical Analysis

Only formulation A2 was analyzed for total phenolic content using the Folin–Ciocalteu approach and for DPPH radical-scavenging activity, reported as the concentration associated with 50% inhibition (IC₅₀). The source specifies a UV–Vis wavelength of 517 nm for the DPPH assay. Extraction conditions, calibration, the number of independent analytical replicates, and the IC₅₀ fitting procedure were not supplied; these details must be verified before submission (Gulcin & Alwasel, 2023). Physicochemical results were reported as analyzed by separate one-way ANOVA tests followed by Duncan's multiple range test at $\alpha = 0.05$. The original sensory analysis named Kruskal–Wallis and Mann–Whitney tests. Because panelist-level repeated-measures structure and full statistical outputs are unavailable, original significance letters are reproduced without reinterpretation or recalculation.



RESULTS AND DISCUSSION

Moisture Content and Instrumental Hardness

Table 1 presents the original reported mean ± standard deviation for both experimental series. In the young-

leaf series, moisture and hardness both increased with powder concentration. In the mature-leaf series, the fortified samples showed lower moisture values than the reported control, while hardness exhibited a non-monotonic response.

Table 1. Reported moisture content and instrumental hardness of crispy brownies in separately analyzed moringa-leaf series

Treatment	Moisture (%) ± SD	Hardness (N) ± SD
Young-leaf series		
A0 (0%)	0.92 ± 0.02 ^a	5.30 ± 0.13 ^a
A1 (1.5%)	1.05 ± 0.02 ^b	7.46 ± 0.11 ^b
A2 (3.0%)	1.20 ± 0.02 ^c	8.73 ± 0.07 ^c
A3 (4.5%)	1.32 ± 0.01 ^d	9.57 ± 0.17 ^d
Mature-leaf series		
B0 (0%)	0.92 ± 0.02	5.30 ± 0.13 ^a
B1 (1.5%)	0.64 ± 0.05	3.72 ± 0.30 ^b
B2 (3.0%)	0.65 ± 0.09	5.08 ± 0.36 ^c
B3 (4.5%)	0.64 ± 0.04	9.05 ± 0.52 ^d

For the young-leaf treatments, moisture ranged from 0.92% in A0 to 1.32% in A3, while hardness increased from 5.30 to 9.57 N. The source assigned distinct letter groups across the four young-leaf treatments for both properties. Among fortified mature-leaf treatments, moisture means were similar (0.64–0.65%); however, the absence of post-hoc labels for this variable prevents a reliable inference about the control-to-fortified contrast. Mature-leaf hardness ranged from 3.72 N in B1 to 9.05 N in B3. The recorded B0 value (5.30 ± 0.13 N) and B2 value (5.08 ± 0.36 N) have different superscripts despite their similar means, so this comparison should not be emphasized pending verification.

Moringa powder may alter water binding and fracture behavior through

changes to the flour–fat–cocoa matrix, as suggested by broader work on moringa bakery applications and fiber-enriched baked goods (Koriyama et al., 2023; Sempio et al., 2024; Marzec et al., 2025). These mechanisms were not directly measured in the present work. Likewise, low measured moisture does not, by itself, demonstrate microbial safety, long shelf life, or compliance with a product-specific statutory threshold.

Consumer Sensory Acceptance

The sensory attributes listed in Table 2 were assessed on the seven-point hedonic scale. For young-leaf treatments, overall-acceptance means did not increase monotonically with concentration; the control A0 had a higher mean than the 3% formulation A2.



Table 2. Reported hedonic scores (mean $\pm$ SD) for crispy brownies with young or mature moringa-leaf powder

Treatment	Aroma	Taste	Texture	Flavor	Overall
Young-leaf series					
A0 (0%)	5.48 $\pm$ 1.26 ^b	5.92 $\pm$ 0.86	5.76 $\pm$ 1.23	5.84 $\pm$ 0.89 ^b	5.92 $\pm$ 0.90 ^b
A1 (1.5%)	5.44 $\pm$ 1.38 ^b	5.60 $\pm$ 1.32	5.68 $\pm$ 1.21	5.40 $\pm$ 1.16 ^{ab}	5.40 $\pm$ 1.15 ^{ab}
A2 (3.0%)	5.68 $\pm$ 1.21 ^b	5.52 $\pm$ 1.41	5.48 $\pm$ 1.29	5.76 $\pm$ 1.56 ^b	5.72 $\pm$ 1.24 ^{ab}
A3 (4.5%)	4.48 $\pm$ 1.61 ^a	5.32 $\pm$ 1.52	5.40 $\pm$ 1.65	4.76 $\pm$ 1.32 ^a	5.16 $\pm$ 1.57 ^a
Mature-leaf series					
B0 (0%)	5.48 $\pm$ 1.26	5.92 $\pm$ 0.86	5.76 $\pm$ 1.23	5.84 $\pm$ 0.89	5.92 $\pm$ 0.90
B1 (1.5%)	4.28 $\pm$ 0.49	4.24 $\pm$ 0.44	4.20 $\pm$ 0.41	4.16 $\pm$ 0.37	4.16 $\pm$ 0.37
B2 (3.0%)	4.28 $\pm$ 0.49	4.28 $\pm$ 0.46	4.28 $\pm$ 0.46	4.28 $\pm$ 0.46	4.28 $\pm$ 0.46
B3 (4.5%)	4.28 $\pm$ 0.49	4.28 $\pm$ 0.46	4.28 $\pm$ 0.46	4.28 $\pm$ 0.46	4.28 $\pm$ 0.46

Within the young-leaf series, the recorded aroma means were 5.48 (A0), 5.44 (A1), 5.68 (A2), and 4.48 (A3). The corresponding flavor means were 5.84, 5.40, 5.76, and 4.76. The source letter groupings distinguish A3 from some lower-concentration treatments on these attributes. Importantly, overall-acceptance values were 5.92 for A0, 5.40 for A1, 5.72 for A2, and 5.16 for A3; A0 and A3 carry different letter labels. It is therefore inaccurate to report that overall acceptance showed no differences across all young-leaf treatments based on the printed table.

The mature-leaf fortified products had recorded overall-acceptance means between 4.16 and 4.28, compared with 5.92 for B0. These observations describe separate groups, but do not demonstrate a statistically significant maturity effect because the experiments were not evaluated through a common factorial analysis. Flavor differences associated with moringa-containing foods are plausible in light of their documented chemical and sensory profiles (Rodrigues et al., 2023; Zhang et al., 2024); the individual flavor compounds responsible were not measured in this study. Evidence from other moringa-fortified bakery

products also points to the importance of balancing incorporation level and consumer liking (Govender & Siwela, 2020; Cervera-Chiner et al., 2024).

A2 was chosen for additional chemical characterization as a moringa-containing formulation with a comparatively favorable aroma score and an overall-acceptance mean of 5.72. This is a pragmatic selection description, not a claim that A2 achieved the highest overall liking: the A0 control had a mean of 5.92, and group labels for A0 and A2 overlap. A multi-criterion optimization protocol was not specified in the source.

Total Phenolic Content and DPPH Activity of the Selected A2 Formulation

Table 3 reports the chemical characterization of A2 only. No corresponding total-phenolic or DPPH result was provided for the controls, mature-leaf treatments, or other young-leaf concentrations.

Table 3. Total phenolic content and DPPH radical-scavenging result reported for crispy brownies containing 3% young moringa-leaf powder (A2)

Parameter	Reported mean $\pm$ SD
Total phenolic content (mg GAE/100 g)	243.08 $\pm$ 0.01
DPPH IC50 (ppm)	8.33 $\pm$ 0.07



The A2 formulation had 243.08 ± 0.01 mg GAE per 100 g and a DPPH IC50 of 8.33 ± 0.07 ppm under the described assay. The Folin–Ciocalteu result reflects the reaction of the analyzed extract and cannot determine the relative contribution of cocoa and moringa ingredients in the absence of separate component or control assays. Phenolic compounds in moringa and cocoa matrices are discussed in the literature (Peñalver *et al.*, 2022; Palma-Morales *et al.*, 2023; Marisa *et al.*, 2025), while baking can influence their recoverability and activity (Blanch & Ruiz del Castillo, 2021). These references support possible interpretations but do not establish a synergistic effect in the present sample.

DPPH activity is an in-vitro, assay-specific result influenced by extraction and experimental conditions (Gulcin & Alwasel, 2023; Inaguma *et al.*, 2026). Thus, the observed A2 value should not be interpreted as proof of an improvement over the control or of a specific physiological health benefit. The findings nevertheless provide an initial characterization of one candidate product developed from an agricultural leaf ingredient. Comparable antioxidant measurements across formulations would be necessary before treatment effects on DPPH activity could be established.

Study Limitations and Applied Significance

The study is limited by the use of separate concentration series rather than a direct statistical maturity comparison, uncertainty about the independence of A0 and B0, unspecified ingredient quantities, incomplete instrumental and sensory protocols, and unavailable statistical outputs. The duplicated mature-leaf

hedonic entries further require data verification. Within these constraints, the work provides preliminary product-quality information that can guide more reproducible development of moringa-based baked goods while avoiding claims of proven shelf life, improved nutritional function, or optimal concentration.

CONCLUSION

Young moringa-leaf powder incorporation was associated with an increase in the recorded mean moisture content (0.92–1.32%) and instrumental hardness (5.30–9.57 N) of crispy brownies across the tested concentration series. For the separate mature-leaf series, the fortified formulations had recorded moisture values of 0.64–0.65% and hardness values of 3.72–9.05 N. In the young-leaf sensory results, the 3% formulation A2 had reasonably favorable hedonic values but did not outperform the no-moringa control in mean overall acceptance. Only A2 was chemically characterized, yielding a reported total phenolic content of 243.08 mg GAE/100 g and a DPPH IC50 of 8.33 ppm. These findings describe the measured quality attributes of the tested products; they do not establish an independent maturity effect, an antioxidant increase attributable to moringa addition, or a statistically optimal formulation. Verification of the original control, sensory, and statistical records is required before definitive treatment comparisons can be made. Moisture Content and Instrumental Hardness

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