



Nutritional Retention and Sensory Properties of Novel Tropical Vegetable Juice Formulations Prepared via Non-Thermal Processing

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ABSTRACT: The development of functional beverages derived from tropical vegetables offers growing potential within the global health-focused food sector. This study formulated and evaluated three non-thermally processed Tropical Vegetable Juice Formulations (TVJF) using *Ipomoea aquatica* (kangkung) as the primary raw material. The objectives were to compare nutrient retention between juice and raw leaves, assess consumer sensory acceptance across different formulations, and evaluate commercialisation potential. Proximate and mineral analyses were conducted on TVJF-K and compared with raw vegetable samples using standard AOAC methods, while sensory evaluation of three formulations (TVJF-1, TVJF-2, and TVJF-3) employed a 5-point hedonic scale assessing colour, aroma, texture/stability, flavour, and overall acceptance among 30 untrained panelists. Results indicated that the juice retained approximately 80–95% of key minerals, particularly calcium, magnesium, iron, and copper, demonstrating effective preservation through non-thermal cold extraction. Sensory analysis revealed no significant differences ($p > 0.05$) in colour, aroma, flavour, or overall acceptance among formulations, although texture/stability differed significantly ($p = 0.02$). All formulations achieved mean scores above 3.0, indicating favourable consumer acceptance. These findings demonstrate that simple non-thermal processing can maintain both nutritional integrity and sensory quality in tropical vegetable juices, highlighting strong potential for industrial application, product diversification, and expansion within the regional functional beverage market.

KEYWORDS: Tropical vegetables, *Ipomoea aquatica*, non-thermal processing, vegetable juice formulation, nutrient retention, sensory evaluation, functional beverage.

1. INTRODUCTION

The global demand for functional beverages has increased significantly in recent years, driven by heightened consumer awareness of health, nutrition, and plant-based dietary practices. As preventive health behaviours become more prevalent, interest in nutrient-dense beverages enriched with natural bioactive compounds has expanded, accelerating the growth of the functional beverage sector (Gupta et al., 2023). Fruit- and vegetable-based beverages are particularly valued for their antioxidant properties, micronutrient density, and potential contribution to reducing nutrition-related non-communicable diseases. Comparable consumption trends are observed in Southeast Asia, where urbanisation, evolving lifestyles, and post-pandemic health priorities have intensified demand for convenient, minimally processed beverages with enhanced nutritional value (RetailAsia, 2024).

Despite this expansion, the development of fresh or minimally processed vegetable-based beverages remains limited in many tropical countries. Tropical leafy vegetables are traditionally consumed in cooked form, and common preparation methods—such as boiling, steaming, stir-frying, and blanching—often result in the loss of heat-sensitive vitamins and phytochemicals (Zia et al., 2024). Although thermal processing techniques such as pasteurisation improve microbial safety and shelf life, they may also lead to nutrient degradation, colour modification, and reduced sensory quality (Kisi Jeevitha, 2023). These challenges have stimulated increasing interest in non-thermal processing approaches capable of preserving nutritional integrity and fresh-like sensory attributes. Non-thermal technologies—including high-pressure processing (HPP), pulsed electric fields (PEF), ultrasonication, membrane filtration, and cold extraction—have demonstrated strong potential in maintaining food quality and nutrient stability (Al-Sharify et al., 2025). Such techniques are particularly effective in protecting thermolabile compounds such as vitamin C, polyphenols, pigments, and flavour precursors. However, advanced non-thermal systems often require substantial capital investment and technical

expertise, limiting their accessibility to small- and medium-scale producers in developing regions. Consequently, simpler non-thermal methods, including mechanical grinding and cold filtration, remain practical alternatives for supporting nutrient retention and preserving natural vegetal characteristics (Kaur et al., 2024).

Malaysia possesses a wide variety of tropical leafy vegetables, among which *Ipomoea aquatica* (water spinach or kangkung) is widely cultivated and consumed (Figure 1). This vegetable is recognised for its high content of iron, calcium, magnesium, dietary fibre, carotenoids, chlorophylls, and bioactive phytochemicals with antioxidant properties. Its affordability, year-round availability, and cultural acceptance make it a suitable candidate for functional beverage development aimed at enhancing micronutrient intake and diversifying vegetable consumption patterns.



Figure 1. Fresh *Ipomoea aquatica* (water spinach or kangkung)

Although Malaysia possesses a strong agricultural base and abundant supply of tropical leafy vegetables, commercially produced fresh vegetable juices—particularly those derived from tropical greens—remain limited in the domestic market. Market analyses indicate growing consumer preference for clean-label beverages with minimal additives and processing, emphasising natural flavour, colour, and nutritional integrity (FoodNavigator, 2024). Younger and health-conscious urban consumers, in particular, increasingly favour vegetable-based beverages as alternatives to sugar-sweetened or artificially flavoured drinks. Despite this demand, the scarcity of non-thermally processed *Ipomoea aquatica* beverages suggests existing gaps in product innovation, technology adoption, and scalable production models.

Previous Malaysian studies evaluating fresh vegetable juices, including those derived from *I. aquatica*, have reported favourable nutritional characteristics and acceptable sensory outcomes. However, many investigations were primarily descriptive, focused on single formulations, and lacked comparative formulation analysis, structured sensory validation, and rigorous nutritional benchmarking. Furthermore, limited application of inferential statistical techniques—such as analysis of variance (ANOVA), post-hoc testing, and effect-size reporting—has restricted deeper interpretation of formulation differences and consumer perception variability.

To address these limitations, the present study formulates and evaluates Tropical Vegetable Juice Formulations (TVJF) derived from *Ipomoea aquatica* using a standardised non-thermal cold extraction method. The objectives are to: (i) quantify nutrient retention in juice relative to raw vegetable tissue, (ii) assess consumer sensory acceptance across multiple formulations, and (iii) evaluate the commercialisation feasibility of the product. The selection of *I. aquatica* is based on its nutritional richness, cultural relevance, affordability, and potential to enhance micronutrient intake through beverage-based consumption. Converting this commonly cooked vegetable into a juice format may also broaden dietary accessibility, particularly for children, older adults, and individuals with limited vegetable intake preferences.

By integrating nutritional analysis with comparative sensory evaluation and statistical validation, this study contributes empirical evidence supporting the development of minimally processed tropical vegetable beverages. The findings provide practical insights for product innovation, small- and medium-scale enterprise (SME) adoption, and regional functional beverage market expansion.



2. MATERIALS AND METHODS

2.1 Raw Materials and Sampling

Fresh *Ipomoea aquatica* (water spinach) was selected due to its high availability, nutritional richness, and common utilisation within Southeast Asian diets. All samples were sourced from a commercial supplier in Kuantan, Malaysia, and transported to the laboratory within 2 hours of harvesting. Only fresh, undamaged, and pest-free leaves were selected, while wilted, yellowing, or damaged leaves were removed to minimise sample variability.

The vegetables were washed thoroughly under running water to eliminate soil, debris, and potential chemical residues, followed by removal of excess moisture using sterile absorbent paper. For nutrient analysis, raw *I. aquatica* leaves were standardised at 100 g per batch. All analyses were conducted in triplicate to ensure reproducibility and analytical reliability.

2.2 Preparation of Tropical Vegetable Juice Formulations (TVJF)

Three Tropical Vegetable Juice Formulations (TVJF) were developed using a simple non-thermal extraction method. Non-thermal processing was selected to preserve heat-sensitive nutrients such as vitamin C, polyphenols, flavonoids, and minerals, while retaining fresh sensory characteristics.

2.2.1 Non-thermal cold extraction method

Fresh *I. aquatica* leaves were chopped into 2–3 cm segments and processed using a cold mechanical grinder operating at 12,000 rpm for 2 minutes without heat generation. The extraction ratio was standardised at 1:1 (100 g leaves per 100 mL chilled distilled water). The blended slurry was filtered through sterile muslin cloth to remove fibrous residues, and the resulting filtrate was used immediately for further formulation.

2.2.2 Formulation and mixing

Three juice formulations (TVJF-1, TVJF-2, TVJF-3) were produced by adjusting the dilution ratio, glucose syrup concentration, and natural flavouring levels. All formulations contained:

- Fresh *I. aquatica* extract
- Distilled water
- Glucose syrup
- Natural flavouring agents
- Food-grade stabilisers (<0.1%)

No heat treatment, pasteurisation, or thermal processing was applied during any stage of preparation.

2.2.3 Bottling and storage

Juices were dispensed into sterilised 100 mL PET bottles under aseptic conditions. Samples used for sensory evaluation were produced fresh on the same day. Samples intended for nutrient analysis were stored at 4°C and analysed within 24 hours to minimise compositional changes.

2.3 Nutritional and Chemical Analysis

Nutritional analysis was performed on *I. aquatica* juice (TVJF-K) and compared with the raw leaves.

2.3.1 Proximate composition

Proximate analyses were performed according to AOAC (2019) standard procedures. Moisture content was determined by oven drying at 105°C; protein content was quantified using the Kjeldahl nitrogen method; fat content was measured via Soxhlet extraction; and ash content was determined by muffle furnace combustion at 550°C. Carbohydrate content was calculated by difference. All results were expressed per 100 g of sample.

2.3.2 Mineral composition

Mineral contents—including calcium (Ca), magnesium (Mg), iron (Fe), copper (Cu), and zinc (Zn)—were measured using Atomic Absorption Spectrophotometry (AAS). Calibration curves for each mineral were prepared using certified standard reference solutions (Merck, Germany). All analyses were conducted in triplicate (n = 3), and blanks and standards were run before and after each analytical batch. The coefficient of variation (CV) was maintained below 5%.



2.4 Sensory Evaluation

2.4.1 Panel selection and sensory design

A total of 30 untrained consumer panelists aged 18–60 years were recruited from a university community. Individuals with known allergies to leafy vegetables, glucose intolerance, or taste/smell-related conditions were excluded. Panelists were briefed on evaluation procedures but were blinded to the differences among formulations to minimise expectancy bias.

Sensory evaluation employed a 5-point hedonic scale (1 = dislike very much; 5 = like very much) for the attributes of colour, aroma, texture/stability, flavour, and overall acceptance. Each 30 mL sample was served at 10°C in identical transparent cups coded with randomised three-digit numbers. Panelists rinsed their mouths with plain water between samples. The order of sample presentation was randomised using a Williams Latin Square design to minimise order and carryover effects.

2.5 Statistical Analysis

Descriptive statistics (mean \pm standard deviation) were computed using SPSS Version 27. A one-way Analysis of Variance (ANOVA) was applied to assess differences among formulations for each sensory attribute. When significant differences were observed ($p < 0.05$), Tukey's Honest Significant Difference (HSD) test was conducted for post-hoc comparisons.

Effect size (η^2) was calculated to evaluate the magnitude of formulation differences, with thresholds of 0.01 (small), 0.06 (medium), and 0.14 (large). The assumptions of normality and homogeneity of variance were assessed using the Shapiro–Wilk test and Levene's test, respectively. All analyses adhered to a significance level of $p < 0.05$.

3. RESULTS

3.1 Nutritional Composition of TVJF Compared to Raw *Ipomoea aquatica*

The nutritional analysis of *Ipomoea aquatica* juice (TVJF-K) (Figure 2) showed that non-thermal cold extraction retained a substantial proportion of nutrients relative to the raw leaves.

Table 1 presents the nutrient composition per 100 g of juice compared with raw vegetable tissue.

Table 1. Nutrient composition of *I. aquatica* juice and raw leaves (per 100 g)

Nutrient	Juice	Raw Leaves
Energy (Kcal)	10.7	12.2
Fat (mg)	0.0	0.1
Protein (mg)	1.8	2.4
Carbohydrate (mg)	4.2	2.8
Iron (mg)	4.1	5.2
Copper (mg)	0.1	0.1
Magnesium (mg)	3.1	4.2
Calcium (mg)	27.6	30.0
Zinc (mg)	0.5	0.8

Energy values were comparable between the juice (10.7 kcal) and raw leaves (12.2 kcal), with the slight reduction attributable to fibre removal during filtration. Protein, iron, magnesium, calcium, and zinc levels remained relatively high in the juice, indicating efficient mineral retention during non-thermal extraction. Carbohydrate content was higher in the juice (4.2 mg) due to glucose syrup addition during formulation.

Fat content was negligible in both samples (0.0–0.1 mg), reflecting the naturally low lipid content of leafy vegetables. Overall, the data show that non-thermal extraction preserved the mineral profile effectively, consistent with literature reporting mineral stability under mechanical and non-thermal processes.

Figure 2 illustrates the retention pattern, where TVJF-K maintained approximately 80–95% of the mineral content of raw leaves, with the highest retention observed for copper (100%), calcium (92%), magnesium (88%), and iron (79%).

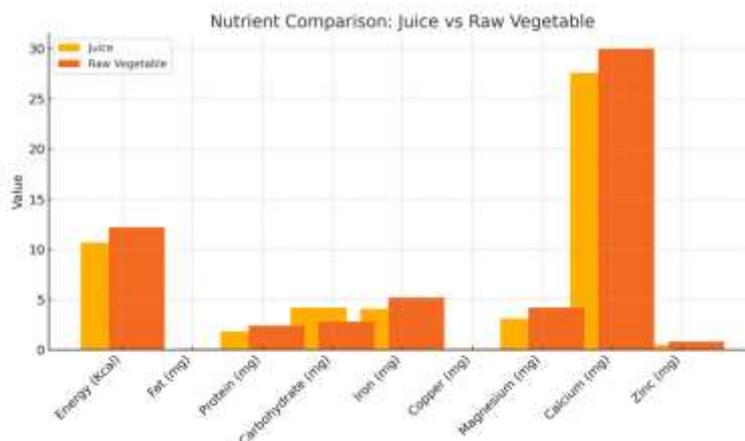


Figure 2. Nutrient comparison chart between juice and raw leaves (TVJF-K).

These findings confirm that TVJF-K maintains key micronutrients and demonstrates the suitability of non-thermal extraction for producing nutrient-dense vegetable beverages.

3.2 Sensory Evaluation of TVJF Formulations

Three formulations (TVJF-1, TVJF-2, TVJF-3) were evaluated for colour, aroma, texture/stability, flavour, and overall acceptance using a 5-point hedonic scale. Table 2 summarises the mean sensory scores (\pm SD) based on data collected from 30 panelists.

Table 2. Mean \pm SD sensory scores for TVJF formulations (n = 30)

Parameter	Formula 1	Formula 2	Formula 3	p-Value
Colour	3.5 \pm 0.8	3.4 \pm 1.1	3.2 \pm 1.1	0.23
Aroma	3.2 \pm 1.1	3.1 \pm 1.0	3.1 \pm 1.1	0.98
Texture/Stability	3.5 \pm 1.0	3.4 \pm 1.1	3.1 \pm 0.9	0.02*
Flavour	3.8 \pm 1.1	3.8 \pm 1.3	3.8 \pm 1.2	0.76
Overall Acceptance	3.3 \pm 1.0	3.3 \pm 1.2	3.0 \pm 0.9	0.21

*Significant at $p < 0.05$.

3.2.1 Colour and Aroma

No significant differences were observed for colour ($p = 0.23$) or aroma ($p = 0.98$). These results indicate that variation in dilution or sweetening levels did not substantially affect pigment stability or aromatic attributes. The similar scores across formulations suggest that non-thermal processing preserved the natural appearance and aroma of *I. aquatica* extracts.

3.2.2 Texture and Stability

Texture/stability was the only attribute with a significant difference among formulations ($p = 0.02$). TVJF-3 exhibited slightly lower texture scores (3.1 ± 0.9) compared with TVJF-1 (3.5 ± 1.0) and TVJF-2 (3.4 ± 1.1). Differences may be related to dilution ratios, viscosity, or sedimentation behaviour due to minimal stabiliser use ($<0.1\%$).

Figure 3 presents the sensory profile of the three formulations across all attributes.

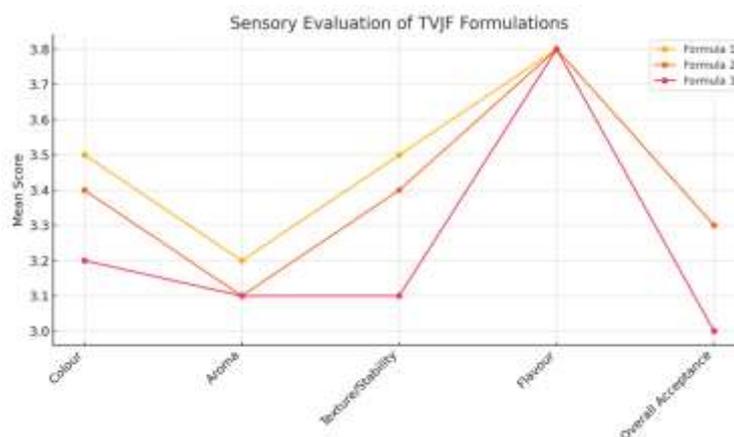


Figure 3. Sensory mean score chart for TVJF-1, TVJF-2, and TVJF-3.

3.3 ANOVA and Effect Size Interpretation

One-way ANOVA revealed that texture/stability was the only attribute significantly affected by formulation differences ($p < 0.05$). Effect size (η^2) analysis further demonstrated:

- Small effect sizes for colour, aroma, flavour, and overall acceptance ($\eta^2 < 0.03$)
- Medium effect size for texture/stability ($\eta^2 \approx 0.058$)

These results indicate that the formulations differed moderately in mouthfeel and sedimentation perception, while variations in sweetness or dilution did not meaningfully influence the other sensory attributes.

3.4 Summary of Key Findings

This study demonstrates that Tropical Vegetable Juice Formulations (TVJF) derived from *Ipomoea aquatica* retain a high proportion of essential minerals (80–95%) following simple non-thermal cold extraction. Sensory evaluation indicates that all three formulations were acceptable to consumers, achieving mean scores ≥ 3.0 across all attributes. Flavour scored highest across formulations, suggesting that mild sweetness complemented the vegetal notes effectively.

Although texture showed significant variation, overall acceptance remained favourable across formulations. These findings highlight the potential of TVJF as a nutrient-dense, minimally processed functional beverage suitable for broader development and future commercial application.

4. DISCUSSION

4.1 Nutrient Retention and the Role of Non-Thermal Processing

The findings of this study demonstrate that simple non-thermal cold extraction is effective in preserving essential minerals in *Ipomoea aquatica* juice. The juice retained approximately 80–95% of calcium, magnesium, iron, zinc, and copper from raw leaves, indicating minimal nutrient degradation during processing. These outcomes align with contemporary evidence suggesting that non-thermal methods better preserve micronutrients compared with traditional heat-based treatments, which are known to degrade heat-sensitive and water-soluble nutrients (Kisi Jeevitha, 2023; Zia et al., 2024).

The high mineral retention observed in TVJF-K supports literature stating that minerals are structurally stable and resistant to loss during mechanical extraction, making cold processing a practical and low-cost option for maintaining nutritional quality, particularly in small-scale or resource-limited settings (Al-Sharify et al., 2025).

4.2 Comparison with Advanced Non-Thermal Technologies

Advanced non-thermal technologies—such as high-pressure processing (HPP), pulsed electric fields (PEF), and ultrasonication—have shown potential in enhancing nutrient stability, microbial safety, and extraction efficiency without compromising sensory attributes (Ağagündüz, 2025; Al-Sharify et al., 2025). These technologies can also improve physicochemical properties such as viscosity and homogeneity.



However, the high cost of equipment, technical capacity requirements, and limited accessibility restrict their adoption by small- and medium-sized enterprises (SMEs). In contrast, this study demonstrates that standardised cold extraction, combined with simple formulation variations, is sufficient to produce a nutritionally meaningful and sensorially acceptable vegetable beverage. Thus, cold extraction offers a realistic, economically feasible alternative for SMEs seeking to innovate within the functional beverage sector (Shinde et al., 2024; Kaur et al., 2024).

4.3 Texture, Stability, and Influence of Formulation Parameters

Of the five sensory attributes evaluated, only texture/stability differed significantly among formulations. This finding is consistent with literature showing that variations in solids content, dilution ratio, and shear forces can influence particle size distribution, sedimentation behaviour, and mouthfeel in minimally processed vegetable juices (Ağagündüz, 2025).

Although TVJF-3 exhibited slightly lower texture scores, overall acceptance remained unaffected, indicating that panelists tolerated minor variations in viscosity and sedimentation. This tolerance suggests potential market acceptance for beverages with natural physical settling—especially within the clean-label category, where consumers increasingly associate visible sedimentation with minimal processing and naturalness.

4.4 Sensory Acceptance and Consumer Drivers

Flavour emerged as the strongest driver of acceptance across the three formulations, consistent with global consumer trends in functional beverages (Gupta et al., 2023; Kaur et al., 2024). The moderate sweetness from glucose syrup appeared to complement the natural vegetal notes of *I. aquatica*, contributing to overall positive flavour ratings.

All formulations achieved mean scores of at least 3.0, indicating broad acceptance even among consumers who may not routinely consume leafy vegetables in beverage form. With functional beverage demand increasing—especially among younger, health-conscious urban populations—*I. aquatica* juice demonstrates strong potential for market viability (FoodNavigator, 2024).

4.5 Shelf-Life and Microbial Stability Considerations

A recognised limitation of cold-extracted beverages is their susceptibility to microbial spoilage. While non-thermal processing preserves nutrients and sensory attributes, it does not inherently extend shelf life (Zia et al., 2024; Al-Sharify et al., 2025). Thus, further work is required to evaluate the microbial stability of TVJF and identify effective preservation strategies.

Potential options include refrigerated storage, mild acidification, incorporation of natural antimicrobial agents, or outsourcing HPP treatment for commercial batches. This study therefore identifies cold extraction as an effective front-end processing strategy, which must be complemented by additional preservation interventions depending on intended distribution and shelf-life requirements (Shinde et al., 2024).

4.6 Implications for SMEs and Scalable Product Development

For SMEs, a hybrid processing model—combining simple cold extraction with mild preservation steps—offers a cost-effective pathway to produce safe, nutrient-dense beverages. Such models have been increasingly reported in recent literature as viable for emerging functional beverage markets (Ağagündüz, 2025; Shinde et al., 2024).

The strong nutrient retention and favourable sensory acceptance demonstrated in this study highlight the feasibility of developing *I. aquatica* juice as a value-added product suitable for local production and commercial scaling, particularly in regions with abundant access to fresh leafy vegetables.

4.7 Contribution to Tropical Vegetable Beverage Research

This study contributes empirical evidence to the limited but growing body of research on tropical leafy vegetables as functional beverage ingredients. Earlier studies tended to focus on descriptive characteristics or single-vegetable evaluations without statistical validation (Hassan, 2011; Rosdi, 2013).

By providing comparative nutrient data, structured sensory evaluation, and ANOVA-based interpretation, the present study enhances methodological robustness and strengthens the evidence base for incorporating *I. aquatica* into functional beverage innovation.

4.8 Synthesis of Practical Implications

Integrating the findings with recent literature, a clear development pathway for *I. aquatica* juice emerges:



1. Use cold extraction to maximise nutrient retention and fresh sensory attributes.
2. Optimise formulation parameters, particularly to improve texture and manage sedimentation.
3. Adopt mild preservation strategies to address microbial limitations inherent in non-thermal beverages.
4. Implement SME-friendly hybrid models that balance affordability, quality, safety, and scalability.

This pathway aligns with broader industry recommendations for developing minimally processed, plant-based beverages using locally abundant tropical vegetables such as *Ipomoea aquatica*.

5. CONCLUSION

This study demonstrates that Tropical Vegetable Juice Formulations (TVJF) produced from *Ipomoea aquatica* through simple non-thermal cold extraction can serve as viable functional beverages with preserved nutritional quality and acceptable sensory characteristics. The formulations retained approximately 80–95% of key minerals present in raw leaves, confirming that cold extraction effectively maintains micronutrient integrity while avoiding the nutrient degradation typically associated with thermal processing.

Sensory evaluation showed that all formulations achieved acceptable consumer ratings, with flavour consistently receiving the highest scores. This indicates that the natural vegetal notes, complemented by mild sweetness, were well received by panelists. Although texture differences among formulations were statistically significant, these variations did not diminish overall acceptance, suggesting that consumers tolerated modest differences in viscosity or sedimentation as long as flavour and freshness were maintained.

Collectively, these findings highlight the potential of TVJF as nutrient-dense, minimally processed beverages that align with current consumer demand for clean-label, health-oriented products. The results also provide a strong foundation for further development and potential industrial scaling, particularly in regions where *I. aquatica* is readily available. However, future research should address microbial stability, shelf-life behaviour, and expanded nutritional profiling to ensure product safety and commercial feasibility.

With appropriate optimisation, TVJF holds strong promise for contributing to the growth of the functional beverage sector and enhancing vegetable intake across diverse population groups.

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