Journal of Applied Food Technology

Home page: https://ejournal2.undip.ac.id/index.php/jaft

Production and Characterization of Flavour Enhancer from Sipou Worm (*Siphonosoma australe-australe*): Effects of Extract-to-Water Ratio on Physicochemical Properties

Muhammad Yusuf[1*], Iga Astrina[1], Yunan Kholifatuddin Sya'di[1], Diode Yonata[1], Boby Pranata[2]

[1]Study Program of Food Technology, Faculty of Agricultural Science and Technology, Universitas Muhammadiyah Semarang, Jl. Kedungmundu Raya No. 18, Semarang 50273, Central Java, Indonesia.
[2]Study Program of Agricultural Product Technology, Faculty of Agriculture, Universitas Sriwijaya, Jalan Palembang-Prabumulih KM 32, Indralaya, Ogan Ilir 30662, South Sumatra, Indonesia.

*Corresponding author (m.yusuf@unimus.ac.id)

Abstract

Marine flavour enhancer have gained increasing attention as natural food ingredients because they are rich in free amino acids and low-molecular-weight peptides that contribute to desirable functional and flavor properties. Among marine resources, the peanut worm *Siphonosoma australe-australe*, which is abundant in the coastal waters of Southeast Sulawesi and the Maluku Islands, possesses a high protein content and naturally occurring glutamic acid, making it a promising raw material for flavour enhancer production. This study investigated the effect of different extract-to-water ratios on the physicochemical properties of foam-mat dried *S. australe-australe* flavour enhancer powder. A single-factor completely randomized design (CRD) was employed using five extract-to-water ratios (7.5:42.5, 10:40, 12.5:37.5, 15:35, and 17.5:32.5 mL), with five replications per treatment, resulting in a total of 25 experimental units. The hydrolysate was subsequently dehydrated using the foam-mat drying technique to produce a stable powder. The resulting samples were analyzed for instrumental color, glutamic acid, protein content, fat content, and sodium chloride content. The results demonstrated that the extract-to-water ratio significantly influenced the color profile of the hydrolysate powder, while increasing the proportion of *S. australe-australe* extract produced a corresponding increase in protein and fat contents. These findings highlight the importance of optimizing the extract-to-water ratio to improve the physicochemical quality of foam-mat dried *S. australe-australe* flavour enhancer powder and support its potential application as a natural marine-based protein ingredient.

Article information:
Received: 10 July 2026
Accepted: 13 August 2026
Available online: 21 August 2026

Keywords:
sipou worms
hydrolisates
foam-mat drying
physicochemical

© 2026
Indonesian Food Technologists
All rights reserved.

This is an open access article under the CC BY-NC-ND license.

doi: 10.17728/jaft.33642

Introduction

Indonesia, one of the world's largest maritime nations, possesses abundant marine biodiversity that remains underutilized as a source of functional food ingredients. Among these underexploited marine resources is the peanut worm, *Siphonosoma australe-australe*, which belongs to the phylum Sipuncula and inhabits tropical coastal ecosystems throughout the Indo-Pacific region. Marine invertebrates have attracted increasing scientific interest because they are rich sources of high-quality proteins and bioactive compounds with considerable potential for food and nutraceutical applications (Kim & Wijesekara, 2010; Bleakley & Hayes, 2017). Previous studies have shown that *S. australe-australe* contains a relatively high protein content (approximately 17.01%) and is particularly rich in free amino acids, especially glutamic acid, making it a promising raw material for natural flavor enhancement. While Yusuf et al. (2025) reported the potential of Sipou worm extract as a source of natural flavor compounds, the current study extends this work by investigating the production of a foam-mat dried flavor enhancer powder and evaluating the effects of different extract-to-water ratios on its physicochemical properties.

The naturally occurring glutamic acid in *S. australe-australe* contributes to its characteristic umami taste, highlighting its potential as a marine-derived source of amino acids and natural flavor-enhancing ingredients. Beyond its potential contribution to umami flavor, valorization of *S. australe-australe* may provide opportunities for recovering other nutritionally relevant amino acids and developing value-added ingredients from underutilized marine resources. Flavour enhancer have attracted considerable attention as multifunctional food ingredients because they not only provide nutritional benefits but also contribute desirable sensory

properties, particularly umami flavor, owing to their high contents of free amino acids and low-molecular-weight peptides (Nielsen et al., 2017; Hou et al., 2023). To maximize these functional and sensory attributes, flavour enhancer should be converted into a stable powdered form while maintaining their nutritional quality and flavor-active compounds. Therefore, the drying process represents a critical stage because it directly influences product stability, physicochemical characteristics, and shelf life.

Among the available dehydration techniques, foam-mat drying (FMD) has emerged as an effective method for producing high-quality flavour enhancer powders. Foam-mat drying enhances moisture removal by incorporating air into the liquid matrix, thereby increasing the evaporation surface area and reducing drying time under relatively mild thermal conditions (Kandasamy et al., 2019; Sangamithra et al., 2015). These lower drying temperatures help minimize thermal degradation of proteins, preserve volatile flavor compounds, and improve the retention of bioactive constituents compared with conventional hot-air drying methods (Kadam et al., 2011; Sangamithra et al., 2015).

The extract-to-water ratio is an important processing parameter because water acts as the extraction medium for transferring water-soluble compounds, including glutamic acid and other soluble protein-derived compounds, into the extract. A higher solvent-to-material ratio can facilitate mass transfer and recovery of soluble compounds, although excessive water produces a more diluted extract and increases the amount of moisture that must be removed during foam-mat drying. In a previous study on *S. australe-australe*, a material-to-solvent ratio of 1:8 (w/v) was used for extraction and affected the recovery of glutamic acid (Yusuf et al., 2025). Similarly, variations in formulation during foam-mat drying have been reported to affect glutamic acid content and the physicochemical properties of flavor enhancer powders (Yonata et al., 2021). Therefore, different extract-to-water ratios were evaluated in this study to determine their effects on the physicochemical characteristics of *S. australe-australe* flavor enhancer powder.

Materials and Methods

Materials

The primary raw material used in this study was dried Sipou worm (*Siphonosoma australe-australe*) in Figure 1 obtained from the coastal waters of Kendari, Southeast Sulawesi, Indonesia. The dried Sipou worm was ground into powder using a grinder (Agrowindo, Indonesia) and subsequently used as the main raw material for the preparation of the foam-mat dried flavour enhancer powder. Additional ingredients included sodium chloride (Dolphin, Indonesia), sucrose (Gulaku, Indonesia), white pepper powder (Ladaku, Indonesia), egg white, maltodextrin, and gum arabic. Analytical-grade reagents used for physicochemical analyses included distilled water, sodium tetraborate decahydrate ($Na_2B_4O_7 \cdot 10H_2O$), sodium hydroxide (NaOH), concentrated sulfuric acid (H_2SO_4), selenium catalyst, methyl orange (MO), phenolphthalein (PP), boric acid (H_3BO_3), hydrochloric acid (HCl), petroleum benzine, silver nitrate ($AgNO_3$), and potassium chromate (K_2CrO_4), which were obtained from Merck (Darmstadt, Germany).

Figure 1. Dried Sipou Worm

Experimental Treatments

The experiment was arranged using a completely randomized design (CRD) with a single experimental factor, namely the ratio of Sipou worm (*Siphonosoma australe-australe*) flavour enhancer extract to distilled water. Five formulation treatments were evaluated, each with five independent replications, as follows:

Table 1. Experimental treatments used for the preparation of foam-mat dried *Siphonosoma australe-australe* flavour enhancer powder.

Treatment	Flavour enhancer extract (mL)	Distilled water (mL)	Total liquid volume (mL)
F1	7.5	42.5	50
F2	10.0	40.0	50
F3	12.5	37.5	50
F4	15.0	35.0	50
F5	17.5	32.5	50

The experiment was arranged using a completely randomized design (CRD) with one factor, namely the ratio of flavour enhancer extract to distilled water. Each treatment was replicated five times. After preparing the liquid formulations, identical concentrations of supporting ingredients were incorporated into all treatments, consisting of 15% sodium chloride, 10% sucrose, 1% white pepper powder, 5% maltodextrin, 10% gum arabic, and 20% whipped egg white prior to foam-mat drying.

Preparation of Flavour enhancer extract

The preparation of flavour enhancer extract was adapted from the method described by Yusuf et al. (2025) with slight modifications. Briefly, 4.8 g of citric acid was dissolved in 160 mL of distilled water and used as the hydrolysis medium for sipou worm powder at a material-to-solvent ratio of 1:8 (w/v). The mixture was homogenized and incubated for 36 h at room temperature to allow acid hydrolysis, with intermittent stirring every 12 h to ensure uniform contact between the substrate and the hydrolyzing solution. After hydrolysis, the suspension was filtered to remove undigested solid residues and then centrifuged (DLAB, Indonesia) at 5,000 rpm for 10 min to separate insoluble materials. The resulting supernatant was collected as the flavour enhancer extract and used for subsequent analyses and formulation.

Preparation of Foam-Mat Dried Flavour enhancer Powder

Preparation of Foam-Mat Dried Flavour enhancer Powder follows Yonata et al. (2021). The flavour enhancer extract was mixed with distilled water according to the respective treatment formulations presented in Table 1. Subsequently, sodium chloride (15%, w/w), sucrose (10%, w/w), white pepper powder (1%, w/w), maltodextrin (5%, w/w), and gum arabic (10%, w/w) were incorporated into the mixture. The suspension was homogenized (B-One, Indonesia) at 3,000 rpm for 5 min to ensure complete dispersion of all ingredients.

Egg white (20%, w/w) was whipped separately using an electric mixer until stiff foam was formed and then carefully folded into the hydrolysate mixture to obtain a stable foam structure. The resulting foam was uniformly spread onto stainless-steel trays at an approximate thickness of 1 mm before being dehydrated using a food dehydrator (Maksindo, Indonesia) at 60°C for 8 h following the foam-mat drying technique. After drying, the product was ground using a blender and sieved to obtain a homogeneous flavour enhancer powder for physicochemical analyses.

Color Profile Analysis

Color measurements were performed according to Nadhifah et al. (2021) using a calibrated colorimeter (HunterLab, USA). Approximately 5 g of sample was evenly distributed on a white background, and the CIE L*, a*, and b* values were recorded.

The total color difference (ΔE) relative to the standard white plate was calculated as:

$$\Delta E = \sqrt{(\Delta \mathbf{L})^2 + (\Delta \mathbf{a}^2) + (\Delta \mathbf{b}^2)}$$

where ΔL represents the difference in lightness between the sample and the standard, calculated as L*sample* − L*standard*; Δa indicates the red–green color deviation, calculated as a*sample* − a*standard*; and Δb represents the yellow–blue color deviation, calculated as b*sample* − b*standard*. The ΔE value represents the total color difference between the sample and the reference standard, with lower ΔE values indicating greater similarity between the sample and the reference color. Therefore, ΔE is commonly used as an indicator of color difference and quality (Nadhifah et al., 2021).

Determination of Glutamic Acid Content

Glutamic acid content was determined using the ninhydrin colorimetric method with slight modifications (Lee *et al.,* 2014). Briefly, 0.5 g of sample was dissolved in 10 mL of distilled water. Subsequently, 2 mL of the sample solution was mixed with 2 mL of ninhydrin reagent and homogenized thoroughly. The mixture was heated in a water bath for approximately 20 min until a purple-colored complex developed. After cooling, 2 mL of ethanol was added, followed by homogenization and incubation for 10 min. The absorbance was measured using a UV–Visible spectrophotometer (Shimadzu, Japan) at a wavelength of 570 nm. Glutamic acid concentration was calculated based on the standard calibration curve.

Protein Content Determination

Crude protein content was determined using the Kjeldahl method (AOAC, 2023), involving digestion, distillation, titration, and acid standardization. Approximately 0.05 g of sample was digested with concentrated sulfuric acid in the presence of a selenium catalyst until a clear digest was obtained. After cooling, the digest was alkalized with 40% NaOH containing phenolphthalein indicator and distilled. The liberated ammonia was trapped in 4% boric acid containing methyl orange indicator and subsequently titrated with standardized 0.1 N hydrochloric acid.

Nitrogen content was calculated as:

$$N\% = (\text{mL HCl sample}) \times N\ \text{HCl} \times 14.007) / \text{Sample weight} \times 100$$

Protein content was calculated using:

$$\text{Protein Content (\%)} = N\% \times 6.25$$

Fat Content Determination

Crude fat was determined using Soxhlet extraction (AOAC, 2023) with petroleum benzene as the extraction solvent. Approximately 1 g of sample was wrapped in filter paper and extracted until the solvent became clear. The solvent was evaporated, and the extraction flask was dried at 103°C, cooled in a desiccator, and weighed. Fat content was calculated using:

$$\text{Fat (\%)} = (W_2 - W_1) / W \times 100\%$$

where W represents the sample weight (g), W_1 represents the weight of the empty extraction flask (g), and W_2 represents the weight of the extraction flask containing the recovered fat after solvent extraction (g).

Sodium Chloride Determination

The sodium chloride content was analyzed using the Mohr argentometric titration method. The $AgNO_3$ solution was standardized with a 0.1 N NaCl standard solution using potassium chromate as the endpoint indicator. Approximately 0.05 g of sample was dissolved in distilled water, diluted to 100 mL, and a 10-mL aliquot was titrated with standardized $AgNO_3$ solution.

NaCl content was calculated according to:

$$NaCl\ (\%) = (V \times N \times 58.44 \times FP \times 100) / (W \times 1000)$$

where (V) represents the volume of $AgNO_3$ used (mL), (N) is the normality of the $AgNO_3$ solution, 58.44 is the molecular weight of NaCl (g/mol), (FP) is the dilution factor, and (W) represents the sample weight (g).

Statistical Analysis

The experiment followed a completely randomized design (CRD) consisting of five treatment levels with five independent replications. All analytical measurements were performed in triplicate, and the results are presented as the mean ± standard deviation.

The experimental data were subjected to one-way analysis of variance (ANOVA) to determine the effect of different flavour enhancer extract-to-water ratios on the physicochemical properties of the foam-mat dried flavour enhancer powder. When significant differences were detected at $p < 0.05$, mean comparisons were performed using Duncan's Multiple Range Test (DMRT) at the 95% confidence level. Statistical analyses were conducted using SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA).

Results and Discussion

Color Profile

The chroma (C*) of the foam-mat dried flavour enhancer increased progressively with increasing proportions of *Siphonosoma australe-australe* extract, from 9.77 in F1 to 10.79 in F5 (Table 2 and Figure 2). The different superscript letters indicate that the extract-to-water ratio significantly affected the C* values ($p < 0.05$). This increase in chroma indicates that the powder became progressively more color-saturated as the proportion of Sipou extract increased. A possible explanation is the greater contribution of color-forming compounds originating from the Sipou extract at higher extract proportions. As the amount of extract increased relative to water, a greater concentration of naturally occurring pigments and other colored compounds from the raw material would be incorporated into the foam matrix and subsequently retained in the dried powder. In addition, the lower dilution of the extract may have increased the relative contribution of these compounds to the measured surface color. Similar changes in color characteristics have been reported in other foam-mat-dried food powders, where differences in formulation and the concentration of the raw material influenced the final color properties of the powders. For example, foam-mat drying of tomato powder produced measurable variation in L*, a*, and b* values across different formulations, demonstrating that changes in formulation can modify the color characteristics of the resulting powder (Hossain et al., 2024). Likewise, foam-mat drying has beenshownto influence the color properties of shrimp powder, indicating that both the composition of the feed material and processing conditions can contribute to changes in powder color. Therefore, the increase in C* observed in the present study is likely associated primarily with the increasing proportion of Sipou extract in the formulation, which resulted in a greater contribution of extract-derived color compounds to the final powder.

The color profile of the foam-mat dried flavour enhancer was characterized by evaluating the CIE L*, a*, b*, chroma (C*), and total color difference (ΔE). The lightness (L*) values ranged from 92.29 to 93.62 and were not significantly affected by the extract-to-water ratio ($p > 0.05$), indicating that increasing the concentration of *Siphonosoma australe-australe* extract did not substantially alter the brightness of the resulting powder. Similarly, the redness parameter (a*) remained relatively constant among treatments, suggesting that the drying process preserved the overall hue regardless of extract concentration.

Figure 2. Flavor Enhancer from Sipou Worm

Table 2. Color Characteristics of Flavour Enhancer Powder Produced Using Different Ratios of Sipou (*Siphonosoma australe-australe*) Extract and Water

Treatment	L*	a*	b*	C*	ΔE
F1	92.45 ± 1.24^{a}	0.70 ± 0.23^{a}	9.75 ± 0.95^{a}	9.77 ± 0.21^{a}	0.33 ± 0.08^{a}
F2	93.12 ± 0.60^{a}	0.65 ± 0.06^{a}	9.76 ± 0.15^{a}	9.77 ± 0.18^{a}	0.67 ± 0.11^{a}
F3	92.29 ± 1.28^{a}	0.79 ± 0.17^{a}	10.19 ± 0.60^{b}	10.22 ± 0.27^{b}	0.56 ± 0.09^{a}
F4	93.62 ± 0.78^{a}	0.86 ± 0.19^{a}	10.20 ± 0.40^{b}	10.24 ± 0.24^{b}	1.22 ± 0.13^{b}
F5	92.64 ± 0.67^{a}	0.78 ± 0.17^{a}	10.76 ± 0.95^{c}	10.79 ± 0.31^{c}	1.06 ± 0.12^{b}

Different letters indicate significant differences among treatments ($p \leq 0.05$), whereas the same letters indicate no significant difference ($p > 0.05$); error bars represent standard deviations.

In contrast, the yellowness (b*) tended to increase as the proportion of the extract increased, resulting in progressively higher chroma values from F1 to F5. Chroma represents the intensity or saturation of color; therefore, the gradual increase from 9.77 to 10.79 indicates that powders produced with higher extract concentrations exhibited more vivid and saturated yellowish-brown coloration. This trend is consistent with the increased concentration of naturally occurring pigments and protein-derived compounds present in the extract. During foam-mat drying at 60°C, free amino acids and reducing sugars can participate in Maillard reactions, producing melanoidins that contribute to darker and more saturated color development (Fan et al., 2023).

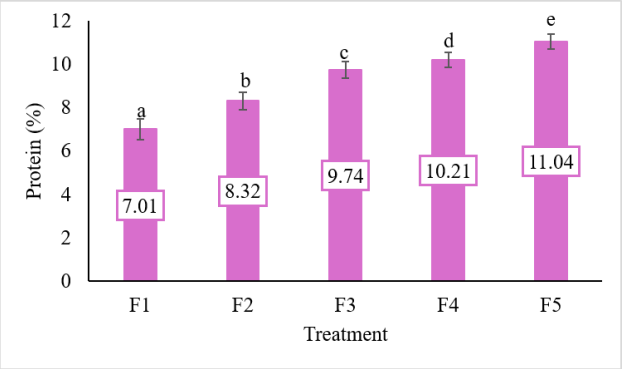
The total color difference (ΔE) further supported these observations. Using F1 as the reference sample, ΔE values increased from 0.33 in F1 to 1.22 in F4 and remained above 1.0 in F5. Although these values indicate measurable color changes, all ΔE values remained below 3.0, indicating that the color differences among the samples were relatively small and would generally be considered difficult to distinguish visually under typical viewing conditions. However, ΔE values should be interpreted as an instrumental measure of color difference rather than a direct sensory threshold, as the perceptibility of color differences can be influenced by viewing conditions, illumination, background, and observer characteristics. Consequently, the differences among treatments would generally be considered slight and only perceptible upon close inspection. This finding suggests that increasing the extract concentration enhanced color saturation without causing excessive discoloration.

The relatively small changes in ΔE among the samples indicate that the color differences were not perceptible to the naked eye, as ΔE values below 2 are generally considered to be visually indistinguishable. The minimal color variation observed may be attributed, at least in part, to the protective encapsulating properties of maltodextrin and gum arabic, which may have helped minimize changes in the color of the encapsulated powder during processing. Both carrier agents form a protective matrix around pigments and Maillard reaction products, reducing pigment degradation and minimizing excessive browning during drying. Consequently, despite the increasing concentration of the Sipou extract, the overall visual appearance of the powders remained relatively stable. Such color stability is advantageous for flavour enhancer powders because consumers generally prefer products with consistent and uniform appearance during storage (Erfianti et al., 2023).

Protein Content

The one-way ANOVA demonstrated that the extract-to-water ratio did not significantly influence the protein content of the foam-mat dried flavour enhancer ($F = 2.244$, $p = 0.101$; $p > 0.05$). However, a consistent upward trend was observed, with protein concentrations increasing from 7.01% in F1 to 11.04% in F5 as the proportion of *Siphonosoma australe-australe* extract increased (Figure 3).

Although the statistical analysis indicated no significant treatment effect, the positive trend reflects the increasing contribution of protein-rich raw material to the hydrolysate formulation. Fresh *Siphonosoma australe-australe* contains approximately 17.01% protein and is particularly rich in glutamic acid, making it a valuable substrate for flavour enhancer production (Yusuf et al., 2025). Furthermore, foam-mat drying at 60°C is considered sufficiently mild to preserve nitrogen-containing compounds and minimize thermal denaturation, thereby maintaining the nutritional quality of the protein fraction (Mayasari et al., 2023). According to the Indonesian National Standard (SNI 01-4273-1996), formulations F3, F4, and F5 exceeded the minimum protein requirement of 7%.



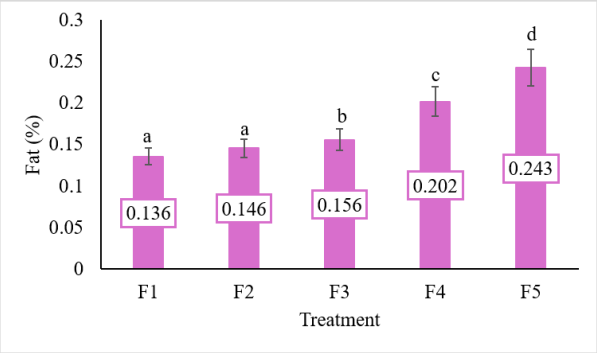
F1: 7.5 mL flavour enhancer extract + 42.5 mL distilled water
F2: 10.0 mL flavour enhancer extract + 40.0 mL distilled water
F3: 12.5 mL flavour enhancer extract + 37.5 mL distilled water
F4: 15.0 mL flavour enhancer extract + 35.0 mL distilled water
F5: 17.5 mL flavour enhancer extract + 32.5 mL distilled water

Figure 3. Protein content of flavor enhancer from Sipou worm

Fat Content

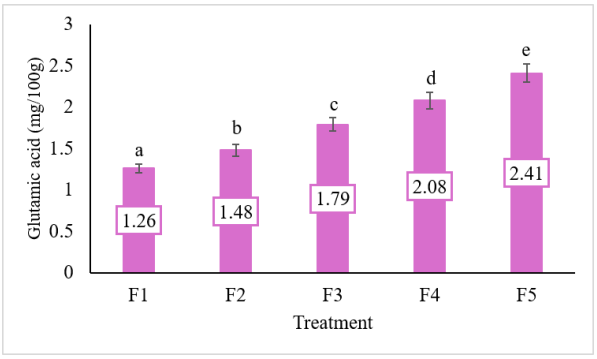
Analysis of variance showed that differences in the proportion of *Siphonosoma australe-australe* extract did not significantly affect the fat content of the foam-mat dried flavour enhancer ($F = 1.773$, $p = 0.174$; $p > 0.05$) (Figure 4). Nevertheless, the average fat concentration increased gradually from 0.136% in F1 to 0.243% in F5, suggesting a positive association with increasing extract concentration.

The consistently low fat content reflects the intrinsic biochemical composition of *Siphonosoma australe-australe*, which contains only about 0.25% fat on a wet-weight basis (Fatimah et al., 2021). In addition, aqueous extraction preferentially solubilizes hydrophilic constituents, while hydrophobic fat fractions remain largely unextracted, resulting in minimal fat recovery in the hydrolysate (Akbar et al., 2019). From a technological perspective, the low fat concentration is advantageous because it reduces the susceptibility of the powder to oxidative rancidity during storage, thereby improving shelf stability (Gumus & Decker, 2021). Moreover, low-fat flavour enhancer are increasingly favored in the functional food market, offering additional commercial value for foam-mat dried *Siphonosoma australe-australe* flavour enhancer.



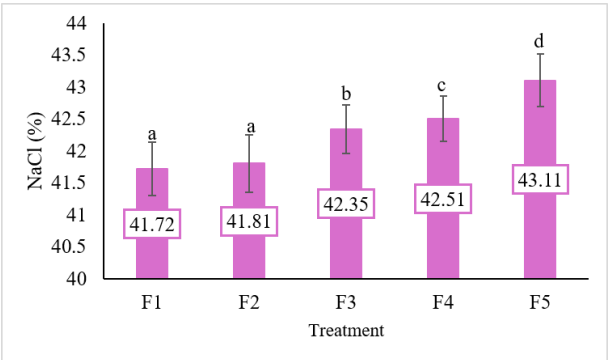
F1: 7.5 mL flavour enhancer extract + 42.5 mL distilled water
F2: 10.0 mL flavour enhancer extract + 40.0 mL distilled water
F3: 12.5 mL flavour enhancer extract + 37.5 mL distilled water
F4: 15.0 mL flavour enhancer extract + 35.0 mL distilled water
F5: 17.5 mL flavour enhancer extract + 32.5 mL distilled water

Figure 4. Fat content of the flavor enhancer from Sipou worms



F1: 7.5 mL flavour enhancer extract + 42.5 mL distilled water
F2: 10.0 mL flavour enhancer extract + 40.0 mL distilled water
F3: 12.5 mL flavour enhancer extract + 37.5 mL distilled water
F4: 15.0 mL flavour enhancer extract + 35.0 mL distilled water
F5: 17.5 mL flavour enhancer extract + 32.5 mL distilled water

Figure 5. Glutamic acid content of flavor enhancer from Sipou worms



F1: 7.5 mL flavour enhancer extract + 42.5 mL distilled water
F2: 10.0 mL flavour enhancer extract + 40.0 mL distilled water
F3: 12.5 mL flavour enhancer extract + 37.5 mL distilled water
F4: 15.0 mL flavour enhancer extract + 35.0 mL distilled water
F5: 17.5 mL flavour enhancer extract + 32.5 mL distilled water

Figure 6. NaCl levels of flavor enhancer from Sipou worms

Glutamic Acid Content

The glutamic acid content increased from 1.26 g/100 g in F1 to 2.41 g/100 g in F5, corresponding to an increase of approximately 91% (Figure 5). This increase was expected because a higher extract-to-water ratio resulted in a greater proportion of extract being incorporated into the formulation, thereby increasing the amount of naturally occurring glutamic acid available in the drying mixture. Importantly, the progressive increase in glutamic acid content across the formulations indicates that the increase in extract proportion was directly reflected in the glutamic acid concentration of the resulting powder. Thus, among the formulations evaluated, F5 provided the highest glutamic acid content and can be considered the most favourable ratio when the primary objective is to maximize the natural glutamic acid content of the flavour enhancer. However, selection of the optimum formulation should also consider other physicochemical and functional properties, as a higher extract proportion may not necessarily provide the most desirable overall powder characteristics.

Glutamic acid is the principal amino acid responsible for the umami taste and is one of the major flavour-active compounds in marine protein hydrolysates. During protein hydrolysis, muscle proteins are degraded into free amino acids and peptides, thereby enhancing savoury flavour and taste complexity (Tang et al., 2023; Liu et al., 2025). The higher glutamic acid content observed in this study is attributed to the greater proportion of Sipou extract, which supplied more soluble proteins available for hydrolysis. Similar increases in glutamic acid and other umami amino acids with higher substrate concentrations have been reported in seafood protein hydrolysates (Kim & Wijesekara, 2023; Tang et al., 2023).

The increasing glutamic acid content was also consistent with the higher protein content across treatments, indicating that formulations containing more Sipou extract provided greater protein substrates for amino acid release. In addition, foam-mat drying at 60°C, together with maltodextrin and gum arabic as encapsulating agents, effectively protected glutamic acid and flavour compounds from thermal degradation and oxidation during drying (Bu et al., 2021). Maltodextrin and gum arabic were selected as encapsulating agents due to their good film-forming and protective properties during spray drying (Laueranty et al., 2023). In this study, their effectiveness in protecting glutamic acid and flavour compounds was evaluated based on the retention of glutamic acid after drying. Therefore, the highest extract-to-water ratio (F5) produced the flavour enhancer with the greatest potential to provide a stronger natural umami taste while supporting the development of clean-label seafood-based flavour enhancers (Kim & Wijesekara, 2023; Tang et al., 2023).

NaCl Content

The results of the one-way ANOVA indicated that the ratio of extract to water had no significant effect on the NaCl content of the foam-mat dried flavour enhancer ($F = 0.283$, $p = 0.885$; $p > 0.05$). The NaCl concentration remained relatively constant across treatments, ranging from 41.72% in F1 to 43.11% in F5 (Figure 6).

The stability of NaCl content among treatments is

primarily attributable to the experimental formulation, in which salt was incorporated at a fixed level equivalent to 15% of the total liquid volume for every treatment. Consequently, variations in the extract-to-water ratio were not expected to alter the final sodium chloride concentration. All formulations remained substantially below the maximum NaCl limit of 65% specified by SNI 01-4273-1996, indicating compliance with national quality standards. In addition to contributing to the characteristic savory taste of flavour enhancer, NaCl also functions as a natural preservative by lowering water activity and inhibiting microbial growth, thereby enhancing product stability during storage (Sainnoin et al., 2019).

Conclusion

The extract-to-water ratio significantly influenced the physicochemical characteristics of the foam-mat dried *Siphonosoma australe-australe* flavour enhancer. Rather than merely reflecting the expected increase in extract-derived components, the results indicate that increasing the extract proportion improved the efficiency of transferring flavour-related constituents from the raw material into the final powder, as reflected by the higher glutamic acid, protein, fat, and NaCl contents. The highest extract-to-water ratio (17.5:32.5 mL) produced the greatest concentration of these constituents and the highest color intensity, indicating a more concentrated extract with greater potential to contribute to the characteristic umami profile of the product. From a processing perspective, these findings suggest that the extract-to-water ratio should be optimized not simply to maximize extract incorporation, but to achieve an effective balance between raw-material utilization, concentration of desirable flavour compounds, and the physicochemical quality of the resulting powder. Thus, the 17.5:32.5 mL ratio represents a promising condition for producing a concentrated marine-derived flavour enhancer with potential as a natural food ingredient.

Acknowledgments

The authors sincerely acknowledge the financial support provided by the Institute for Research and Community Service (LPPM), Universitas Muhammadiyah Semarang, which made this research possible. The authors also express their gratitude for the continuous support and facilities provided throughout the completion of this study.

References

AOAC International. (2023). *Official methods of analysis of AOAC International* (22nd ed.). AOAC International.

Bleakley, S., & Hayes, M. (2017). The bioactive potential of marine invertebrates. *Trends in Food Science & Technology, 64*, 44–56. https://doi.org/10.1016/j.tifs.2017.04.006

Bu, Y., He, W., Zhu, L., Zhu, W., Li, J., Liu, H., & Li, X. (2021). Effects of different wall materials on stability and umami release of microcapsules of Maillard reaction products derived from seafood hydrolysates. *International Journal of Food Science & Technology, 56*(12), 6484–6496. https://doi.org/10.1111/ijfs.15341

Erfianti, R., Kiranawati, T. M., & Rohajatien, U. (2023). Effects of maltodextrin on the physical and chemical properties of periwinkle flower (*Catharanthus roseus*) colorant as a food biocolour.

Fan, Y., Yu, M., Li, D., Zhao, G., Zhang, M., Wang, Z., Liu, Y., & Zhou, D. (2023). Effects of non-enzymatic browning and lipid oxidation on color of ready-to-eat abalone during accelerated storage and its control. *Foods, 12*(7), 1514. https://doi.org/10.3390/foods12071514

Fatimah, S. A., Asnani, & Suwarjoyowirayatno. (2021). Sipou (*Siphonosoma australe-australe*): Its utilization as a food ingredient. *Jurnal Fish Protech, 4*(1), 19–27. https://doi.org/10.33772/jfp.v4i1.18139

Gumus, C. E., & Decker, E. A. (2021). Oxidation in low-moisture foods as a function of surface lipids and fat content. *Foods, 10*(4), 860. https://doi.org/10.3390/foods10040860

Hossain, M. A., Ahmed, T., Ferdaus, J., & Zzaman, W. (2024). Optimization of the foam-mat drying process to develop high-quality tomato powder: A response surface methodology approach. *Heliyon, 10*(21), e39811. https://doi.org/10.1016/j.heliyon.2024.e39811

Hou, Y., Tang, T., Wu, N., Tang, S., Xiao, N., Jiang, Y., Tu, Y., & Xu, M. (2023). Industrial application of flavour enhancer in food. *Journal of Agricultural and Food Chemistry, 71*(4), 1788–1801.

Kadam, D. M., Rai, D. R., Patil, R. T., Wilson, R. A., Kaur, S., & Kumar, R. (2011). Quality of fresh and stored foam-mat dried mandarin powder. *International Journal of Food Science & Technology, 46*(4), 793–799. https://doi.org/10.1111/j.1365-2621.2011.02559.x

Kandasamy, P., Varadharaju, N., Kalemullah, S., & Maladhi, D. (2015). Foam-mat drying of food materials: A review. *Journal of Food Processing and Preservation, 39*(6), 3165–3174. https://doi.org/10.1111/jfpp.12421

Kim, S. K., & Wijesekara, I. (2023). Fish protein hydrolysates and their industrial applications as natural flavour enhancers: A review. *Heliyon, 9*, e14358.

Kim, S.-K., & Wijesekara, I. (2010). Development and biological activities of marine-derived bioactive peptides. *Journal of Functional Foods, 2*(1), 1–9. https://doi.org/10.1016/j.jff.2010.01.003

Laureanti, E. J. G., Paiva, T. S., de Matos Jorge, L. M., & Jorge, R. M. M. (2023). Microencapsulation of bioactive compound extracts using maltodextrin and gum arabic by spray and freeze-drying techniques. *International Journal of Biological Macromolecules, 253*, 126969. https://doi.org/10.1016/j.ijbiomac.2023.126969

Lee, Y. P., & Takahashi, T. (1966). An improved colorimetric determination of amino acids with the use of ninhydrin. *Analytical Biochemistry, 14*(1), 71–77. https://doi.org/10.1016/0003-2697(66)90057-1

Liu, Y., Zhang, H., Chen, J., Li, Q., & Wang, X. (2025). Improving the flavor of protein hydrolysates from

shrimp processing by-products via Maillard reaction: Towards structure–flavor relationships. *Food Chemistry, 505*, 143968.

Nadhifah, A., Kholifatuddin, Y., & Handarsari, E. (2021). Moisture content and color of natural oyster mushroom (*Pleurotus ostreatus*) seasoning based on pretreatment. *Jurnal Gizi, 10*(2), 33–40.

Nielsen, P. M., Petersen, D., & Dambmann, C. (2017). Improved food flavor by enzymatic protein hydrolysis. *Current Opinion in Food Science, 13*, 31–38.

Sainnoin, R. A., Mauboy, R. S., & Ati, V. M. (2019). Effect of NaCl concentration on the fat content of several types of salted fish sold at Oeba and Oesapa Markets, Kupang City. *Jurnal Biotropikal Sains, 16*(1), 41–48.

Sangamithra, A., Venkatachalam, S., John, S. G., & Kuppuswamy, K. (2015). Foam-mat drying of food materials: A review. *Journal of Food Processing and Preservation, 39*(6), 3165–3174. https://doi.org/10.1111/jfpp.12421

Susi, S., & Al Hakim, H. M. (2022). Comparison of NaCl levels in seasoning powder formulation of Nagara bean flour (*Vigna unguiculata* ssp. *cylindrica*) and oyster mushroom using the Mohr method by direct titration and ash mineral titration. *Journal of Applied Food Technology, 9*(2), 24–29. https://doi.org/10.17728/jaft.12547

Yonata, D., Nurhidajah, N., Pranata, B., & Yusuf, M. (2021). Development of natural flavor enhancer from swimming crab shells using the foam-mat drying method. *Agrointek: Jurnal Teknologi Industri Pertanian, 15*(1), 371–381. https://doi.org/10.21107/agrointek.v15i1.8799

Yusuf, M., Hardiwinoto, Rosli, S. Z., Yonata, D., & Pranata, B. (2025). Effect of type and concentration of organic acids on the extraction efficiency of glutamic acid and bioactive compounds from sipou (*Siphonosoma australe-australe*). *Jurnal Pengolahan Hasil Perikanan Indonesia, 28*(10), 853–866. https://doi.org/10.17844/mbj25v10