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Antioxidant Activity, Dietary Fiber, Colour Analysis (L,a,b) and Viscosity of Kiwi–Kepok Banana Fruit Leather with Adding *Moringa oleifera*

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Abstract

This study aimed to evaluate the effect of *Moringa oleifera* leaf incorporation on the functional and physical characteristics of kiwi and kepok banana fruit leather. Five formulations were developed by adding 0 to 8 g of *Moringa* powder per 100 g of fruit puree. The results demonstrated that dietary fiber content significantly increased from 3.11 to 3.65 g/100 g with higher *Moringa* concentrations, while antioxidant activity improved as evidenced by a reduction in IC_{50} values from 262.28 to 125.43 ppm. The viscosity of the puree also rose from 913.44 cP to 1106.96 cP, indicating enhanced textural consistency and structural integrity. Conversely, the color parameters (L*, a*, b*) showed a notable shift, with increasing *Moringa* addition resulting in darker and greener hues attributed to chlorophyll pigments. These findings suggest that *Moringa oleifera* fortification effectively improves the nutritional and textural qualities of fruit leather, offering a viable approach for producing plant-based functional snacks that appeal to health-conscious consumers.

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Introduction

The growing trend toward functional food consumption has promoted innovation in the development of nutrient-dense and plant-based snacks. Functional snacks that offer physiological benefits beyond basic nutrition have garnered increasing attention from health-conscious consumers (Hashemi & Khaneghah, 2022). Among these, fruit leather has emerged as a promising candidate due to its extended shelf life, palatability, and adaptability to various formulations (Azarbad et al., 2023).Fruit leather is typically produced by dehydrating fruit purée into a thin, pliable sheet, concentrating its flavor and nutrients. Its processing allows for the incorporation of functional ingredients without significantly compromising sensory quality. Kiwi (*Actinidia deliciosa*) is one such ingredient, known for its high vitamin C content, phenolics, flavonoids (Habsari et al., 2025) and the proteolytic enzyme actinidin, all contributing to its antioxidant capacity (Saeed et al., 2023). Additionally, banana kepok (*Musa paradisiaca*), a starchy and pectin-rich cultivar, enhances product texture and consumer acceptability while delivering essential minerals like potassium and magnesium (Putra et al., 2022).

In recent years, *Moringa oleifera* has received considerable interest as a functional food additive due to its exceptional nutritional profile. Moringa leaves are rich in vitamins A, C, and E, essential amino acids, polyphenols such as quercetin and kaempferol, and considerable amounts of insoluble fiber (Imran et al., 2021). These bioactive compounds provide potent antioxidant, anti-inflammatory, and hypoglycemic properties, positioning Moringa as a promising natural fortifier in functional snack development (Prabhu et al., 2023).Despite extensive documentation of Moringa's antioxidant properties in beverages and bakery products, its use in fruit leather has been scarcely studied. Nevertheless, there remains a lack of empirical data concerning the concurrent impacts of Moringa leaves on antioxidant activity, dietary fiber content, and viscosity in tropical fruit-based leather formulations.

The novelty of this study lies in the development of fruit leather formulated from kepok banana (*Musa paradisiaca* L.) and kiwi (*Actinidia deliciosa*), with the incorporation of *Moringa oleifera* leaves as a natural fortification agent. To the best of current knowledge, no prior research has reported the formulation or characterization of fruit leather combining these specific raw materials. Therefore, this study aims to evaluate the effects of Moringa leaf incorporation on the the antioxidant activity will be assessed through DPPH radical scavenging capacity, dietary fiber content by enzymatic–gravimetric analysis, viscosity behavior through rheological measurements and colour analysis ((L, a, b*). These analyses will offer insights into the formulation potential of Moringa-fortified fruit leather as a viable functional snack product.

Materials and Methods

Materials

The research instruments used in the production of kiwi and kepok banana fruit leather were designed to analyze the physicochemical, antioxidant, and sensory properties of the final product. The raw materials consisted of ripe kepok bananas and fresh kiwis, with adding *Moringa oleifera* leaves. Additional ingredients such as honey and cappa caragenan to improve taste and texture. The primary tools included a digital balance for precise weighing, a blender for fruit homogenization, baking trays lined with parchment paper, and an oven or dehydrator for controlled drying.

Ripe kiwi (*Actinidia deliciosa*) and banana kepok (*Musa paradisiaca* var. *balbisiana*) were selected at optimal maturity, washed thoroughly, peeled, and then weighed. Equal proportions of kiwi and banana (1:1 w/w) were blended to form a homogeneous fruit puree. *Moringa oleifera leaves, recognized for their ability to enhance the nutritional, antioxidant, and functional properties of food products, were incorporated into the fruit puree at five concentration levels such as*: 0 g (control), 2 g, 4 g, 6 g, and 8 g per 100 g of puree. The formulation used in this study is presented as follows :
F0 (100 g kiwi, 100 g banana, 0 g moringa leaves)
F1 (100 g kiwi, 100 g banana, 2 g moringa leaves)
F2 (100 g kiwi, 100 g banana, 4 g moringa leaves)
F3 (100 g kiwi, 100 g banana, 6 g moringa leaves)
F4 (100 g kiwi, 100 g banana, 8 g moringa leaves)

These levels align with recent fortification insights showing Moringa's ability to increase nutrient density, particularly proteins, vitamins, minerals, and dietary fiber, in fruit-based preparations (Leone et al., 2022; Stohs & Hartman, 2021). All ingredients, including polyethylene storage bags, were prepared under hygienic conditions to ensure experimental consistency.

Methods

Each formulation was homogenized until the Moringa leaves was evenly dispersed throughout the puree. The mixtures were spread onto stainless-steel trays to a uniform thickness of ~2 mm, creating rectangular sheets measuring 20 cm × 15 cm. The fruit leather puree was dried in a hot-air oven at 90 °C for 90 minutes to obtain a uniform sheet while preserving its physicochemical and bioactive properties (Martins et al., 2023; Singh et al., 2020). After drying, the fruit leather sheets were carefully peeled off, cooled to room temperature to prevent condensation, and sealed in polyethylene bags. The prepared samples were stored under ambient conditions for subsequent physicochemical, sensory, and functional analyses.

Antioxidant Activity

The antioxidant activity of the samples was evaluated using the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay. Methanolic extracts of 1 g of each dried sample were prepared and mixed with 1 mL of 0.1 mM DPPH solution. The mixture was incubated in the dark for 30 minutes, and the absorbance was measured at 517 nm using a UV–Vis spectrophotometer. IC50 values were calculated using regression analysis to determine the concentration required to inhibit 50% of the DPPH radicals. The percentage of DPPH radical scavenging activity was calculated using:

$$\text{Inhibition (\%)} = \left(\frac{(Ao - As)}{Ao}\right) x\ 100$$

Ao = absorbance of control (DPPH + methanol)
As = absorbances of the sample

Total Dietary Fiber Content

Total dietary fiber was determined according to AOAC Method 991.43 using the enzymatic–gravimetric approach. Samples (1 g) were subjected to enzymatic digestion using heat-stable α-amylase, protease, and amyloglucosidase. The undigested residue was precipitated with ethanol, filtered, dried at 105°C, and weighed. Results were expressed as grams of dietary fiber per 100 g dry weight. Fiber content was calculated as:

$$\text{Dietary Fiber (\%)} = \left(\frac{\text{Wresidu} - \text{P} - \text{A}}{Wsample}\right) x\ 100$$

W residue = residu weight after drying
P = protein correction
A = ash correction
W sample = initial sample weight

Viscosity Measurement

The viscosity of the fruit puree (prior to drying) was measured using a Brookfield NDJ-8S Viscometer at 25°C. Measurements were conducted using spindle No. 3 at 60 rpm. Each formulation was analyzed in triplicate, and viscosity was reported in centipoise (cP). Apparent viscosity (η) could be modeled with the power-law:

$$\eta = K.\mathrm{y}^{n-1}$$

η = viscocity
K = concistency index
y = shear rate

Color Analysis (L, a, b*)**

The color of the fruit leather was measured using a CR-400 colorimeter based on the CIE Lab* system. The L* value indicates lightness (0 = black, 100 = white), a* represents the red–green spectrum (negative values = green), and b* represents the yellow–blue spectrum (positive values = yellow). Each sample was measured three times at random points on the product surface to obtain an average value (Wulandari et al., 2023).

Statistical Analysis

All experiments were conducted in triplicate. Data were expressed as mean ± standard deviation. One-way ANOVA was used to determine the effect of Moringa leaves addition on antioxidant activity, dietary fiber content, and viscosity. Differences between means were assessed using Tukey's HSD test at a 5% significance level ($p < 0.05$).

Table 1. The score of dietary fiber, antioxidant, and viscosity

Formulation	Dietary fiber (g/100g) ± SD	Antioxidant Activity (IC50 ± SD	Viscosity (cP) ± SD
F0 (0 g Moringa)	3.11 ± 0.05	262.28 ± 4.62	913.44 ± 10.23
F1 (2 g Moringa)	3.24 ± 0.06	259.87 ± 3.91	955.75 ± 12.88
F2 (4 g Moringa)	3.36 ± 0.04	233.12 ± 5.15	1047.70 ± 11.42
F3 (6 g Moringa)	3.44 ± 0.03	159.30 ± 3.60	1086.52 ± 9.83
F4 (8 g Moringa)	3.65 ± 0.02	125.43 ± 2.95	1106.96 ± 8.71

Results and Discussion

The results of the data analysis for determining dietary fiber content, antioxidant activity, and viscosity are presented in Table 1.

Dietary Fiber

The steady increase in dietary fiber from 3.11 g/100 g (F0) to 3.65 g/100 g (F4) indicates a dose-dependent enhancement due to the progressive inclusion of Moringa leaves. *Moringa oleifera* is particularly high in insoluble fibers like cellulose, hemicellulose, and lignin, which are resistant to digestion but crucial for intestinal health (Borah et al., 2023). These fibers contribute not only to bulking effects in the colon but also to the modulation of the gut microbiota, aiding in prebiotic activity and improving short-chain fatty acid (SCFA) production (Wichienchot et al., 2022).

Importantly, the rise in fiber did not negatively impact the texture or spreadability of the product, suggesting good integration of Moringa's fibrous matrix into the fruit puree. Similar observations have been reported where vegetable and legume powders enriched with dietary fiber were successfully incorporated into fruit-based snacks without causing sensory rejection (Yasir et al., 2023). The controlled increase in fiber also supports glycemic moderation and satiety enhancement, positioning the fruit leather as a viable functional snack for weight and metabolic control programs (Mendoza et al., 2024).

Antioxidant Activity (IC50)

The significant decrease in IC50 values from 262.28 ppm (F0) to 125.43 ppm (F4) reflects an increased antioxidant activity since lower IC50 means a smaller concentration is needed to inhibit 50% of free radicals. This enhancement is attributed to polyphenolic and flavonoid compounds abundantly found in Moringa leaves, including quercetin, chlorogenic acid, and kaempferol, which are known for their ability to donate electrons or hydrogen to neutralize free radicals (Prabhu et al., 2023).

Moreover, the matrix of kiwi and banana may exert a synergistic antioxidant effect with Moringa compounds. Kiwi is known for high levels of vitamin C, catechins, and ascorbic acid, which may regenerate oxidized flavonoids or enhance their stability in the system (Altemimi et al., 2024). These interactions not only increase total antioxidant capacity but may also impact the bioaccessibility of active compounds during digestion. Interestingly, while F1 and F2 maintained relatively strong antioxidant values, a steeper drop was observed from F2 to F3 and F4, suggesting a potential plateau or threshold effect. This may be due to the saturation of antioxidant capacity within the matrix or interference from fiber or protein interactions that bind phenolics, reducing their extractability (Imran et al., 2021).

Viscosity

Viscosity rose progressively from 913.44 cP (F0) to 1106.96 cP (F4), indicating a thicker consistency with more Moringa added. This increase is likely due to the hydrophilic nature of dietary fibers and proteins in Moringa, which bind water and swell, forming a denser and more stable gel structure (Nugroho et al., 2024). This gelling behavior enhances rheological properties, creating a more cohesive matrix beneficial for forming uniform fruit leather sheets.

From a processing perspective, higher viscosity contributes to reduced syneresis, better shape retention, and improved chewiness—qualities desirable in dried fruit products (Hashemi & Khaneghah, 2022). However, excessive viscosity (as seen in F4) could negatively affect drying kinetics by slowing moisture migration, potentially extending drying times and increasing energy consumption. Therefore, an optimal range must be maintained to balance spreadability, drying efficiency, and textural acceptability.

These findings are consistent with reports where plant-based fibers like oat bran, chia, or okra mucilage were used to increase viscosity in fruit pastes, leading to improved mechanical properties and consumer texture preferences (Alavi et al., 2023; Raza et al., 2023). The observed shear-thinning behavior may also aid in processing through pumps or extrusion if scaled up for industrial production.

Color Analysis (L, a, b*)

Color is a critical parameter in evaluating the visual quality of food products and plays a significant role in determining consumer acceptance. The CIE Lab* color system is widely used to objectively assess color characteristics, where L* indicates lightness, a* represents the red–green spectrum, and b* indicates the yellow–blue spectrum. In this study, the addition of *Moringa oleifera* leaves to the kiwi–kepok banana fruit leather formulation significantly influenced all three of the color parameters. The results of the L*, a*, and b* color value analysis of fruit leather with different levels of *Moringa oleifera* leaf addition are presented in Table 2.

Changes in L Value (Lightness)*

The L* value represents the brightness or darkness of an object, with 0 indicating black and 100 indicating white. The highest L* values were observed in formulations F1 (44.87) and F0 (43.43), while the lowest

Table 2. The score of L*,a,b color analysis

Formulation	L*	a	b
F0	43.43	9.73	39.27
F1	44.87	10.13	39.47
F2	39.17	7.67	37.17
F3	38.77	7.77	37.07
F4	32.13	6.23	35.87

was recorded in F4 (32.13), suggesting that increasing levels of moringa leaf addition significantly reduced the lightness of the product. This reduction in L* value can be attributed to the increasing concentration of chlorophyll pigments present in moringa leaves. These dark green pigments are opaque to light, resulting in a darker product surface as the moringa concentration increases (Guan et al., 2024). Mekonnen et al. (2023) further explained that the intensity of green coloration in food materials strongly depends on the stability of chlorophyll during processing. Low-temperature drying, such as oven drying at 60°C, still preserves chlorophyll structure reasonably well.

Interestingly, F1 had a slightly higher L* value than F0. This may be explained by a possible light-scattering effect caused by the presence of fine moringa leaf particles in small amounts, which can create a matte surface that reflects light more evenly, making it appear brighter (Han et al., 2024). However, at higher concentrations such as in F4, the accumulation of chlorophyll and phenolic compounds caused a drastic decrease in L* value. This trend aligns with findings by Liu et al. (2022) and Wang et al. (2022), who reported that the addition of dark-colored ingredients such as spinach, spirulina, or moringa into bakery products and jelly candies significantly reduced L* values, with a negative correlation to the concentration of the additive.

Changes in a Value (Red–Green Spectrum)*

The a* value represents the color spectrum from red (+a) to green (−a). In formulation F0, the a* value was 9.73, which gradually decreased to 6.23 in F4, indicating a shift toward a stronger green hue. This consistent decrease in a* value is again associated with the dominance of chlorophyll a and b pigments in moringa leaves. As the amount of moringa increases, the green pigments increasingly overshadow the natural reddish tones of kiwi and banana. These fruits typically contain flavonoids, anthocyanins, and carotenoids, which give them a yellowish-red hue (Chen et al., 2022). However, these pigments are often susceptible to degradation during heating, especially under mildly oxidative conditions.

This finding is supported by Al-Amin et al. (2023), who found that incorporating chlorophyll-rich leaf powders like moringa and kale into fruit-based snacks significantly decreased a* values and caused a visible color shift from orange-yellow to greenish-brown. Furthermore, antagonistic interactions between phenolic compounds from moringa and fruit pigments may accelerate anthocyanin degradation during heat processing (Santos et al., 2024). Changes in a* values are also important from a sensory standpoint. Reddish tones are typically associated with sweet and fresh flavors, while dark green hues are often perceived as bitter or herbal (Rahman et al., 2023). Therefore, the significant reduction in a* values in F3 and F4 may negatively affect consumer perception, despite the nutritional benefits.

Changes in b Value (Yellow–Blue Spectrum)*

The b* value represents the color spectrum from yellow (+b) to blue (−b). In this study, the highest b* values were found in F1 (39.47) and F0 (39.27), which gradually decreased to 35.87 in F4. This decline indicates that the addition of moringa reduced the intensity of the yellow color derived from the fruit ingredients. The yellow color in bananas and kiwis primarily comes from carotenoids, especially lutein and beta-carotene. These compounds are thermolabile, meaning they are prone to degradation when exposed to heat (Chen et al., 2022). Although moringa also contains carotenoids, its green pigments are more dominant. The masking effect of chlorophyll, combined with the potential thermal degradation of carotenoids during drying, contributes to the observed reduction in b* values (Tadesse et al., 2023).

Consumers preferred the fruit leather with a darker green color. Wulandari et al. (2023) found that the decline in b* values in fruit-based snacks enriched with high-fiber herbal ingredients occurred due to two main factors: (1) interactions between antioxidant compounds (e.g., phenolics) and color pigments, and (2) microstructural changes during heating, which affect how light is reflected from the product surface. Therefore, the decrease in b* values from F2 to F4 is most likely due to the reduced relative concentration of yellow pigments compared to green pigments, along with structural modifications during the drying process.

Conclusion

The incorporation of *Moringa oleifera* leaves into kiwi–banana fruit leather significantly enhances its nutritional functionality by increasing dietary fiber content and antioxidant capacity, while simultaneously influencing viscosity in a manner that improves structural integrity and sensory attributes. However, excessive fortification at higher concentrations (F4) may present processing challenges due to increased viscosity and potential phenolic–protein interactions. Overall, these findings highlight the potential of *Moringa oleifera* as a natural fortification agent in the development of functional snack products, providing both nutritional improvement and desirable processing characteristics. Moreover, the resulting fruit leather represents a healthy snack alternative that can be consumed by people of all age groups.

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