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EFFECTS OF CONTROLLED THERMAL PROCESSING AND FORMULATION ON NUTRIENTS AND TAURINE IN BRUNOK (*Acaudina molpadioides*) BEVERAGE

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Abstract

Brunok (*Acaudina molpadioides*) is a functional marine ingredient that is rich in protein, essential amino acids, minerals, and taurine. This study aimed to evaluate the effects of controlled thermal processing and formulation on the nutrient composition and taurine retention in brunok-based instant beverages. Thermal processing was conducted under constant and controlled temperature conditions at 90°C, and its effects were evaluated by comparing fresh brunok, extracts, and the final powdered products. Three formulations (MFB1–MFB3) containing ginger, *Curcuma xanthorrhiza*, and lemon were prepared using varying proportions of brunok and subsequently processed via spray drying. Controlled thermal treatment significantly reduced moisture content, resulting in an apparent increase in protein (17.12–46.72%) and lipid content (5.42–7.18%), primarily due to the concentration effects associated with water loss. In contrast, the essential amino acids showed a decreasing trend after processing. The taurine content increased in the extract (75.05–81.73 mg/kg), suggesting enhanced extractability during heating, but decreased in the final powdered product (66–70 mg/kg), likely due to thermal degradation and spray-drying exposure. The formulation significantly affected the amino acid composition and taurine retention, with higher brunok proportions demonstrating improved taurine preservation.

Keywords: *Acaudina molpadioides* extract, amino acid profile, marine bioactive compounds, spray drying

Pengaruh Pemanasan Terkontrol dan Formulasi terhadap Nutrien dan Taurin pada Minuman Brunok (Acaudina molpadioides)

Abstrak

Brunok (*Acaudina molpadioides*) merupakan bahan pangan laut fungsional yang kaya akan protein, asam amino esensial, mineral, dan taurin. Penelitian ini bertujuan untuk mengevaluasi pengaruh pengolahan termal terkendali dan formulasi terhadap komposisi nutrien serta retensi

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taurin pada minuman instan berbasis brunok. Pengolahan termal dilakukan pada kondisi suhu yang konstan dan terkendali, yaitu pada suhu 90°C, dan pengaruhnya dianalisis melalui perbandingan antara brunok segar, ekstrak, dan produk minuman serbuk instan. Tiga formulasi (MFB1–MFB3) yang mengandung jahe, temulawak, dan lemon disiapkan dengan proporsi brunok yang berbeda dan diproses menggunakan metode *spray drying*. Pengolahan termal pada suhu 90°C menurunkan kadar air dan menyebabkan peningkatan kadar protein (17,12–46,72%) serta lemak (5,42–7,18%), yang terutama disebabkan oleh efek konsentrasi akibat kehilangan air selama proses pemanasan. Sementara itu, kandungan asam amino esensial mengalami penurunan. Kandungan taurin meningkat pada tahap ekstrak (75,05–81,73 mg/kg), namun menurun pada produk minuman serbuk instan (66–70 mg/kg). Perbedaan formulasi berpengaruh signifikan terhadap profil asam amino dan retensi taurin, dengan proporsi brunok yang lebih tinggi menunjukkan kemampuan mempertahankan taurin yang lebih baik.

Kata kunci: ekstrak *Acaudina molpadioides*, pengeringan semprot, profil asam amino, senyawa bioaktif laut

INTRODUCTION

Brunok (*Acaudina molpadioides*), a member of the Holothuroidea class, is a marine organism with high potential as a functional food. Previous studies have reported that sea cucumbers are rich in high-quality proteins, essential amino acids, unsaturated fatty acids, minerals, and bioactive compounds, such as saponins and taurine (Senadheera *et al.,* 2023; Hossain *et al*., 2022). Taurine, a non-proteinogenic sulfonic amino acid, plays a crucial role in maintaining cardiovascular health, supporting nervous system development, regulating energy metabolism, and contributing to antioxidant function (Tzang *et al*., 2024). These properties highlight Brunok as a promising candidate for functional food development.

Powdered beverages are increasingly being explored as functional food products, largely because of their extended shelf stability, simplified handling, and convenient use. Recent studies have reported an increasing demand for functional beverages enriched with health-promoting bioactive compounds (Kaur *et al*., 2024). Functional beverages in powdered form are increasingly being developed as carriers of amino acids, antioxidants, and other bioactive compounds, as powdered formats offer improved stability, transport, and storage compared to ready-to-drink products (Gupta *et al*., 2023; Kaur *et al*., 2024). However, the application of thermal processes in powdered beverage production presents certain challenges, as many bioactive compounds are heat-sensitive. Thermal treatment may affect the stability of nutrients and bioactive compounds, potentially leading to degradation or alterations in the antioxidant capacity, phenolic profiles, and sensory characteristics (Bonilla *et al*., 2024). Therefore, careful optimization of processing conditions is essential to preserve the functional properties of bioactive-rich powdered beverages.

In the current food industry, diversifying products derived from marine resources is vital for enhancing their economic value and broadening consumer acceptance. One promising innovation is instant powdered beverages, which are practical, stable during storage, and easy to distribute (Jiang *et al*., 2025). However, a major challenge in developing products from Brunok extract is nutrient stability during processing, particularly under heat exposure. Thermal treatments, such as extraction and spray drying, have been shown to reduce essential nutrients through protein denaturation, lipid oxidation, vitamin degradation, and the loss of water-soluble bioactive compounds, such as taurine (Li *et al*., 2023; Haas *et al*., 2024). Thermal and mechanical processing has been reported to cause significant losses of taurine, which has driven increasing interest in non-thermal extraction and processing technologies to better preserve taurine content and functionality in food systems (Ujong *et al*., 2025).

Research on the effect of heating on nutritional composition and taurine is particularly important, given the high

sensitivity of taurine to temperature. Several studies have reported that exposure to high heat significantly decreases the free amino acid concentrations, including taurine, in fishery products (Gómez-Limia *et al*., 2020; Bae *et al*., 2022). These changes directly affect the nutritional and functional quality of processed products. To date, there have been no reports on the effects of thermal processing on brunok formulated as an instant powdered beverage. Therefore, this study is the first to investigate the impact of thermal processing on the physicochemical properties and nutritional quality of brunok (*Acaudina molpadioides*) for instant powdered beverage development. A comprehensive understanding of the nutrient changes induced by thermal treatment is therefore essential as a scientific basis for designing optimal processing conditions to maintain the functional value of brunok. This study aimed to investigate the effects of controlled thermal processing and formulation on nutrient composition and taurine retention in brunok (*Acaudina molpadioides*)-based instant beverages.

MATERIAL AND METHODS

Preparation of Raw Material

Only mature brunok specimens (average wet weight 250–300 g) with intact body structures were used in this study. Fresh samples were obtained from the Tanjung Balai Karimun waters, Riau Islands, Indonesia. The samples were immediately washed with freshwater to remove sand and impurities, followed by evisceration and cleaning before further processing. The yield of fresh brunok was approximately 25%, calculated as the ratio of the edible flesh weight after cleaning to the initial whole-body weight. This yield value was used as the basis for the formulation calculations.

Extraction of Brunok

Cleaned brunok flesh was cut into small pieces and blended with water (1:1, w/v) for 10–30 min to extract the juice. The homogenate was heated at 90°C for 8–10 min and filtered through a muslin (blacu) cloth to obtain the aqueous extract. No additional evaporation step was applied at this stage, and the filtrate was directly used for subsequent formulation and processing. The extraction procedure was adapted from the method described by Putri *et al*. (2013).

Instant Powder Formulation with *Spray Drying*

The formulation was developed based on experimental evaluations of the organoleptic quality attributes of instant brunok powder beverages, resulting in a product with high taurine content and favorable sensory acceptance by the panelists. Fresh ginger and *Curcuma xanthorrhiza* were peeled, washed with potable water, and blended for 10–20 min to obtain smaller particle sizes, with the addition of water at a 1:1 (b/v) ratio. The mixture was subsequently filtered using a muslin cloth to obtain the extract, followed by thermal processing at 90°C for 6–10 min. The incorporation of ginger and temulawak extracts aimed to reduce the fishy odor inherent to brunok and enhance the synergistic effect on taurine functionality. Based on the study conducted by Putri *et al*. (2013), the combination of *Discodoris* sp. and *Curcuma xanthorrhiza* can produce a synergistic effect on taurine, thereby increasing the taurine content in functional beverages. Fresh lemons were squeezed, and the resulting juice was diluted with water at a 1:1 (v/b) ratio to obtain a fresh lemon extract.

The primary ingredients and supplementary components were mixed according to a predetermined formulation. Maltodextrin, amounting to 10% of the total weight of the beverage solution, was added during the spray-drying process to prevent nutrient degradation caused by heat exposure. The spray drying was carried out at an inlet temperature of 180 °C and an outlet temperature of 110 °C for 45 min, ensuring proper drying while minimizing nutrient loss. Following dehydration, sucrose (1:1, w/w) and seaweed-derived carrageenan (1%) were added. The final product was obtained as an instant powdered beverage (Modified from Putri *et al*., 2013). The formulation was conducted in three independent replicates

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for each sample. The compositions of the functional brunok instant powdered beverages formulated at different ratios are shown in Table 1.

Proximate Analysis

Proximate composition (moisture, protein, ash, lipid, and carbohydrate content) of fresh brunok and its extract. Moisture content was determined using the oven-drying (thermogravimetric) method, and protein content was measured using the Kjeldahl method. The ash content was determined by incineration in a muffle furnace, and the lipid content was analyzed using the Soxhlet extraction technique. The carbohydrate content was calculated using the difference method by subtracting the combined percentages of moisture, ash, protein, and lipids from 100%. All proximate analyses were conducted in accordance with the standard procedures of the AOAC (2005).

Amino Acid and Taurine Analysis (AOAC 2005)

Amino acid profiles were determined according to AOAC Official Method 982.30 E (a,b,c) using high-performance liquid chromatography (HPLC). Samples were homogenized and hydrolyzed with 6 N HCl at 110°C for 24 h under vacuum to release protein-bound amino acids. After cooling, the hydrolysates were filtered and neutralized before derivatization. Pre-column derivatization was performed using phenylisothiocyanate (PITC) to form phenylthiocarbamyl (PTC) amino acid derivatives. Chromatographic separation was performed on a reversed-phase C18 column (250 mm × 4.6 mm i.d., 5 µm particle size). The mobile phase consisted of (A) 0.1 M sodium acetate buffer (pH 6.5) and (B) acetonitrile–water (60:40, v/v) and was subjected to gradient elution at a flow rate of 1.0 mL/min. The column temperature was maintained at 30°C. The detection was performed using a UV–Vis detector at 254 nm. Quantification was achieved using external calibration with certified amino acid standards.

Taurine concentration was determined according to the AOAC Official Method 997.05 using high-performance liquid chromatography (HPLC). Samples were prepared and derivatized prior to analysis, and chromatographic separation was performed on a reverse-phase column under controlled conditions. Taurine was identified based on its retention time by comparison with a certified taurine standard (≥99% purity). Quantification was performed using an external calibration curve constructed from standard solutions at various concentrations. The results were expressed as mg per 100 g of sample.

Statistical Analysis

The experimental data were analyzed using a Completely Randomized Design and processed using SPSS Version 33. A one-way analysis of variance (ANOVA) was performed to evaluate the effect of treatments, and when significant differences ($p < 0.05$) were detected, the means were compared using Tukey's Honestly Significant Difference (HSD) test. For proximate, amino acid, and taurine parameter comparisons between fresh brunok and brunok extract, a t-test was applied to ensure appropriate statistical evaluation. All results are presented as mean ± standard deviation (SD).

Table 1 Formulation of brunok functional instant powder beverage

Formula	Base ingredient (%)	Additional ingredients (%)		
	Brunok extract	Ginger extract	*C. xanthorrhiza* extract	Lemon extract
MFB1	30	30	20	20
MFB2	35	30	15	20
MFB3	40	30	10	20

RESULT AND DISCUSSION

Chemical Composition

Chemical composition is one of the most important parameters for determining the quality of raw materials or processed products. Proximate analysis was performed on fresh brunok and its extract to identify changes during extraction. Thermal treatment of fresh brunok at 90°C resulted in significant changes in the proximate composition of the bruno extract, as indicated by a decrease in moisture content and a relative increase in protein and lipid levels. This finding is consistent with that of Panayotova *et al*. (2025) on bluefish (*Pomatomus saltatrix*), who reported that cooking processes such as grilling, pan-frying, and smoking reduced moisture content by 7–18% and increased total lipid content by 26–80% due to moisture loss during heating. The results of the proximate analysis are presented in Table 2.

As shown in Table 2, significant differences (p<0.05) were observed in the ash, fat, and carbohydrate contents on a dry basis between fresh brunok and its extract, as indicated by different superscript letters within the same row. In contrast, the protein content did not differ significantly after heat-assisted extraction. These findings indicate that thermal processing primarily affects mineral and lipid fractions through leaching and thermal degradation, whereas the total protein content remains relatively stable. The apparent increases observed on a wet basis were mainly attributable to moisture reduction rather than to actual nutrient enrichment.

The chemical composition of fresh brunok showed high nutritional value, particularly in terms of protein (17.12%) and lipid (5.42%) content. After heating at 90°C for 8–10 min, the brunok extract exhibited an increase in protein (46.72%) and lipid (7.18%) contents, largely due to the reduction in moisture content (from 72.18% to 18.17%). This phenomenon is consistent with studies on *Holothuria* sp., which demonstrated that heating causes water loss (cooking loss), resulting in a relative increase in the protein and lipid concentrations (Bilgin & Tanrikulu, 2018).

The moisture content of fresh brunok (72.18%) decreased significantly to 18.17% in the extract after heating at 90°C for 8–10 min. This decline is consistent with the cooking loss phenomenon, which leads to the loss of water and soluble substances in the meat. Similar findings were reported by Bilgin and Tanrikulu (2018) for *Holothuria atra*, where moisture content significantly decreased after cooking, affecting both texture and shelf life. Zhang *et al*. (2022) also reported that heat treatment can reduce moisture content by up to 60–70%. The protein content in brunok increased from 17.12% in fresh flesh to 46.72% in the extract. This increase occurred as a result of the reduced water content, which led to a relative increase in protein concentration. A similar phenomenon was observed in *Holothuria scabra*, where protein levels increased from 38% to 50% after boiling (Bilgin & Tanrikulu, 2018). Although the protein content increased, its quality may decline due to damage to the amino acid structures.

The results of this study revealed a significant decrease in the ash content. This significant reduction in ash content indicates that the loss of soluble components, including minerals and water-soluble

Table 2 Proximate composition of fresh and extract of brunok

Nutrition	Fresh*(%)	Extract* (%)	Fresh** (%)	Extract ** (%)
Moisture	72.18±0.03^{b}	18.17±0.03^{a}	-	-
Ash	1.43±0.00^{a}	1.12±0.03^{a}	5.14±0.01^{b}	1.37±0.04^{a}
Protein	17.12±0.08^{a}	46.72±0.06^{b}	61.54±0.37^{b}	57.09±0.09^{b}
Fat	5.42±0.03^{a}	7.18±0.00^{b}	19.48±0.08^{b}	8.77±0.00^{a}
Carbohydrate	3.85±0.08^{a}	26.81±0.11^{b}	13.84±0.29^{a}	32.76±0.13^{b}

*= wet base, **= dry base

Different superscript letters within the same row denote significant differences (p<0.05)

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carbohydrates, during thermal processing exceeds the concentration effect caused by water loss. Zhang *et al*. (2022) reported that boiling induces the leaching of potassium and sodium into the cooking medium. Singh *et al*. (2023) further emphasized that minerals such as calcium are relatively stable, whereas iron is highly susceptible to loss owing to oxidation during heating. The lipid content of fresh brunok flesh was 5.42%, which increased to 7.18% after thermal processing during extraction. This increase was primarily attributed to the substantial reduction in moisture content from 72.18% to 18.17%, thereby elevating the proportion of lipids within the total solids. Similar phenomena have been reported in various marine organisms, such as fish and mollusks, where boiling leads to water evaporation and an increase in the concentration of lipid components (Tan *et al*., 2023). Although the relative lipid content increased, the lipid quality was significantly affected by heating. Lipids, particularly those containing unsaturated fatty acids, are susceptible to thermal oxidation. This process produces secondary compounds, such as aldehydes and ketones, which can impair sensory quality and reduce the nutritional value of the product (Fan *et al*., 2025). Several studies have shown that heating at temperatures above 100°C can accelerate the degradation of polyunsaturated fatty acids (PUFAs), particularly EPA and DHA, which are crucial for cardiovascular health (Bae *et al.,* 2022).

The carbohydrate content of fresh brunok flesh was 3.85%, which significantly increased to 26.81% in the extract. Similar to proteins and lipids, this increase was not due to new biosynthesis but rather to the relative concentration of solid components following water reduction. This mechanism is known as the solid-concentration effect (Jiang *et al*., 2025). Carbohydrates in marine organisms, particularly Holothuroidea, are generally present as glycogen, mucopolysaccharides, and dietary fibers (Senadheera *et al*., 2023). Some of these, especially sulfated polysaccharides, are known to possess bioactive properties, such as antioxidant, immunomodulatory, and anticoagulant activities (Hossain *et al*., 2023). Carbohydrates are highly susceptible to Maillard reactions during heating, particularly when they interact with proteins or amino acids. These reactions may lead to the formation of melanoidin compounds, which influence the color and flavor of the product while also reducing the availability of essential amino acids (Shakoor *et al*., 2022). In the context of instant powdered beverage development, a high carbohydrate content can provide advantages as a natural carrier agent, enhancing the solubility and improving the texture and sensory quality of the product. Additionally, maltodextrin added to the formulation serves as a nutrient stabilizer and prevents bioactive degradation caused by heat.

Amino Acid Composition

Amino acids are essential components that determine the nutritional and functional qualities of protein-rich foods. Changes in amino acid composition may occur during thermal processing due to protein degradation, leaching, or structural modification. Therefore, evaluating the amino acid profile is important for assessing the impact of processing on the nutritional quality of brunok. The amino acid composition of brunok is shown in Table 3.

As shown in Table 3, significant differences ($p<0.05$), as indicated by different superscript letters within the same row, were observed for most individual amino acids between fresh brunok and its extract. Both essential and non-essential amino acids exhibited significant changes following heat-assisted extraction, indicating that the extraction process substantially modified their amino acid profile. These alterations may be attributed to protein structural modifications, differences in amino acid solubility, and leaching during extraction.

The amino acid profile of brunok showed notable changes after its processing. In the fresh sample, the total essential amino acids reached 6.19 g/100 g sample and non-essential amino acids 11.09 g/100 g sample. After extraction with heat treatment, these values decreased drastically to 1.35% (essential amino acids) and 1.98 g/100 g sample(non-essential amino acids). This decline in amino acid content observed in this study is

Table 3 The amino acid composition of brunok (g/100 g sample)

No	Amino acid	Fresh brunok	Extract of brunok
Essential amino acid		6.19	1.35
1	Histidine	0.24±0.00[a]	0.02±0.00[b]
2	Threonine	0.75±0.00[a]	0.12±0.01[b]
3	Methionine	1.60±0.00[a]	0.47±0.00[a]
4	Leucine	2.53±0.00[a]	0.60±0.00[a]
5	Lysine	1.07±0.00[a]	0.14±0.00[a]
Non-essential amino acid		11.09	1.98
6	Aspartic acid	2.54±0.03[a]	0.31±0.01[a]
7	Glutamic acid	2.96±0.04[a]	0.52±0.01[a]
8	Serine	0.89±0.00[a]	0.03±0.00[a]
9	Glycine	1.52±0.00[a]	0.08±0.00[a]
10	Proline	1.90±0.04[a]	0.44±0.03[a]
11	Alanine	0.11±0.02[a]	0.42±0.00[b]
12	Tyrosine	1.17±0.00[a]	0.18±0.01[b]

Different superscript letters within the same row denote significant differences ($p<0.05$)

consistent with the findings of Li *et al.* (2023), who reported that thermal treatment reduces amino acids through oxidation, deamination, and other forms of thermal degradation, resulting in the loss of free amino acid residues in the protein. Amino acids, such as lysine, histidine, and threonine, are particularly heat-sensitive because of their reactive amino groups. In this study, the Brunok extract was processed at 90°C for 8–10 min.

Taurine

Taurine is an organic compound classified as a sulfonic amino acid (β-amino acid). Although often referred to as an amino acid, taurine is non-proteinogenic because it is not incorporated into proteins and contains a sulfonate group instead of a carboxylate group. In aquatic organisms, taurine plays vital physiological roles in metabolism, antioxidant defense, and regulation of various body functions (Bae *et al.* 2022; Tzang *et al.* 2024). The taurine content (g/100 g sample) was 75.05±0.07 for fresh Brunok and 81.73±0.03 for Brunok extract. The paired samples *t*-test revealed a statistically significant difference ($p<0.05$) in taurine content between fresh Brunok and Brunok extract. These results suggest that heat-assisted extraction at 90°C significantly increased taurine levels compared to the fresh conditions.

Taurine is a key bioactive component of brunok, functioning as an antioxidant, osmoregulatory agent, and supporter of cardiovascular and nervous system health. Based on the analysis, the taurine content in fresh brunok flesh was 75.05 mg/kg and increased to 81.73 mg/kg after heating during the extraction process. This increase is relative and results from moisture reduction, which leads to a higher concentration of soluble compounds, including taurine. A similar observation was reported by Hossain *et al.* (2023), who found that boiling can release free amino acids previously bound within the tissue, making them more detectable in extracts.

Nutritional Composition of Brunok Beverage

Although nutritional composition generally includes a wide range of macro- and micronutrients, the present study specifically focused on the amino acid profile and taurine content as the main nutritional components of the brunok beverage. These parameters

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were selected because of their important physiological roles, sensitivity to thermal processing, and relevance to the functional characteristics of marine-based beverages. The amino acid composition of the Brunok instant beverage powder is presented in Table 4, with changes in essential and non-essential amino acids discussed in relation to controlled thermal processing and formulation variations. The taurine content of the Brunok instant beverage powder is presented in Table 4.

Table 4 shows the amino acid compositions of the brunok instant beverage powders formulated as MFB1–MFB3. Both essential and non-essential amino acids were detected in all samples, with significant differences among the formulations ($p<0.05$). Leucine and methionine were the dominant essential amino acids in all formulations, with leucine ranging from 3.01% to 3.21% and methionine ranging from 2.28% to 2.62%. Lysine was present at lower levels (0.48–0.73%) in all samples. The total essential amino acid content ranged from 5.99% to 6.72%, with the highest value observed in MFB3.

Non-essential amino acids were present in higher proportions than those of essential amino acids. Aspartic and glutamic acids were the major non-essential amino acids, although their concentrations decreased from MFB1 to MFB3. Proline showed relatively higher values (2.00–2.53%) than other non-essential amino acids. The total non-essential amino acid content ranged from 6.54% to 8.51% in the samples.

The increase observed in methionine and leucine levels may be explained by several factors, including the contribution of added ingredients such as ginger (*Zingiber officinale*) and *Curcuma xanthorrhiza*, which are known to possess rich and diverse amino acid profiles (Ajayi *et al*. 2013). In addition, the drying process plays a role, as the loss of water and non-protein components produces a concentration effect, resulting in relatively high amino acid levels (Li *et al*. 2023). The stability of proline against thermal

Table 4 The amino acid composition of brunok instant beverage powder

No	Amino acid (%)	Formulation of functional brunok*		
		MFB1	MFB2	MFB3
Essential amino acid		6.44	5.99	6.72
1	Histidine	0.17±0.00^{a}	0.09±0.00^{b}	0.08±0.00^{c}
2	Threonine	0.18±0.00^{a}	0.11±0.00^{b}	0.13±0.03^{b}
3	Methionine	2.35±0.07^{b}	2.28±0.07^{b}	2.62±0.07^{a}
4	Leucine	3.01±0.00^{c}	3.03±0.02^{b}	3.21±0.02^{a}
5	Lysine	0.73±0.01^{a}	0.48±0.01^{c}	0.68±0.01^{b}
Non-essential amino acid		8.51	6.97	6.54
6	Aspartic acid	2.55±0.88^{a}	1.80±0.04^{c}	1.96±0.04^{b}
7	Glutamic acid	1.93±0.05^{a}	1.36±0.05^{b}	0.91±0.10^{c}
8	Serine	0.23±0.01^{a}	0.21±0.03^{a}	0.09±0.00^{b}
9	Glycine	0.45±0.00^{a}	0.22±0.00^{b}	0.23±0.00^{b}
10	Proline	2.00±0.00^{c}	2.53±0.00^{a}	2.41±0.13^{b}
11	Alanine	0.15±0.01^{a}	0.07±0.00^{c}	0.12±0.02^{b}
12	Tyrosine	1.20±0.06^{a}	0.78±0.00^{c}	1.05±0.00^{b}

Different superscript letters within the same row denote significant differences ($p<0.05$);

MFB1: Brunok extract 30%, ginger extract 30%, *C. xanthorrhiza* extract 20%, lemon extract 20%

MFB2: Brunok extract 35%, ginger extract 30%, *C. xanthorrhiza* extract 15%, lemon extract 20%

MFB3: Brunok extract 40%, ginger extract 30%, *C. xanthorrhiza* extract 10%, lemon extract 20%

degradation makes it more resistant to heating than other amino acids (Li *et al.* 2023). This stability is further reinforced by the fact that proline rarely participates in the initial stages of the Maillard reaction, allowing it to persist after food processing. In contrast, glutamic acid showed a decreasing trend among the powdered beverage samples, declining from 1.93% in MFB1 to 0.91% in MFB3, which may be attributed to its sensitivity to heat-induced reactions and involvement in flavor-forming processes.

From a nutritional perspective, although reductions were observed in several essential amino acids, such as lysine, the high levels of leucine and methionine still provide positive value. Leucine, for instance, is essential for muscle protein synthesis, whereas methionine functions as a methyl group donor and plays a key role in sulfur metabolism. Nevertheless, the low lysine content represents a limitation, as powdered brunok may have reduced protein biological value, particularly if lysine becomes the limiting amino acid in the diet (Zhang *et al.*, 2022). The Maillard reaction not only affects nutritional quality but also impacts sensory properties, as melanoidin formation contributes to color and characteristic aroma; however, in advanced stages, it may yield undesirable compounds (El Hosry *et al.* 2025).

Based on the amino acid profiles observed in Table 4, further efforts to preserve amino acid quality in brunok-based instant beverages may benefit from the application of more nutrient-friendly processing methods. Previous studies have shown that freeze-drying is more effective in maintaining essential amino acid content than spray drying or direct heating (Li *et al.* 2023). Incorporating carriers or excipients during spray drying has been reported to protect proteins and amino acids from degradation, thereby enhancing their stability during storage (Dieplinger *et al.* 2023). Therefore, although brunok-based instant powdered beverages have demonstrated potential as functional drinks rich in amino acids, optimizing processing conditions and selecting appropriate drying methods are essential steps to further improve their nutritional quality. The taurine content of an instant brunok beverage powder was evaluated to determine the effect of the formulation on taurine retention. The results are shown in Table 5.

Table 5 shows the taurine content of the brunok instant beverage powder formulated as MFB1–MFB3. The taurine content ranged from 65.63 to 70.06 g/100 g sample and increased with higher proportions of brunok extract in the formulation. Formulation MFB3 exhibited the highest taurine content and differed significantly from MFB1 and MFB2 ($p<0.05$). This trend suggests that the formulation composition, particularly the proportion of brunok extract, along with controlled processing conditions, plays a key role in determining taurine retention in the instant beverage powder.

The taurine content of the brunok instant beverage powder ranged from 66 to 70 g/100 g sample, as shown in Table 5. These

Table 5 Taurine content of brunok instant beverage powder (g/100 g sample)

Formulation of functional brunok*	Taurine
MFB1	65.63±0.04^{c}
MFB2	68.42±0.03^{b}
MFB3	70.06±0.08^{a}

Different superscript letters within the same row denote significant differences ($p<0.05$);

MFB1: Brunok extract 30%, ginger extract 30%, *C. xanthorrhiza* extract 20%, lemon extract 20%

MFB2: Brunok extract 35%, ginger extract 30%, *C. xanthorrhiza* extract 15%, lemon extract 20%

MFB3: Brunok extract 40%, ginger extract 30%, *C. xanthorrhiza* extract 10%, lemon extract 20%

values indicate relatively low taurine levels following the conversion of the extract into a powdered form using spray drying. Although taurine is considered relatively stable under moderate heating, high drying temperatures and prolonged exposure during spray drying may promote degradation and loss due to its high water solubility and hygroscopic nature. Haas *et al*. (2024) reported that taurine is highly susceptible to loss during thermal processing, particularly during drying, because it can diffuse with evaporating moisture. Previous studies have also shown that short-term heating during extraction may increase the detectable taurine content due to concentration effects, whereas subsequent spray-drying can reduce the initial taurine content by up to 20–30% (Tzang *et al*. 2024).

In the present study, formulation MFB3, which contained the highest proportion of brunok extract, exhibited the highest taurine content, indicating that the formulation composition plays a critical role in taurine retention during processing. Increasing the proportion of Brunok extract while reducing the concentration of *Curcuma xanthorrhiza* significantly influenced the taurine content of the instant beverage powder. This finding suggests that Brunok, as the primary taurine source, contributes more substantially to taurine levels than the plant-based additive, which primarily affects the formulation through dilution. During spray drying, matrices with higher marine-derived protein content may facilitate better taurine retention, whereas *C. xanthorrhiza* appears to contribute only indirectly to taurine stability.

CONCLUSION

Controlled thermal processing and formulation variations significantly affected the nutrient composition and taurine retention in brunok instant beverages. Heating at 90 °C for 8–10 min reduced the moisture content and increased the relative concentrations of protein and lipid, whereas several essential amino acids decreased during subsequent processing. Taurine levels increased at the extraction stage but declined in the final powdered beverage, primarily due to dilution effects from added formulation components (e.g., maltodextrin, sugar, and other extracts) in the instant powder rather than the spray-drying process itself. The formulation variations (MFB1–MFB3) influenced the amino acid composition and taurine retention, with higher proportions of brunok extract showing better taurine preservation. These findings confirm that controlling the thermal conditions and optimizing the formulation are key factors in maintaining the nutritional quality and taurine content of brunok-based instant beverage.

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