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Mineral Characteristics and Organoleptic Properties of *Musa balbisiana* (Wild Banana) Pseudostem collected from San Francisco, Mainit, Surigao del Norte, Philippines and Incorporated into Patty Formulations

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ABSTRACT: A patty is a crushed, compacted and flattened small cake of ground meat (beef) or fish or legumes, grains, vegetables, or meat alternatives usually fried. The objective of this paper is to evaluate the mineral characteristics and organoleptic properties of *Musa balbisiana* (wild banana) pseudostem collected from San Francisco, Mainit, Surigao del Norte and Philippines incorporated into patty formulations using appropriate standard procedures. The study employed a completely randomized design with five treatments replicated three times, where patties were formulated with different proportions of *M. balbisiana* pseudostem core (MB): T1: Flour-based T2: MB 100% T3: MB 75% T5: MB 50% T5: MB 25%. The pseudostem core showed the following chemical contents in ppm: Potassium-106,451, phosphorus-3,682, calcium-3,817, and magnesium-2,977. Sensory evaluation by 50 semi-trained panelists showed that MB 75% achieved optimal results, performing comparably or superior to the control in several attributes, notably surpassing it in color (8.49 vs. 8.14, $p<0.05$) and texture (8.39 vs. 7.78, $p<0.05$) ratings while maintaining high acceptability in appearance (7.59), aroma (7.41), and taste (7.61). Correlation analysis revealed strong positive relationships between appearance and aroma ($r = 0.988$) and general acceptability ($r = 0.942$). At the same time, mineral content showed consistent moderate negative correlations with taste ($r = -0.697$) and general acceptability ($r = -0.497$). These findings demonstrate that *M. balbisiana* pseudostem core can effectively replace up to 75% of flour in patty formulations while maintaining or enhancing sensory qualities, significantly advancing sustainable ingredient utilization in food product development.

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The global imperative for sustainable resource utilization has become increasingly critical as agricultural waste management, food security, and environmental conservation present interconnected challenges worldwide (Koul *et al.,* 2021). Agricultural by-products, particularly from major crops like bananas (*Musa* spp.), represent a significant waste management challenge and an untapped opportunity for value-added product development (Serna-Jiménez *et al.,* 2023). The banana industry, which produces over 116 million tonnes annually worldwide (Friesen, 2016), generates

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substantial biomass waste of 60% after harvest, including pseudostems, leaves, and other parts (Alzate Acevedo *et al.,* 2021; Zaini *et al.,* 2023). The Asia-Pacific region accounts a significant portion of global banana production, faces challenges in managing agricultural waste while addressing food security concerns. In the Philippines, these challenges present unique opportunities for sustainable resource utilization, mainly by exploiting underutilized wild banana varieties. One such resource is *M. balbisiana*, locally known as "Paguha," (Maglinte *et al.,* 2020), which grows abundantly in secondary forests. However, it is often perceived as a "poor man's food," leading to its neglect, elimination, and discarded in favor of more commercially viable crops, creating both environmental wastes and missed economic opportunities for local communities.

Recent studies have highlighted the remarkable nutritional profile of *M. balbisiana*, particularly its pseudostem. Chemical analysis reveals notably high potassium content, along with substantial amounts of phosphorus, calcium, and magnesium (Ho *et al.,* 2012; Ma *et al.,* 2017; Sangroula, 2018; Devi *et al.,* 2023). These mineral concentrations significantly exceed those reported in cultivated banana varieties, suggesting the unique nutritional advantages of wild varieties. The pseudostem's rich mineral composition presents an opportunity for addressing nutritional deficiencies while creating value-added products from what is currently considered waste material. Global research on banana pseudostem incorporation into food products has shown promising results across various applications. Studies have successfully demonstrated incorporation into diverse products, including brownies at 45% levels (Go *et al.,* 2021), biscuits with enhanced nutritional profiles (Chakraborty *et al.,* 2021), and cutlets achieving high cooking yields (Raju *et al.,* 2019). More innovative applications have emerged, such as blended jams with up to 50% incorporation (Raghavendra *et al.,* 2021), enhanced bread formulations (Ho *et al.,* 2017), and food bars with improved dietary fiber and antioxidant activity (Welli *et al.,* 2020). Unlike cultivated bananas explicitly grown for fruit production, wild *M. balbisiana* represents an untapped resource that could provide additional income streams for local communities while promoting sustainable forest management practices. Hence, the objective of this paper is to evaluate the mineral characteristics and organoleptic properties of *Musa balbisiana* (wild banana) pseudostem collected from San Francisco, Mainit, Surigao del Norte and Philippines incorporated into patty formulations using appropriate standard procedures.

MATERIALS AND METHODS

Experimental design: The study employed a completely randomized design (CRD) with five treatments replicated three times. Treatments consisted of varying proportions of wild banana stem (*Musa balbisiana*) pseudostem (MB): T1 (Flour-based), T2 (MB 100%), T3 (MB 75%), T5 (MB 50%), and T5 (MB 25%).

Sample preparation: Fresh *M. balbisiana*, locally known as "Pahuha" (Bisayan-Philippines), pseudostems were collected from San Francisco, Mainit, Surigao del Norte, Philippines. The outer leaf sheaths were removed to extract the central cylinder (pseudostem core). The white-colored core was cleaned and cut into uniform pieces (5 cm × 1 cm). Samples were boiled for 15-20 minutes until tender, drained for 10 minutes, and ground into a fine paste using a food processor. The paste was squeezed through a clean cloth to remove excess moisture.

Chemical analysis: Plant tissue analysis was conducted to determine the nutritional composition of the banana stem. Parameters measured included total nitrogen (Kjeldahl method) (Jones, 1991), phosphorus (Vanadomolybdate method) (Burns and Hutsby, 1986), potassium, sodium, calcium, magnesium, iron, copper, and manganese (Aqua-regia digestion), and pH (1:10 w/v, pH meter) (Chen and Ma, 2001).

Patty formulation: Patties were prepared following standard food processing procedures. The basic formulation included processed banana pseudostem core (0 – 1000g), all-purpose flour (APF) (0 - 800g), beef (0-200g), eggs (4 pcs), and seasonings (onion, garlic, ground pepper, salt, and turmeric) in specified proportions. Ingredients were thoroughly mixed and formed into uniform patties (8 cm diameter × 1 cm thickness). Patties were pan-fried at medium heat until golden brown (3-4 minutes per side). Detailed ingredients are presented in Table 1.

Fifty panelists (aged 18-50 years) underwent pre-training before the sensory evaluation. Training consisted of sessions covering (1) basic taste recognition and threshold tests, (2) texture and appearance evaluation techniques, and (3) specific product attribute assessment using reference standards. Panelists consisted of faculty, administrative staff, and Surigao del Norte State University – Mainit Campus students, screened for normal taste and smell sensitivity, and only those achieving >80% accuracy in discrimination tests were selected.

Table 1: List of ingredients that were used and mixed along their measurements

Ingredients	Treatments				
	T1 (Flour-based)	T2 MB 100%	T3 MB 75%	T4 MB 50%	T5 MB 25%
M. balbisiana pseudostem core (MB)	0	1000g	750g	500g	250g
All-purpose flour	800g	0	250g	500g	750g
Meat (beef)	200g	0	0	0	0
Eggs	4 pcs	4 pcs	4 pcs	4 pcs	4 pcs
Onion	5 tsp	5 tsp	5 tsp	5 tsp	5 tsp
Garlic	5 tsp	5 tsp	5 tsp	5 tsp	5 tsp
Ground pepper	2 tsp	2 tsp	2 tsp	2 tsp	2 tsp
Salt	1 tsp	1 tsp	1 tsp	1 tsp	1 tsp
Turmeric	2 tsp	2 tsp	2 tsp	2 tsp	2 tsp
Oil	½ cup	½ cup	½ cup	½ cup	½ cup

The panel evaluated samples using a 9-point hedonic scale (1 = dislike extremely to 9 = like extremely). Evaluated attributes included appearance, aroma, color, taste, texture, and overall acceptability. Samples were served at room temperature (25±2°C) in randomized order using three-digit coded containers. Water (room temperature) and unsalted crackers were provided for palate cleansing between samples. Following standard sensory evaluation protocols, evaluations were conducted in individual booths under controlled conditions (temperature: 22±2°C; relative humidity: 50-55%; lighting: 750-1000 lux).

Statistical analysis: Data were analyzed using Analysis of Variance (ANOVA), and treatment means were compared using the Least Significant Difference (LSD) test at 5% and 1% significance levels. Statistical analyses were performed using SPSS software.

RESULTS AND DISCUSSIONS

Mineral composition of M. balbisiana pseudostem core: Chemical analysis of the *M. balbisiana* pseudostem core revealed distinctive mineral concentrations, with potassium showing notably high levels at 106,451 ppm. Other significant minerals included calcium (3,817 ppm), phosphorus (3,682 ppm), and magnesium (2,977 ppm). Trace elements were also detected, including iron (233 ppm), manganese (72.9 ppm), and copper (29.2 ppm), alongside a nitrogen content of 1.03%. Comparison with previous studies revealed substantial variations in mineral profiles. The potassium content exceeded levels reported in earlier research of 5015-6091 mg/100g by Ma *et al.* (2017), 944.1 mg/100g by Ho *et al.* (2012), and 680 mg/100g by *Sangroula, (2018)*. Similarly, calcium surpassed the 115-145 mg/100g reported by Ma *et al.* (2017) and the 318 mg/100g reported by *Sangroula, (2018)*, though they were lower than the 1335.3 mg/100g values reported by Ho *et al.* (2012). Magnesium levels aligned more closely with those reported by Ma *et al.* (2017) of 196-255 mg/100g and Ho *et al.* (2012) with 255 mg/100g. The nitrogen content exceeded those reported by Devi *et al.* (2023) by 0.0205%, suggesting significant protein content variation.

These mineral variations reflect the influence of geographical location, environmental factors, and cultivation practices. Research by Devarajan *et al*. (2021) has demonstrated that genetic variability in Musa species can result in 4.7-fold differences in potassium and magnesium content and up to 111.1-fold in calcium content. The mineral profile of the pseudostem core aligns with broader findings on wild banana varieties, which often show higher mineral concentrations than cultivated varieties (Das *et al*., 2021). The elevated potassium levels are particularly notable, as they exceed those typically found in other plant-based materials and even surpass levels reported in other parts of the *M. balbisiana* plant (Basumatary and Nath, 2018). The comprehensive mineral profile established here suggests significant potential for nutritional enhancement in food applications. The high potassium content, in particular, could contribute to addressing dietary mineral deficiencies, while the balanced presence of calcium and magnesium suggests potential functionality in food systems. These findings align with recent research on wild banana varieties as sources of essential minerals (Gurumayum *et al*., 2023) and support the potential of *M. balbisiana* pseudostem core as a nutrient-rich food ingredient.

Appearance: Sensory evaluation revealed significant variations in appearance acceptability across treatments ($p<0.001$). The control (flour-based) achieved the highest mean score of 8.29 ("like very much"), with MB 75% performing optimally among pseudostem formulations at 7.59 ("like moderately"). Complete flour replacement (MB 100%) and minimal incorporation (MB 25%) received significantly lower

scores of 6.05 and 5.55 respectively, while MB 50% achieved an intermediate rating of 6.84. The successful performance of MB 75%, showing statistical comparability with the control, demonstrates that substantial pseudostem core incorporation can maintain desirable visual characteristics. This effectiveness at 75% substitution appears to result from balanced interactions between the pseudostem core's fibrous structure and the remaining flour's binding properties. Research by Lee *et al*. (2021) on plant-based patty formulations has shown that optimal ratios between novel ingredients and traditional binders are crucial for maintaining desirable appearance characteristics. The findings align with Go and co-workers (2021) observations that appropriate incorporation levels of banana pseudostem flour can preserve or enhance visual appeal in food products. The lower acceptability scores for extreme incorporation levels provide important insights into formulation boundaries. Complete flour replacement (MB 100%) compromises visual appeal due to lost structural properties typically provided by wheat flour proteins (Chakraborty *et al*., 2021). Conversely, insufficient incorporation (MB 25%) appears to create an inconsistent appearance, potentially due to uneven distribution within the flour matrix. These observations support Monaco and co-workers (2003) findings that visual uniformity significantly influences consumer perception and acceptance of novel food products. Recent research by Forster *et al*. (2024) on plant-based patties further emphasizes that achieving optimal visual characteristics requires carefully balancing novel ingredients with traditional components.

Our achievement with high pseudostem incorporation parallels findings from Bin Mohd Zaini *et al*. (2019), who successfully incorporated *M. balbisiana* peel powder into fish patties. While their study focused on lower incorporation levels, they found that proper incorporation of banana-derived ingredients could enhance visual appeal through optimal color development, particularly when the formulation balanced ingredient interactions. The strong performance in appearance also aligns with research by Raghavendra *et al*. (2021) on banana pseudostem incorporation in jams. Their study achieved successful visual appeal with up to 50% pseudostem core incorporation, demonstrating that banana pseudostem materials can maintain or enhance appearance characteristics even at substantial incorporation levels while providing improved nutritional qualities.

Table 2: Mineral composition of *M. balbisiana* pseudostem core: comparison between current study and published data

Sources	Current study	Ma *et al*., 2017	Devi *et al*., 2023	Ho *et al*., 2012	Sangroula, 2018
Parts of *M. balbisiana*	Pseudostem	Pseudostem	Pseudostem	Pseudostem	Pseudostem
Nitrogen	1.03%	-	0.02%	-	-
Total Phosphorus	3682.00ppm	5015-6091mg/100g	-	944.1mg/100g	680mg/100g
Total Potassium	106451.00ppm	59-69.3mg/100g	-	137.8mg/100g	-
pH	7.53	0.7-13.6mg/100g	-	444.1mg/100g	104mg/100g
Sodium	372.00ppm	-	-	-	-
Calcium	3817.00ppm	115-145mg/100g	-	1335.3mg/100g	318mg/100g
Magnesium	2977.00ppm	196-255mg/100g	-	255mg/100g	-
Iron	233.00ppm	6-11.6mg/100g	-	3.3mg/100g	-
Copper	29.20ppm	0.5-0.9mg/100g	-	-	-
Manganese	72.90ppm	0.5-0.7mg/100g	-	1.3mg/100g	-

Effects of Incorporating M. balbisiana pseudostem on patty's sensory properties

Aroma: The sensory evaluation revealed significant variations in aroma acceptability across treatments ($p<0.001$). The control (flour-based) achieved the highest mean score of 7.63 ("like moderately" to "like very much"), with MB 75% performing comparably with a rating of 7.41, showing no statistical difference. Lower acceptance ratings were observed for MB 100% (6.39) and MB 25% (5.85), while MB 50% achieved an intermediate rating of 6.80. The strong performance of MB 75% can be attributed to optimal interactions between precursor compounds during cooking, supported by Wang and Kays' (2000) findings that aroma development results from complex interactions between multiple compounds rather than single dominant components. The lower acceptance of MB 25% suggests insufficient pseudostem core diminishes aromatic properties, due to inadequate flavor precursor concentrations affecting Maillard reactions during cooking (Chen *et al*., 2000). The ideal performance at 75% substitution aligns with research demonstrating that balanced ingredient proportions are crucial for optimal aroma development in baked products (Belz *et al*., 2017). This finding is particularly relevant as aroma compounds significantly influence product acceptance in novel food formulations (Torrea *et al*., 2011). Recent research by Han *et al*. (2023) demonstrated that polysaccharide-rich plant ingredients can contribute positively to sensory

properties in plant-based patties, particularly when optimal concentrations are achieved. Our findings extend beyond traditional approaches to plant-based ingredient incorporation, as demonstrated by Bueno *et al*. (2012), who achieved positive results with banana peduncle powder at much lower incorporation levels (0.5-2.0%). Sogari *et al*. (2023) found that plant-based burgers typically show reduced aroma intensity compared to conventional products, while Hernandez *et al*. (2023) reported distinct differences in volatile profiles between plant-based and conventional formulations. Our achievement of comparable aroma scores between MB 75% and the control suggests that proper formulation with *M. balbisiana* pseudostem core can overcome typical aroma limitations associated with plant-based ingredients.

Color: Color evaluations demonstrated significant differences across treatments ($p<0.001$), with MB 75% achieving the highest mean score of 8.49 ("like very much" to "like extremely"), surpassing even the control (flour-based) which scored 8.14. MB 100% maintained moderate acceptance with a rating of 7.20 ("like moderately"), while both MB 50% and MB 25% received significantly lower scores of 6.46 and 6.39, respectively ("like slightly" to "like moderately"). The superior color development at 75% substitution results from an optimal combination of natural pigments in the pseudostem core and ideal conditions for browning reactions during cooking. This finding aligns with research by Go *et al*. (2021) demonstrating that appropriate incorporation levels of banana pseudostem flour can enhance color development in baked products. The lower ratings for MB 50% and MB 25% suggest that insufficient pseudostem core incorporation compromises color development and uniformity, supported by Monaco and co-workers (2003) findings that color uniformity significantly influences consumer perception. The interaction between turmeric and pseudostem components at the 75% incorporation level creates an optimal golden-brown color that exceeds consumer expectations. This finding is particularly significant as Clydesdale, (1991) established that color is food's most important sensory attribute, directly influencing consumer judgments of other sensory characteristics and serving as a predictor of quality attributes.

The study by Go *et al*. (2021) demonstrated that increasing pseudostem flour concentrations significantly improved color acceptability, with scores rising progressively as incorporation levels increased. Their formulations with higher pseudostem flour content achieved dark brown coloration that was significantly preferred by participants, suggesting that the natural pigments and browning reactions from banana pseudostem materials can enhance product appearance. Lee *et al*. (2021) findings on plant-based meat analogs demonstrated that proper incorporation of plant materials could enhance color development through optimal interaction with other ingredients. Their research showed that plant-based formulations could achieve higher L* and a* values compared to conventional products, indicating successful color development. The exceptional color performance also parallels findings from Welli *et al*. (2020), who successfully incorporated banana pseudostem flour into food bars. Their optimal formulation at an 85:15 ratio achieved superior color brightness ($L^* = 52.52 \pm 0.60$), demonstrating that banana pseudostem materials can contribute to desirable color development even at substantial incorporation levels. Their research showed that proper formulation could maintain consistent and appealing color characteristics while delivering enhanced nutritional benefits.

Texture: Texture evaluation revealed significant differences among treatments ($p<0.001$), with MB 75% achieving the highest mean score of 8.39 ("like very much" to "like extremely"), notably surpassing the control (flour-based) which received a score of 7.78. Both extreme ratios – MB 100% and MB 25% - received significantly lower ratings of 5.74 and 5.92, respectively, while MB 50% achieved an intermediate score of 7.31. The exceptional performance of MB 75% suggests an ideal balance between the pseudostem core's fibrous structure and flour's binding properties. This finding aligns with research by Guiné, (2022), establishing that texture plays a pivotal role in consumer acceptance, particularly when optimal ingredient combinations are achieved. The poor performance of MB 100% indicates that complete flour replacement compromises essential structural properties, while the low acceptance of MB 25% suggests insufficient pseudostem core to contribute beneficial textural attributes. The successful texture development at 75% incorporation represents a significant advancement in sustainable ingredient substitution, surpassing previously reported optimal incorporation levels. For instance, Sangroula (2018) found declining textural acceptance above 2.5% incorporation in biscuits, while Go *et al*. (2021) reported optimal results at 15% in brownies. Our findings demonstrate that substantially higher incorporation levels can be achieved while enhancing textural qualities when proper formulation ratios are maintained. The texture enhancement of the current study parallels the findings from Geraldo, (2020), who found that incorporating banana flour at

reasonable percentages (5% mass basis) significantly improved textural quality, particularly crunchiness. Their study demonstrated that the synergistic presence of resistant starch, dietary fiber, protein, and non-starch polysaccharides from banana materials contributed to superior textural development. The superior texture development also aligns with Ho and co-workers (2017) research on banana pseudostem flour in bread formulations. Their study found that when properly formulated with hydrocolloids, particularly sodium carboxymethyl cellulose (Na CMC), banana pseudostem flour incorporation resulted in improved crumb softness and a more continuous protein network with larger gas cells, demonstrating enhanced textural properties compared to conventional formulations.

Taste: Sensory evaluation revealed significant variations in taste acceptability across treatments ($p<0.001$). The control (flour-based) achieved the highest mean score of 8.19 ("like very much"), while both MB 75% and MB 50% performed comparably with statistically similar scores of 7.61 and 7.45, respectively. MB 100% received the lowest acceptance rating (5.83), while MB 25% achieved an intermediate score of 6.84. The strong performance of both MB 75% and MB 50% demonstrates that substantial pseudostem core incorporation can maintain highly acceptable taste characteristics. This finding extends beyond previous studies, such as Sangroula (2018), which found acceptable taste scores only at much lower incorporation levels (2.5%) in biscuits. The statistical similarity between these two formulations suggests a broader optimal range for pseudostem core incorporation, offering flexibility in formulation without compromising flavor quality. The significantly lower acceptance of MB 100% reveals important limitations in complete flour replacement. This effect result from the loss of flavor compounds associated with flour-based products, supported by research by Champagne *et al*. (2009) demonstrating that balanced protein-ingredient interactions are crucial for optimal flavor development in food products. The successful taste maintenance at higher incorporation levels (50-75%) represents a significant advancement in sustainable ingredient utilization while maintaining sensory appeal.

The banana pseudostem central core incorporation in jams achieved superior taste acceptance even at 50:50 blending ratios of banana pulp and pseudostem central core (Raghavendra *et al*., 2021). Our achievement in taste maintenance at 75% incorporation also parallels findings from Bin Mohd Zaini *et al*. (2019), who successfully incorporated *M. balbisiana* peel powder in fish patties. Their study found that moderate incorporation levels achieved optimal taste scores, with 2% incorporation receiving the highest taste acceptability ratings among all treatments, indicating that proper formulation with banana-derived ingredients can enhance taste profiles. Moreover, Nurdjanah *et al*. (2012) found superior taste acceptance in biscuits incorporating *M. balbisiana* flour. Their optimal formulation at 85:15 (balbisiana flour: wheat flour) ratio demonstrated that high incorporation levels of *M. balbisiana* materials could maintain excellent taste characteristics while delivering enhanced nutritional benefits.

General acceptability: Overall acceptability analysis revealed significant differences among treatments ($p<0.001$). The control (flour-based) received the highest mean score of 8.75, followed closely by MB 75% with a notably high rating of 7.97. Lower incorporation levels showed declining acceptance, with MB 50%, MB 25%, and MB 100% receiving progressively lower ratings of 6.62, 6.35, and 6.16 respectively. The strong performance of MB 75% demonstrates the potential for significant flour replacement while maintaining high consumer acceptance. This finding substantially exceeds typically reported optimal incorporation levels in previous studies. For instance, Go *et al*. (2021) found optimal acceptance at 15% incorporation in brownies, while Sangroula (2018) reported best results at just 2.5% in biscuits. The progressive decline in acceptability with both lower substitution levels and complete substitution indicates that 75% incorporation represents an optimal balance point for overall product quality.

Findings from Geraldo, (2020) demonstrated that incorporating banana flour at optimal levels significantly enhanced overall acceptability scores. Their study found that flour-enriched formulations were "significantly higher in all the sensory attributes considered" and showed favorable acceptability. Raghavendra *et al*. (2021) successfully incorporated banana pseudostem central core in blended jams up to 50% levels. Their products maintained high overall acceptability while delivering enhanced nutritional qualities, particularly in terms of iron, potassium, fiber, and lipid values. *M. balbisiana* peel powder in fish patties achieved the highest overall acceptability scores compared to control samples in multiple sensory dimensions with optimal incorporation levels. The achievement of high acceptability at 75% incorporation substantially exceeds traditional successful incorporation levels reported in other studies, such as Go *et al*. (2021) at 15% in brownies and Welli *et al*. (2020) at 15% in food bars,

demonstrating the potential for much higher sustainable ingredient utilization while maintaining consumer acceptance when proper formulation ratios are established.

Table 3: Mean sensory evaluation scores† of *M. balbisiana* pseudostem core patties with varying levels of flour substitution.

Treatment	Appearance†	Aroma†	Color†	Texture†	Taste†	General Acceptability†
Flour-based (control)	8.29^{d}	7.63^{d}	8.14^{c}	7.78^{d}	8.19^{d}	8.75^{e}
MB 100%	6.05^{a}	6.39^{ab}	7.20^{b}	5.74^{a}	5.83^{a}	6.16^{a}
MB 75%	7.59^{c}	7.41^{cd}	8.49^{d}	8.39^{e}	7.61^{c}	7.97^{d}
MB 50%	6.84^{b}	6.80^{bc}	6.46^{a}	7.31^{c}	7.45^{c}	6.62^{c}
MB 25%	5.55^{a}	5.85^{a}	6.39^{a}	5.92^{b}	6.84^{b}	6.35^{b}
p=Value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
CV	15.21%	10.37%	12.11%	15.31%	11.76%	14.61%

†Values represent mean scores from 50 trained panelists using a 9-point hedonic scale (1 = dislike extremely to 9 = like extremely)
Means within a column followed by different superscript letters are significantly different ($p < 0.001$).

Correlation analysis of mineral-sensory interactions: The correlation analysis revealed complex relationships between mineral content and sensory attributes, providing insights into the role of minerals in product quality (Table 4). Visual characteristics emerged as dominant factors, with appearance showing positive correlations with both aroma ($r = 0.988$, $p < 0.01$) and general acceptability ($r = 0.942$, $p < 0.05$). These strong correlations illustrate the integrated nature of sensory perception, where visual cues significantly influence overall product acceptance. The mineral composition demonstrated consistently moderate negative correlations with taste ($r = -0.697$) and general acceptability ($r = -0.497$), suggesting excessive mineral concentrations adversely affect flavor perception. This relationship aligns with research by Albarracín *et al*. (2011), who found that mineral content influences flavor development through various biochemical mechanisms. The uniform negative correlations across appearance ($r = -0.347$) and aroma ($r = -0.199$) indicate that mineral content influences these attributes through similar mechanisms, though varying degrees.

The influence of specific minerals on sensory attributes can be explained through several mechanisms. Potassium plays a crucial role in flavor development through its effects on cellular processes during cooking (Torrea *et al*., 2011), while calcium and magnesium contribute to texture development through protein-mineral interactions (Emorine *et al*., 2015) These mineral interactions are particularly evident in color development, where iron and copper contribute to favorable Maillard browning reactions (Kocadağlı and Gökmen, 2016). The interplay between minerals and sensory attributes is further demonstrated by the strong correlations between texture and taste ($r = 0.850$) and taste with general acceptability ($r = 0.845$). These relationships suggest that optimal mineral content is crucial for balancing multiple sensory attributes. Research by Zhang *et al*. (2023) supports this finding, demonstrating that mineral content influences texture perception and flavor development in food products. An unexpected finding emerged in the relationship between color and taste ($r = 0.460$), which showed the weakest correlation among sensory attributes. This relatively low correlation suggests that color perception operates somewhat independently of taste evaluation, contrasting with the stronger correlations observed between other sensory parameters. This finding adds nuance to our understanding of how mineral content influences different sensory attributes independently.

The hierarchical influence of sensory attributes on general acceptability provides crucial insights for product development. The strong correlations of appearance ($r = 0.942$), aroma ($r = 0.905$), and taste ($r = 0.845$) with general acceptability establish these as primary drivers of overall product acceptance. These patterns align with Moskowitz and Krieger's (1993) findings on the relative importance of sensory attributes in determining product quality.

The correlation patterns suggest that maintaining balanced mineral content while maximizing positive sensory attributes is crucial for product success, particularly when incorporating novel ingredients at high levels. The consistent moderate negative correlations between mineral content and various sensory attributes suggest an optimal range for mineral concentration, beyond which sensory quality may decline.

This finding is particularly relevant for product development, as it indicates that while minerals contribute positively to sensory attributes at appropriate levels, excessive concentrations compromise overall product acceptance. This understanding provides valuable guidance for optimizing pseudostem core incorporation levels in future product formulations.

Table 4: Pearson correlation coefficients (r) between mineral composition and sensory attributes of *M. balbisiana* pseudostem core patties

Attributes	Appearance	Aroma	Color	Texture	Taste	General Acceptability
Nitrogen	-0.347	-0.199	0.036	-0.219	-0.697	-0.497
phosphorus	-0.347	-0.199	0.036	-0.219	-0.697	-0.497
Potassium	-0.347	-0.199	0.036	-0.219	-0.697	-0.497
pH	-0.347	-0.199	0.036	-0.219	-0.697	-0.497
Sodium	-0.347	-0.199	0.036	-0.219	-0.697	-0.497
Calcium	-0.347	-0.199	0.036	-0.219	-0.697	-0.497
Magnesium	-0.347	-0.199	0.036	-0.219	-0.697	-0.497
Iron	-0.347	-0.199	0.036	-0.219	-0.697	-0.497
Copper	-0.347	-0.199	0.036	-0.219	-0.697	-0.497
Manganese	-0.347	-0.199	0.036	-0.219	-0.697	-0.497
Appearance		0.988**	0.789	0.883*	0.825	0.942*
Aroma			0.833	0.896*	0.755	0.905*
Color				0.71	0.46	0.828
Texture					0.85	0.824
Taste						0.845
Gen. Acc.						

*** Correlation is significant at the 0.01 level (2-tailed).* Correlation is significant at the 0.05 level (2-tailed).*

Conclusions: The *M. balbisiana* pseudostem core demonstrated significant mineral content, particularly rich in potassium, phosphorus, calcium, and magnesium, establishing its nutritional value as a food ingredient. Sensory evaluation revealed that pseudostem core in patty formulations achieved optimal results, performing comparably or superior to the control in several attributes - surpassing the control in color and texture ratings while maintaining high acceptability in appearance, aroma, and taste. Correlation analysis revealed complex relationships between mineral content and sensory attributes, with significant correlations observed between appearance and both aroma and general acceptability. These findings demonstrate that M. balbisiana pseudostem core can effectively replace up to 75% of flour in patty formulations while maintaining or enhancing sensory qualities, representing a significant advancement in sustainable ingredient utilization in food product development.

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Data Availability Statement: Data are available upon request from the first author or corresponding author or any of the other authors

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