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Development and Characterization of Launaea sarmentosa-Based Jelly Candy: Nutritional Composition,Antioxidant Activity, Lead Safety, and Sensory

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ABSTRACT:

Background: Stunting remains a major child nutrition problem in Indonesia, requiring strategies that address protein quality, micronutrient content, and food acceptability. Sea lettuce (Launaea sarmentosa), an underutilized coastal plant traditionally consumed in Aceh, is a potential raw material for processed food development.

Objective: To develop a L. sarmentosa-based jelly candy, characterize its nutritional and bioactive properties, assess lead contamination, and identify the formulation with the highest sensory acceptability.

Methods: Three formulations containing 40 mL (F1), 50 mL (F2), and 60 mL (F3) of L. sarmentosa juice were prepared, with total liquid phase and all other components held constant. Raw material and products were analyzed for proximate composition, minerals, DPPH antioxidant activity, total flavonoids, and lead. Sixty semi-trained panelists rated color, taste, aroma, texture, and overall acceptability on a five-point hedonic scale. Differences were analyzed by one-way ANOVA ($\alpha = 0.05$).

Results: Fresh leaves contained 5.54% protein, 7.71% crude fiber, 14.6 mg/100 g zinc, and 5.5 mg/100 g iron. Mean acceptability rose from F1 (3.437) to F2 (3.559) and F3 (3.790), with significant differences for color ($p = 0.004$), taste ($p = 0.029$), texture ($p = 0.034$), and overall acceptability ($p < 0.001$), but not aroma ($p = 0.371$). F3 scored highest on all attributes (overall acceptability 4.032) and showed the highest protein (4.32%), crude fiber (2.26%), and flavonoids (78.08 mg QE/100 g), with the lowest IC_{50} (11.29 ppm). Lead remained ≤0.001 mg/kg throughout.

Conclusion: Increasing juice proportion to 60 mL improved nutritional-bioactive quality and sensory acceptability concurrently. F3 performed best within the tested range, though not necessarily optimally, as it coincided with the upper boundary tested. Given its modest micronutrient contribution, the product suits dietary diversification rather than targeted micronutrient intervention. Efficacy in stunted children requires direct evaluation.

1. INTRODUCTION

Stunting is a form of chronic linear growth impairment characterized by a height-for-age z-score (HAZ) below −2 standard deviations according to the World Health Organization (WHO) Child Growth Standards. It reflects the cumulative effects of inadequate nutrient intake, recurrent infections, and exposure to adverse social, economic, environmental, and caregiving conditions during the critical first 1,000 days of life[1]. The consequences of stunting extend beyond impaired physical growth and are associated with delayed cognitive and motor development, increased susceptibility to illness, impaired learning capacity,

and reduced productivity and economic potential in adulthood. Thus, stunting should not be regarded solely as an indicator of inadequate nutritional intake but rather as a complex manifestation of health and developmental inequalities with potential intergenerational consequences [add recent primary or review references[2].

Globally, approximately 150.2 million children under five years of age were estimated to be stunted in 2024 (WHO, 2025). In Indonesia, the national prevalence of stunting declined from 21.5% in 2023 to 19.8% in 2024 (Ministry of Health of the Republic of Indonesia, 2024)[3]. Despite this progress, stunting remains a substantial public health burden, with considerable disparities across regions. These persistent disparities highlight the need for intervention strategies that extend beyond increasing nutrient intake and also address the availability, affordability, safety, sustainability, and cultural acceptability of locally available food resources[4,5]. The development of supplementary foods for children at risk of or experiencing growth faltering presents challenges that extend beyond formulating products with high nutrient density[6–8]. The biological effectiveness of a food-based intervention ultimately depends on the amount consumed and the consistency of consumption under real-world conditions. Accordingly, product characteristics—including physical form, texture, color, aroma, taste, portion size, stability, microbiological and chemical safety, and sensory acceptability—are critical determinants of sustained consumption. From a food-based intervention perspective, compliance should therefore be considered an integral component of intervention effectiveness rather than merely an additional product attribute[9]. Jelly- or gummy-based matrices have attracted interest in this context because they are convenient, readily consumed, require no additional preparation, and can be formulated to incorporate a range of nutrients and bioactive food components[10,11]. For example, the development of the multivitamin–mineral jelly candy "Previmin" demonstrated the feasibility of using a jelly matrix as a vehicle for nutrient delivery, although sensory characteristics and safety require optimization according to the formulation and target population (Ryveka et al., 2023).

Similarly, studies of jelly products formulated with marine-derived ingredients have shown that variations in ingredient composition can simultaneously influence proximate composition and organoleptic characteristics (Matti et al., 2024). These findings suggest that the development of jelly-based functional foods requires an integrated formulation strategy that considers nutritional value, bioactive potential, safety, and consumer acceptability. Within the context of locally sourced food diversification, *Launaea sarmentosa* (Willd.) Sch.Bip. ex Kuntze, locally known as sea lettuce or *sawi laut*, represents a potentially valuable underutilized coastal plant resource[12–15]. This species is a coastal herb adapted to tropical sandy environments and has traditionally been consumed as a vegetable by several coastal communities. Its nutritional and functional potential is of particular interest because phytochemical investigations have identified a range of bioactive compounds, particularly phenolic and flavonoid constituents, including caffeic acid, ferulic acid, apigenin, luteolin, quercetin, and rutin[16,17]. This phytochemical profile is consistent with previous reports documenting flavonoids and phenolic compounds in *L. sarmentosa* leaves, together with proteins and amino acids that further support its potential as a functional food resource. [18,19]. In addition to its nutritional constituents, antioxidant activity has been reported for *L. sarmentosa* extracts, indicating potential biological properties that may provide added value beyond its contribution of macronutrients and micronutrients[19–21].

In Aceh, Indonesia, *L. sarmentosa* is traditionally consumed as a vegetable, including in the local dish *sambai sawi laot*, providing an established cultural context for its use as food. Previous local research has also explored its potential as an ingredient for processed food products. Its relatively abundant availability in coastal areas, status as an underutilized food resource, and potential integration into local food systems make *L. sarmentosa* a promising candidate for the development of value-added food products. Nevertheless, the presence of bioactive compounds in a plant material does not, by itself, establish its suitability as an ingredient for foods intended for children. The development of *L. sarmentosa*-based food products requires comprehensive characterization encompassing nutritional composition, mineral content, antioxidant activity, phytochemical constituents, chemical safety, and sensory acceptability. This consideration is particularly important for plants growing in coastal ecosystems, where exposure to environmental contaminants, including heavy metals, may represent a potential food safety concern[21]. Safety assessment should therefore be considered alongside the potential nutritional and functional benefits of the plant. Moreover, food processing may alter the physicochemical properties and bioactive capacity of plant-derived ingredients, while increasing the proportion of plant material within a jelly matrix may substantially affect color, taste, aroma, texture, and, ultimately, consumer acceptance. Comprehensive evaluation of both the raw material and the final product is therefore necessary to ensure that improvements in functional value are not achieved at the expense of product safety or acceptability. Although research on the chemical composition and biological activities of *L. sarmentosa* has increased, evidence regarding its application as an ingredient in supplementary jelly-based foods remains limited[22,23]. In particular, there is a lack of integrated evidence examining how different proportions of *L. sarmentosa* in jelly formulations affect proximate composition, mineral profiles, antioxidant capacity, total flavonoid content, lead (Pb) contamination, and sensory acceptability[23,24]. This evidence

gap represents a translational gap between the documented bioactive potential of the plant and the development of a food product that is nutritionally relevant, safe, and acceptable for consumption. Consequently, formulation research should move beyond assessments limited to the nutrient composition or antioxidant activity of the raw plant material toward a multidimensional evaluation of the final food product. Such an approach enables the identification of formulations that achieve an optimal balance among nutritional value, bioactive potential, chemical safety, and sensory acceptability—key prerequisites before further development and evaluation in the intended target population. Against this background, the present study developed and evaluated three jelly candy formulations containing different proportions of *L. sarmentosa*. The study aimed to characterize the proximate composition, mineral profile, antioxidant capacity, total flavonoid content, and lead (Pb) contamination of each formulation and to assess sensory acceptability among semi-trained panelists. By integrating nutritional, functional, safety, and sensory parameters, this study provides an initial evidence base for the development of *L. sarmentosa*-based value-added food products and their potential future application within locally sourced, food-based strategies to support efforts to prevent and address childhood stunting.

2. MATERIALS AND METHODS

Study Design and Product Development

This experimental study employed a one-factor Completely Randomized Design (CRD) to develop *Launaea sarmentosa* jelly candy. Three formulations containing different proportions of *L. sarmentosa* juice were prepared: F1 (40 mL), F2 (50 mL), and F3 (60 mL), with three independent production replicates. The study was conducted from March to July 2026 at the Food Processing Laboratory and Organoleptic Testing Room, Department of Nutrition, Poltekkes Kemenkes Aceh, Indonesia. Chemical and mineral analyses were performed at the Integrated Laboratory of Poltekkes Kemenkes Aceh and Universitas Syiah Kuala.

Raw Material and Extract Preparation

Launaea sarmentosa was collected from the coastal areas of Lampuuk and Lhoknga, Lhoknga Subdistrict, Aceh Besar Regency, Aceh Province (approximately 5°28'N, 95°14'E). Botanical identity was authenticated at the Herbarium, Department of Biology, Universitas Syiah. Only fresh, uniformly green leaves free from physical damage and pest infestation were used. Leaves were harvested between 07:00 and 09:00 WIB and processed within 4 h of harvest to minimize degradation of thermolabile compounds. Leaves were separated from stalks, washed under running water, and drained. A 1,000 g portion was blanched at 90 ± 2 °C for 5 min, immediately cooled in iced water (≈4 °C) for 2 min to inactivate enzymes, and drained. Blanched leaves were homogenized in a blender for 5 min at a material-to-water ratio of 1:1.5 (w/v). The resulting slurry was filtered through an 80-mesh cloth, and the filtrate was used as the sea lettuce extract. Extract yield was calculated as the percentage of filtrate weight relative to initial fresh leaf weight. Extract not used immediately was stored at 4 °C and used within 24 h.

Formulation and Preparation of Jelly Candy

Three formulations were prepared by varying the extract volume: 40 mL (F1), 50 mL (F2), and 60 mL (F3). Water volume was adjusted proportionally to maintain a constant total liquid phase of 160 mL across formulations, ensuring that observed differences were attributable to extract proportion rather than to variation in total soluble solids. All other components were held constant (Table 1).

Table 1. Composition of three sea lettuce jelly candy formulations

Component	F1	F2	F3
Sea lettuce extract (mL)	40	50	60
Water (mL)	120	110	100
Liquid fructose (mL)	40	40	40
Sucrose (g)	100	100	100
Plain agar (g)	2	2	2
Plain gelling agent (g)	2	2	2
Halal-certified gelatin (g)	3	3	3
Liquid vanilla (mL)	2	2	2
Citric acid (g)	1	1	1

Gelatin was first rehydrated in 30 mL of warm water (≈60 °C) until fully dissolved. Sucrose, fructose, the remaining water, agar, gelling agent, and gelatin solution were combined, homogenized, and heated to boiling. Sea lettuce extract, vanilla, and citric acid were added at the final stage to limit thermal exposure of phenolic compounds, and the mixture was cooked for approximately 15 min to a final temperature of 103–105 °C, corresponding to 65 ± 2 °Brix (digital refractometer). The mixture was poured into silicone molds, cooled at ambient temperature (≈27 °C) for 60 min, demolded, air-dried for 12 h, and packaged in airtight polypropylene pouches. Each batch yielded approximately 18 units with a mean weight of 8.5 g. The entire process was replicated three times.

Laboratory Analyses

Moisture, ash, crude fat, crude protein, and crude fiber were determined according to AOAC International (2019, 21st ed.) methods 925.10, 923.03, 920.39, 984.13, and 962.09, respectively. Carbohydrates were calculated by difference. Zn, Fe, and Pb concentrations were determined by atomic absorption spectrophotometry (Shimadzu AA-7000, Japan) following wet digestion with HNO_{34} (4:1). Measurements were conducted at 213.9, 248.3, and 283.3 nm for Zn, Fe, and Pb, respectively. Calibration curves had $R^2 \geq 0.995$. Pb concentrations were compared with the applicable maximum limits established by Indonesian Food and Drug Authority Regulation No. 9 of 2022. Antioxidant activity was assessed using the DPPH radical-scavenging assay. Samples were extracted with 80% methanol (1:10, w/v) for 24 h in the dark. Extracts were reacted with 0.1 mM DPPH and incubated for 30 min, followed by absorbance measurement at 517 nm. Ascorbic acid was used as the positive control. Antioxidant activity was expressed as percentage inhibition and IC_{50}.

Total flavonoid content was determined using the aluminum chloride colorimetric method, with quercetin as the standard. Absorbance was measured at 415 nm, and results were expressed as mg quercetin equivalents (QE)/100 g. All laboratory analyses were performed in triplicate and expressed as mean ± SD.

Sensory Evaluation

Sensory acceptability was evaluated by 60 semi-trained panelists aged 18–25 years. Panelists were recruited based on general health, normal taste and olfactory function, absence of known allergies to product ingredients, and willingness to participate. Written informed consent was obtained before testing. Color, aroma, taste, texture, and overall acceptability were evaluated using a five-point hedonic scale (1 = dislike very much; 5 = like very much). Samples were coded with random three-digit numbers and presented in randomized order. Each panelist evaluated one approximately 8.5-g piece of each formulation, with mineral water provided for palate cleansing between samples. Testing was conducted under controlled room conditions, and the formulation composition was not disclosed to panelists.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics version 26. Results were expressed as mean ± SD. Normality and homogeneity were assessed using the Shapiro–Wilk and Levene tests, respectively. Differences among formulations were analyzed using one-way ANOVA followed by Duncan's multiple range test. When parametric assumptions were not met, the Kruskal–Wallis test followed by Bonferroni-adjusted Mann–Whitney U tests was used. Statistical significance was set at $p < 0.05$. The optimal formulation was determined using the De Garmo effectiveness index based on weighted sensory and laboratory parameters.

Ethical Considerations

The study was approved by the Health Research Ethics Committee of Poltekkes Kemenkes Aceh (No. DP.04.03/12.7/123/2026; 5 March 2026). All panelists provided written informed consent before participation.

3. RESULTS

3.1. Nutritional Characteristics of Fresh *Launaea sarmentosa*

The proximate and mineral composition of fresh *Launaea sarmentosa* leaves is presented in Table 2. The leaves contained 83.99% moisture, 5.54% protein, 7.71% crude fiber, 2.11% ash, 0.65% crude fat, and 2.81% carbohydrate. The high moisture content is consistent with the characteristics of fresh leafy vegetables and indicates the perishable nature of the raw material, supporting the need for prompt processing following harvest. The protein content of 5.54% on a fresh-weight basis corresponds to approximately 34.6% on a dry-weight basis, indicating a relatively high protein concentration compared with many conventional leafy vegetables. The crude fiber content (7.71%) further suggests a substantial structural carbohydrate fraction. These

characteristics support the potential use of *L. sarmentosa* as a value-added plant ingredient, although the transfer of nutrients from the raw material into the final jelly product may be affected by filtration and processing losses.

Table 2. Proximate and mineral composition of fresh *L. sarmentosa* leaves

Parameter	Unit	Value
Moisture	%	83.99
Ash	%	2.11
Crude fat	%	0.65
Protein	%	5.54
Crude fiber	%	7.71
Carbohydrate	%	2.81
Zinc (Zn)	mg/100 g	14.6
Iron (Fe)	mg/100 g	5.5
Lead (Pb)	mg/kg	0.001

The mineral profile was characterized by Zn and Fe concentrations of 14.6 and 5.5 mg/100 g, respectively. These values indicate that *L. sarmentosa* may represent a potentially useful plant source of these minerals. Zinc is involved in cellular proliferation, protein synthesis, and growth-related physiological processes, whereas iron is essential for hemoglobin synthesis and normal cognitive and developmental function. However, the nutritional relevance of these minerals cannot be inferred from total concentration alone. Their physiological contribution depends on bioaccessibility and absorption, which may be influenced by phytate, oxalate, phenolic compounds, and other antinutritional factors. Therefore, further assessment of mineral bioaccessibility and relevant molar ratios would be required to establish the nutritional significance of the mineral profile. Lead was detected at 0.001 mg/kg in the fresh leaves. This low concentration provides an initial indication of limited Pb contamination in the samples collected from Lampuuk and Lhoknga. Nevertheless, because heavy-metal accumulation in coastal plants can vary spatially according to sediment characteristics and anthropogenic inputs, this finding should not be generalized to other harvesting locations without additional monitoring.

3.2. Sensory Acceptability of *L. sarmentosa* Jelly

The sensory scores of the three jelly formulations are presented in Table 3. Formula III (60 mL *L. sarmentosa* juice) consistently obtained the highest mean scores across all evaluated attributes.

Table 3. Sensory acceptability scores of *L. sarmentosa* jelly formulations

Attribute	F1 (40 mL)	F2 (50 mL)	F3 (60 mL)	F	*p*
Color	3.150	3.417	3.630	5.759	0.004
Taste	3.652	3.663	3.907	3.605	0.029
Aroma	3.522	3.568	3.688	0.997	0.371
Texture	3.392	3.408	3.695	3.449	0.034
Overall acceptability	3.467	3.740	4.032	14.904	<0.001
Mean across attributes	3.437	3.559	3.790	–	–

One-way ANOVA indicated significant differences among formulations for color ($p = 0.004$), taste ($p = 0.029$), texture ($p = 0.034$), and overall acceptability ($p < 0.001$), whereas aroma did not differ significantly ($p = 0.371$). The consistently higher scores observed for F3 suggest that increasing the proportion of *L. sarmentosa* juice within the tested range did not compromise sensory acceptance. The absence of a decline in acceptability at the highest tested concentration may be related to the processing conditions and formulation matrix. Blanching may have reduced enzymatic activity and some undesirable green-leaf volatiles, while the relatively high sugar content, vanilla, and citric acid may have moderated vegetal and bitter sensory notes. However, these mechanisms were not directly measured in the present study and should therefore be regarded as plausible explanations

rather than demonstrated causal effects. Color showed a significant increase in acceptance from F1 to F3. The darker green appearance associated with the higher proportion of *L. sarmentosa* may have been perceived positively as a visual indicator of the product's plant-based identity. Overall acceptability exhibited the largest statistical difference among the evaluated attributes, with F3 achieving a mean score above 4.0, corresponding to "like" on the five-point hedonic scale. Importantly, the highest sensory scores were obtained at the upper boundary of the experimental range. Therefore, 60 mL should be interpreted as the best-performing formulation within the tested range, rather than as the absolute sensory optimum. Further formulation studies using concentrations above 60 mL would be required to determine whether acceptance increases further or eventually declines.

3.3. Proximate Composition, Bioactive Properties, and Mineral Content of Jelly

The chemical characteristics of the three jelly formulations are shown in Table 4.

Table 4. Chemical composition, antioxidant activity, and mineral content of *L. sarmentosa* jelly

Parameter	Unit	F1	F2	F3
Moisture	%	16.22	14.22	17.23
Ash	%	0.29	0.31	0.25
Crude fat	%	0.31	0.27	0.11
Protein	%	3.99	4.14	4.32
Crude fiber	%	1.25	1.78	2.26
Antioxidant activity (IC_{50})	ppm	17.94	16.35	11.29
Total flavonoids	mg/100 g	53.57	65.82	78.08
Zinc (Zn)	mg/100 g	1.70	1.14	1.14
Iron (Fe)	mg/100 g	1.0	1.0	1.1
Lead (Pb)	mg/kg	0.001	0.001	<0.001

Protein and crude fiber increased progressively with increasing *L. sarmentosa* incorporation. Protein increased from 3.99% in F1 to 4.32% in F3, whereas crude fiber increased from 1.25% to 2.26%. This pattern is consistent with the contribution of the plant material to the final product and provides evidence that variation in juice proportion was reflected in selected nutritional characteristics. A similar concentration-dependent pattern was observed for total flavonoid content, which increased from 53.57 mg QE/100 g in F1 to 65.82 mg QE/100 g in F2 and 78.08 mg QE/100 g in F3. The progressive increase suggests that greater incorporation of *L. sarmentosa* resulted in higher retention of flavonoid compounds in the jelly matrix. Nevertheless, the extent of flavonoid retention cannot be determined without comparing the concentration in the raw juice with that in the processed product. Antioxidant activity showed an inverse pattern, with IC_{50} values decreasing from 17.94 ppm in F1 to 11.29 ppm in F3. Because lower IC_{50} values indicate greater radical-scavenging potency, F3 exhibited the strongest DPPH-scavenging activity among the formulations. The concurrent increase in total flavonoid content and reduction in IC_{50} suggests an association between flavonoid concentration and antioxidant activity. However, correlation alone does not establish flavonoids as the sole contributors because other phenolic compounds and processing-derived antioxidants may also contribute to DPPH radical scavenging. Moisture content varied from 14.22% to 17.23% without a consistent relationship with *L. sarmentosa* concentration. This variation may reflect differences in evaporation and drying conditions between batches. Standardizing the endpoint based on °Brix and water activity rather than heating time alone would therefore be useful for improving process reproducibility. Ash and crude fat also showed no consistent concentration-dependent pattern. Interestingly, Zn concentration was highest in F1 (1.70 mg/100 g) and remained lower in F2 and F3 (1.14 mg/100 g), despite the higher proportion of *L. sarmentosa*. This unexpected pattern should be interpreted cautiously. Possible explanations include analytical variability, heterogeneous mineral distribution, differences in solid retention during filtration, or matrix-related effects during digestion. Because replicate variability and recovery data are not presented, the current results do not permit discrimination among these possibilities. Fe concentration was comparatively stable across formulations (1.0–1.1 mg/100 g), suggesting limited variation associated with the treatment level. Pb concentrations were 0.001 mg/kg in F1 and F2 and below the detection limit in F3. These concentrations indicate that increasing *L. sarmentosa* incorporation within the tested range did not result in detectable Pb accumulation in the

final product. The results support the chemical safety of the formulations with respect to Pb under the conditions evaluated.

4. DISCUSSION

This study demonstrated that increasing the proportion of *Launaea sarmentosa* juice from 40 to 60 mL improved selected nutritional and bioactive characteristics without compromising sensory acceptability. The raw material contained 5.54% protein, 7.71% crude fiber, and 14.6 mg/100 g Zn, indicating considerable nutritional potential as an underutilized coastal food resource. However, the relatively high protein value should be interpreted cautiously because the Kjeldahl method measures total nitrogen rather than true protein. Similarly, the high mineral content does not necessarily indicate high physiological availability because phytate, oxalate, and phenolic compounds may limit mineral absorption [insert citation]. Sensory evaluation showed significantly higher scores for color, taste, texture, and overall acceptability as *L. sarmentosa* incorporation increased, whereas aroma did not differ significantly ($F = 0.997$, $p = 0.371$). The absence of reduced acceptability at the highest concentration may reflect the effects of blanching, which could reduce enzymatic formation of grassy green-leaf volatiles, together with the masking and flavor-balancing effects of vanilla, citric acid, and the high-solids jelly matrix. These mechanisms, however, were not directly measured and should therefore be regarded as plausible explanations rather than established causal effects.

The significant improvement in color suggests that the more intense green appearance may have reinforced the product's plant-based identity. Overall acceptability showed the strongest response ($F = 14.904$, $p < 0.001$), with F3 achieving a score of 4.032. Nevertheless, because 60 mL represented the highest concentration tested, F3 should be considered the **best-performing formulation within the tested range**, rather than the definitive sensory optimum. Further optimization using a broader concentration range or response-surface methodology is warranted. Increasing *L. sarmentosa* incorporation was also associated with higher protein and crude fiber contents and a marked increase in total flavonoids, from 53.57 to 78.08 mg QE/100 g. This increase was accompanied by a reduction in DPPH IC_{50} from 17.94 to 11.29 ppm, indicating greater *in vitro* radical-scavenging activity in F3. The parallel responses of flavonoid content and antioxidant activity support an association between the plant-derived phenolic fraction and antioxidant capacity. However, DPPH activity cannot be attributed exclusively to flavonoids because other reducing compounds, including phenolic acids and processing-derived Maillard products, may contribute.

Moreover, *in vitro* antioxidant activity should not be interpreted as evidence of physiological antioxidant or health effects in humans. Several parameters showed no clear concentration-dependent response. Moisture varied from 14.22% to 17.23%, potentially reflecting differences in evaporation and drying conditions, whereas fat remained consistently low. Zn concentration unexpectedly decreased from 1.70 mg/100 g in F1 to 1.14 mg/100 g in F2 and F3. This pattern cannot be conclusively explained without replicate variability, recovery data, and mineral measurements in both the juice and filtration residue. Fe remained relatively stable at 1.0–1.1 mg/100 g. These findings emphasize that incorporation of a plant ingredient does not necessarily result in proportional nutrient retention in the final product. From a safety perspective, Pb concentrations remained at or below 0.001 mg/kg, with F3 below the detection limit, indicating no evidence of Pb accumulation within the tested formulations. Nevertheless, this result applies to the sampled material and should not be interpreted as evidence that *L. sarmentosa* is inherently resistant to heavy-metal accumulation. Given its coastal origin, future studies should include multi-site sampling and surveillance of additional contaminants such as Cd, Hg, and As[25] At an average unit weight of 8.5 g, one jelly provides approximately 6.6 mg flavonoids, 0.10 mg Zn, and 0.09 mg Fe. Thus, the product is more appropriately positioned at this stage as a vehicle for dietary diversification and plant-derived bioactive compounds rather than as a stand-alone micronutrient intervention. Its potential application should also be interpreted in light of several limitations, including the use of adult semi-trained panelists rather than children, absence of shelf-life and microbiological assessments, high sugar content, lack of mineral bioaccessibility data, and limited inferential interpretation of laboratory parameters because replicate variability was not reported[26]. F3 demonstrated the most favorable combination of sensory acceptance, nutritional characteristics, flavonoid content, antioxidant activity, and Pb safety within the tested range. Further research should extend the formulation range, quantify nutrient and phytochemical retention during processing, assess bioaccessibility and product stability, and evaluate acceptance among the intended pediatric population before progression to controlled nutritional or efficacy studies.

5. CONCLUSION

This study demonstrated the feasibility of developing jelly candy incorporating *Launaea sarmentosa* juice at 40, 50, and 60 mL, with increasing incorporation generally associated with improved nutritional, bioactive, and sensory characteristics. Fresh *L. sarmentosa* leaves contained 5.54% protein and 14.6 mg/100 g Zn, while Pb was detected at a low concentration (0.001 mg/kg). Among the formulations, F3 (60 mL) exhibited the highest protein (4.32%), crude fiber (2.26%), and total flavonoid content

(78.08 mg QE/100 g), together with the lowest DPPH IC_{50} (11.29 ppm) and the highest sensory acceptance. Pb concentrations remained at or below 0.001 mg/kg across all formulations, with no evidence of concentration-dependent accumulation. Overall, F3 was the best-performing formulation within the tested concentration range**,** demonstrating a favorable balance between compositional quality, *in vitro* antioxidant activity, sensory acceptance, and Pb safety. However, 60 mL should not be interpreted as the definitive formulation optimum because it represented the upper limit of the concentrations evaluated. Moreover, the product should currently be regarded as a potential vehicle for dietary diversification and delivery of plant-derived bioactive compounds rather than as a stand-alone micronutrient intervention. Further studies should establish nutrient retention and bioaccessibility, physicochemical and microbiological stability, the optimum formulation beyond 60 mL, and acceptability among the intended pediatric population before its potential use as a supplementary food for children with growth faltering can be evaluated.

DECLARATIONS

Ethics approval and consent to participate. This study was approved by the Health Research Ethics Committee of Politeknik Kesehatan Kementerian Kesehatan Aceh (approval number DP.04.03/12.7/123/2026, dated 5 March 2026). All panelists received verbal and written information regarding the objectives, procedures, and potential risks of the study, and provided written informed consent prior to participation. Participation was voluntary, and panelists were free to withdraw at any stage without consequence. The study was conducted in accordance with the principles of the Declaration of Helsinki. No animal subjects were involved in this research.

Trial registration. Not applicable. This study was a laboratory-based food product development study and did not constitute a prospective clinical trial.

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Conflicts of interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability. The datasets generated and analyzed during the current study — comprising the de-identified hedonic scores obtained from the 60 semi-trained panelists and the complete laboratory analysis reports for the raw material and all three formulations — are available from the corresponding author upon reasonable request. Statistical analyses were performed using IBM SPSS Statistics version 26 (IBM Corp., Armonk, NY, USA); no custom analysis code was generated for this study.

Author contributions. Author contributions are described in accordance with the CRediT taxonomy. Ampera Miko: Conceptualization; Methodology; Supervision; Project administration; Writing – review and editing. Rachmawati: Methodology; Investigation; Formal analysis; Writing – original draft. Andriani M.S.: Investigation; Validation; Data curation. Wiqayatun Khazanah: Investigation; Formal analysis; Writing – original draft. Iskandar: Methodology; Validation; Writing – review and editing. Abdul Hadi: Formal analysis; Visualization; Writing – review and editing. Susi Andayani: Investigation; Data curation; Writing – review and editing. All authors have read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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