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# MORPHOMETRIC CHARACTERISTICS AND CHEMICAL COMPOSITION OF PEANUT WORM (*Sipunculus nudus*) FROM WATERS OF KONAWE ISLANDS REGENCY, SOUTHEAST SULAWESI, INDONESIA

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**Abstract**

Peanut worms (*Sipunculus nudus*) are marine benthic organisms that are promising locally sourced alternative functional foods for communities in Southeast Sulawesi, Indonesia. Integrated morphometric characteristics and chemical composition data on peanut worms sourced from the Konawe Islands Regency in Southeast Sulawesi are limited. This study aimed to determine the morphometric characteristics and chemical composition, including the proximate, mineral, and fatty acid profiles, of *S. nudus* from the waters of the Konawe Islands Regency. This study employed an experimental approach using an independent samples t-test consisting of two treatments: fresh and dried, each with three replicates. The results showed that *S. nudus* had average morphometric values of length 12.36 cm, diameter 2.97 cm, and weight 46.40 g, with a meat yield of 34.62%. Sun-drying reduces moisture and carbohydrate levels but increases the relative proportion of protein, fat, ash, minerals, and fatty acids owing to concentration. This increase from fresh to dried samples is shown in the protein content from 17.83% to 80.32%, ash content from 1.74% to 7.34%, and fat content from 0.22% to 0.76%. Sodium had the highest mineral content in both fresh and dried peanut worms, with values of 38,725 mg/kg and 56,820 mg/kg, respectively. Fourteen fatty acids were identified in the sample, consisting of eight SFAs, three monounsaturated fatty acids (MUFAs), and three polyunsaturated fatty acids (PUFAs). Palmitic acid was the most abundant SFA at 1.76%, whereas oleic acid (MUFA) and linoleic acid (PUFA) were present at 0.22% and 0.21%, respectively. These findings confirm *S. nudus* as an alternative functional food source derived from local marine biota.

Keywords: palmitic acid, peanut worm, proximate, sodium, yield http://dx.doi.org/10.17844/b26sgx17

# Karakteristik Morfometrik dan Komposisi Kimia Cacing Kacang (*Sipunculus nudus*) dari Perairan Kabupaten Konawe Kepulauan, Sulawesi Tenggara, Indonesia


## Abstrak

Cacing kacang (*Sipunculus nudus*) merupakan organisme bentik laut yang berpotensi tinggi sebagai sumber pangan alternatif dan pangan fungsional berbasis sumber daya laut lokal, tetapi data ilmiah yang terintegrasi mengenai karakteristik morfometrik dan komposisi kimianya di Kabupaten Konawe Kepulauan, Provinsi Sulawesi Tenggara, Indonesia masih terbatas. Penelitian ini bertujuan untuk menentukan karakteristik morfometrik dan komposisi kimia meliputi proksimat, mineral, dan asam lemak pada *S. nudus* dari Perairan Kabupaten Konawe Kepulauan. Penelitian ini menggunakan pendekatan eksperimental dengan uji-t sampel independen yang terdiri dari dua perlakuan, segar dan kering, masing-masing dengan tiga ulangan. Hasil penelitian menunjukkan bahwa *S. nudus* memiliki nilai rata-rata morfometrik, yaitu panjang 12,36 cm, diameter 2,97 cm, bobot 46,40 g dengan rendemen daging sebesar 34,62%. Proses pengeringan matahari menyebabkan penurunan kadar air dan karbohidrat, tetapi meningkatkan proporsi relatif protein, lemak, abu, mineral, dan asam lemak akibat efek konsentrasi setelah kehilangan air. Kadar protein meningkat dari 17,83 % (segar) menjadi 80,32 % (kering), kadar abu dari 1,74 % menjadi 7,34 %, dan kadar lemak dari 0,22 % menjadi 0,76 %. Kandungan mineral tertinggi pada cacing kacang segar dan kering adalah natrium, masing-masing sebesar 38.725 mg/kg dan 56.820 mg/kg. Analisis asam lemak menunjukkan teridentifikasinya 14 jenis asam lemak yang terdiri atas 8 SFA, 3 MUFA, dan 3 PUFA. Asam palmitat merupakan SFA tertinggi sebesar 1,76%, sedangkan asam oleat dan asam linoleat masing-masing merupakan MUFA dan PUFA tertinggi dengan nilai sebesar 0,22% dan 0,21%. Temuan ini menunjukkan potensi *S. nudus* sebagai sumber protein alternatif dan bahan baku pangan fungsional berbasis biota laut lokal.


Kata kunci: asam palmitat, cacing kacang, natrium, proksimat, rendemen

## INTRODUCTION

Indonesia possesses the highest biodiversity as it is one of the largest archipelagos worldwide. The tropical coastal ecosystem supports various marine biota in Indonesian waters, including fish, crustaceans, mollusks, echinoderms, algae, and benthic organisms, which have important nutritional and economic value. Recently, alternative and functional foods from marine organisms have been considered for further exploration to diversify and develop sustainable marine products (Nugraha *et al.,* 2023; Aulia *et al.,* 2024; Erlangga *et al.,* 2025; Saputri *et al.,* 2025).

Peanut worms, especially *Sipunculus nudus*, are marine benthic organisms that have traditionally served as local food sources for Indonesian coastal communities, particularly in Southeast Sulawesi. However, their potential as alternative food sources has not yet been fully explored (Silaban & Rieuwpassa, 2019; Cintra *et al.*, 2024). Peanut worms are commercially available in dried form and can be used after boiling and cooking. They can also be consumed raw as a side dish (Akbar *et al.*, 2019; Rahayu *et al.*, 2019). *S. nudus* is widely known in many Asian countries as a food and traditional medicine because of its nutritional value and potential bioactive compounds (Lemer *et al.*, 2015; Li *et al.*, 2019; Yang *et al.*, 2020).

*S. nudus* is a benthic organism from the phylum Sipuncula in taxonomy, but the latest complete mitochondrial genomic analysis (mt) classifies this species within, or as having a close relationship with, Annelida (Qi *et al.,* 2023). This cylindrical, non-segmented-bodied organism lives beneath sandy to muddy substrates in shallow intertidal to subtidal waters and is widely distributed in tropical and subtropical areas (Vargas *et al.,* 2016 & Guo *et al.,* 2019).

The presents this species as a bioprospecting commodity with complete macronutrients, including protein, fat, and carbohydrates. Proximate analysis of *S. nudus* shows a protein content of 9.79% (wet) to 80.83-82.46% (dried), with a fat content of approximately 1.34-1.70%, and carbohydrate of 6.80-7.26% (Huong *et al*., 2019 & Hartanti *et al*., 2023). Fatty acids (e.g., palmitic, palmitoleic, arachidonic, and oleic acids), essential amino acids, minerals, and various vitamins (A, B1, B6, B12, and E) are also present in this organism, suggesting that its quality is comparable to that of fish (Silaban, 2019). This nutritional value highlights its potential as an alternative source of protein and raw material in the food processing industry. However, its nutritional quality and chemical characteristics are greatly influenced by habitat and ecological conditions, which are reflected in its morphometric and other biological characteristics.

The environmental conditions of the Konawe Islands waters strongly influence *S. nudus* biological characteristics and nutritional content, which is yet to be discussed, presenting an important research gap that needs to be studied to optimize the use of these resources. The linked correlation between the morphometric characteristics and chemical composition of *S. nudus* from this area and its local habitat conditions was tested as a hypothesis in this study. Accordingly, this study aimed to determine the morphometric characteristics and chemical composition, including proximate, mineral, and fatty acid profiles, of *S. nudus* from the waters of the Konawe Islands Regency.

## MATERIALS AND METHODS

### Sample Collection

A total of 30 *S. nudus* specimens were collected in January 2024 using a purposive sampling method based on species presence. The sampling locations were two sites in coastal areas, namely Langara Tanjung Batu Village and Baho Bubu Village in the Konawe Islands Regency, Southeast Sulawesi Province, Indonesia. Langara Tanjung Batu Village was selected because it has a sandy-muddy substrate suitable for the burrowing behavior of *S. nudus*, while Baho Bubu Village was chosen because it represents an intertidal zone with high organic matter content, thereby supporting the availability of food sources for the species. Thus, the two locations together represent the natural habitat of *S. nudus*. Specimens were collected at low tide using a serampang, in accordance with the sampling procedure described by Nurhikma *et al.* (2017). Immediately following collection, the samples were transported to the laboratory under cool, oxygenated conditions to minimize stress and mortality. All individuals were thoroughly rinsed under running tap water to remove residual sediment, epibionts, and other external debris. Following cleaning, morphometric and yield analyses were performed on each specimen.

### Sample Preparation

Samples of live and fresh peanut worms were prepared by immersion in ice water for 10-15 min to induce a state of immobility. The worm's trunk (flesh), water content, and viscera were separated and cleaned with running water, according to the method described by Nurhikma *et al.* (2017). Some samples were sun-dried, around weather with temperatures of 27-37°C for two days, about 8 hours per day (Imbir *et al.,* 2015). The fresh and dried peanut worm samples were then subjected to proximate analysis (water, ash, protein, fat, and carbohydrate content), mineral analysis, and fatty acid and phytochemical profiling.

### Morphometric Measurements of Peanut Worms

Morphometric measurements of *S. nudus* were conducted following the methodology described by Ferdinandus *et al.* (2022), as follows. Each *S. nudus* specimen was measured for total body length (cm), body diameter (cm), and total body weight (g). Body length and diameter were measured to the nearest millimeter using a ruler, and body weight was determined using a digital analytical balance.

### Peanut Worms Yield Analysis

Yield analysis was performed by calculating the percentage ratio between the final component weight and the initial total body weight of each *S. nudus* specimen, following the standard procedures outlined by Nurhikma *et al.* (2017). This approach enables a quantitative assessment of the meat, viscera, and water content relative to the total mass of the organism. The yield (%) was calculated using the following formula:

$$\%\text{yield} = \frac{\text{final weight of } S.\ nudus \text{ (g)}}{\text{initial weight of } S.\ nudus \text{ (g)}} \times 100$$

## Proximate analysis

The proximate analysis in this study was performed according to the modified AOAC (2005) method, which includes water, ash, protein, and fat. Moisture and ash contents were analyzed using an oven and furnace, respectively. Protein and fat contents were analyzed using the Kjeldahl and Soxhlet methods, respectively, while carbohydrates were tested using the difference method.

## Mineral Analysis

The analysis of calcium (Ca), potassium (K), sodium (Na), magnesium (Mg), and phosphorus (P) was performed using an atomic absorption spectrophotometer (AAS) in this study, referring to the method by modified AOAC (2005). The mineral content was determined using atomic absorption spectroscopy (AAS). Samples (approximately 1-2 g) were first dried, crushed, and transferred into a beaker that had been cleaned with 1 N HCl. Following the addition of 25 mL of 1 N HCl, the mixture was agitated on a shaker for 24 hours. The resulting extract was filtered through a Whatman No. 1 filter paper. A 1 mL aliquot of the filtrate was transferred to a volumetric flask, combined with 2 mL of lanthanum oxide solution and 1 N HCl to a volume of 10 mL, and then diluted with distilled water to a total volume of 50 mL. The absorbance was measured using AAS at specific wavelengths for each element: 422.7 nm (Ca), 766.5 nm (K), 213.9 nm (Na), 285.2 nm (Mg), and 248.3 nm (P).

## Fatty Acid Analysis

Fatty acid analysis was conducted using gas chromatography, as described by the modified AOAC (2005) method. Samples were prepared via solvent extraction using a Soxhlet apparatus, yielding 0.02 g of liquid fat. Separately, a methanolic NaOH solution (5 mL) was prepared and heated at 80°C for 20 min before cooling to room temperature. This solution was added to the liquid fat sample and heated at 80°C for an additional 20 min. Subsequently, 2 mL of saturated NaCl and 5 mL of hexane were added and homogenized; the resulting hexane layer was then transferred to a reaction tube containing the pre-heated sample, and an aliquot of 2-5 µL was injected into a gas chromatograph (GC) equipped with a flame ionization detector (FID). The GC was operated under the following conditions: the column used was a Pico-Tag (3.9×300 mm) with a diethyl glycol succinate (DEGS) stationary phase and nitrogen ($N_2$) as the mobile phase. The oven temperature was programmed with an initial temperature of 150°C, increasing at a rate of 5°C/min to a final temperature of 180°C, while the detector was maintained at 250°C. The flow rates of $H_2$ and $N_2$ were set at 2.5 kgf/cm$^2$ and 50 kgf/cm$^2$, respectively, with a pressure of 3,000 psi. Fatty acids were identified based on the FID response recorded in the chromatogram. The quantitative measurement of fatty acids was calculated using the following formula:

$$\text{Fatty acid (mg/fat)} = \frac{A}{100 - B} \times 100\%$$

A = Sample concentration
B = Solvent concentration

## Data Analysis

Data obtained from the proximate composition (moisture, ash, protein, fat, and carbohydrate content), mineral composition (Ca, K, Mg, Na, and P), and fatty acid content of fresh and sun-dried *S. nudus* were determined in triplicates. The resulting data were statistically compared between the two treatment groups using an independent samples t-test. Statistical analyses were performed using IBM SPSS Statistics version 26.0, and differences were regarded as statistically significant at $p<0.05$.

# RESULTS AND DISCUSSIONS

## Peanut Worms Morphometrics

Morphometrics is a morphological measurement method using standardized body morphology adapted to the life phase of the pea worm *S. nudus* to measure length, weight, and physical scale (Figure 1). Morphological systematics of animals is determined by morphological measurements such as length and weight; therefore, it has valid evidence and is the easiest to identify (Gonzalez-Martinez *et al.,* 2020; Labidi *et al.,* 2021; Bhatkar *et al.,* 2025; Currie *et al.,* 2025). Morphometric observations of *S. nudus* peanut worm include measurements of total length, total weight, meat weight, viscera weight, water weight and yield (meat, viscera and water). The results of the morphometric observations and yield of peanut worms are presented in Table 1.

The morphometric measurements of *S. nudus* specimens in the present study yielded mean values of 12.36 cm in length, 2.97 cm in diameter, and 46.40 g total body weight. These findings indicate larger dimensions than those reported by Silaban (2018), who recorded average values of 10.04 cm in length, 1.81 cm in diameter, and 25.84 g in body weight for the same species. In contrast, when compared with the morphometric data from Nurhikma *et al.* (2017) on a different species, *S. australe*, our specimens were found to be shorter in length (17.07 cm) and lighter in body weight (49.77 g). However, they exhibited a greater body diameter than *S. australe*, which averaged 1.47 cm. These inter-study variations suggest that morphometric traits, such as length, diameter, and body mass, in peanut worms are influenced by a range of biological and ecological factors.

Growth in *S. nudus*, as with many marine invertebrates, is likely governed by both intrinsic species characteristics and extrinsic environmental conditions. Body length and diameter were closely correlated with body mass, indicating that morphometric parameters are reliable indicators of growth status. The growth dynamics of peanut worms appear to be analogous to those observed in teleost fish. Mounir *et al.* (2017), Dubuc *et al.* (2024), and Yang *et al.* (2024) outlined that fish growth rates are regulated by a combination of age, species, nutrition, physiological conditions, climatic factors, and genetic predispositions, all of which interact to influence the overall growth trajectory. Environmental conditions also play a pivotal

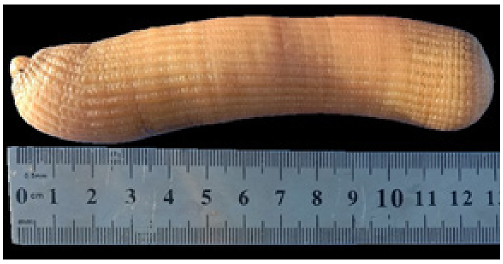


Figure 1 Morphometric observation of peanut worms

Table 1 Morphometrics and yield of peanut worms

| Parameters | *S. nudus* | *S. nudus*[a] | *S. australe*[b] |
|---|---|---|---|
| Length (cm) | 12.36±1.36 | 10.04±1.82 | 17.07±2.73 |
| Diameter (cm) | 2.97±3.69 | 1.81±0.39 | 1.47±0.24 |
| Total weight (g) | 46.40±9.16 | 25.84±9.58 | 49.77±14.02 |
| Meat weight (g) | 16.07±4.61 | - | 21.62±6.27 |
| Offal weight (g) | 8.51±3.16 | - | 10.36±3.50 |
| Water weight (g) | 21.83±5.82 | - | - |
| Meat yield (%) | 34.62±4.97 | - | 67.25 |
| Offal yield (%) | 18.33±5.49 | - | 32.39 |
| Water yield (%) | 47.03±6.88 | - | - |

[a]Silaban (2018); [b]Nurhikma *et al.* (2017)

role in shaping the morphometric outcomes. According to Marzouk *et al.* (2016), López-Rocha *et al.* (2018), and Maiorova and Adrianov (2018), variables such as salinity, habitat suitability, and availability of nutrient-rich particulate matter significantly influence the growth of benthic marine invertebrates.

## Peanut Worms Yield

Yield, commonly expressed as a percentage, reflects the proportion of usable products derived from a given amount of raw material. It is a critical parameter for evaluating material efficiency, particularly in food processing and product development. In the present study, the yield analysis of *S. nudus* collected from Southeast Sulawesi revealed a composition of 34.62% edible meat, 18.33% offal, and 47.03% water. These results indicate that water comprises the largest component of the organism by weight, exceeding the combined weights of meat and offal. This finding is consistent with the existing literature, which consistently reports that peanut worms and related species exhibit high moisture content. For example, Cutler (1994) and Goto *et al.* (2016) noted that water typically accounts for 60% to 80% of the total body mass in similar marine invertebrates. The high-water content observed in *S. nudus* is not merely a compositional trait but also reflects its physiological importance. Water plays an essential role in maintaining osmotic balance, supporting metabolic processes, and preserving the structural integrity of organisms.

Nurhikma *et al.* (2017) reported that the yield of *Siphonosoma australe* collected from the coastal waters of Toronipa, Southeast Sulawesi, consisted of 67.25% meat and 32.39% of offal. These data demonstrate that the proportion of edible meat significantly exceeds that of offal, a pattern consistent with the yield composition observed in *S. nudus* specimens obtained from the waters of Konawe Kepulauan Regency. The comparability of the yield profiles between these two species suggests a potentially similar anatomical or ecological adaptation that favors higher meat content.

The rapid growth characteristics of juvenile peanut worms may also contribute to yield variability. According to Wati *et al.* (2021), *S. nudus* individuals aged between 0.08 and 2.50 months exhibit accelerated growth, with the most rapid increase in body length occurring at approximately 0.16 months of age. At this stage, worms reach an average length of 124.701 mm, suggesting a corresponding increase in biomass, including meat mass. This growth pattern may be influenced by their deposit-feeding behavior, which enables them to accumulate substantial quantities of organic matter and sedimentary particles within their bodies, thus supporting growth and nutrient assimilation.

Environmental conditions, particularly sediment dynamics, play a critical role in the growth and yield potential of these organisms. Huang *et al.* (2023) and Liu *et al.* (2023) observed that elevated hydrodynamic flow rates contribute to the aggregation of larger sand and mud particles, thereby enhancing food particle availability for deposit feeders, such as peanut worms. Increased food availability positively influences somatic growth, which subsequently affects the overall size, length, and meat yield of these marine invertebrates.

## Proximate Profile of Dried and Fresh Peanut Worms

The proximate composition of fresh and sun-dried *S. nudus* was evaluated by determining the moisture, ash, protein, fat, and carbohydrate contents. Statistical analysis using an independent samples t-test revealed significant differences in moisture, ash, protein, lipid, and carbohydrate contents between the two treatments ($p<0.05$). The proximate composition of fresh and sun-dried peanut worms is presented in Table 2.

The average water content of peanut worms was 79.01% (fresh) and 11.32% (sun-dried), as presented in Table 2. As Avila *et al.* (2022) explained, drying causes the release of water molecules from the product, thereby reducing the water content. Tapotubun (2018) stated that the drying process using sunlight tends to be slower because of the

Table 2 Chemical composition of peanut worms

| Chemical composition (%) | *S. nudus* | | | | *S. australe* | | | *S. robustus* | *Xenisifon* sp. |
|---|---|---|---|---|---|---|---|---|---|
| | Fresh | Sun-dried | Fresh[1] | Sun-dried[2] | Fresh[3] | Freeze dry[3] | Fresh[4] | Fresh[5] | Fresh[6] |
| Moisture | 79.01±0.29[a] | 11.32±0.20[b] | 82.00 | 22.25 | 85.25 | 13.69 | 9.59 | 79.87 | 76.47 |
| Ash | 1.74±0.13[a] | 7.34±0.21[b] | 0.74 | 27.85 | 3.03 | 15.08 | 0.64 | 2.20 | 2.20 |
| Protein | 17.83±0.27[a] | 80.32±0.17[b] | 12.80 | 48.15 | 10.11 | 56.35 | 17.39 | 17.61 | 10.61 |
| Lipid | 0.22±0.08[a] | 0.76±0.08[b] | 1.56 | 1.12 | 0.54 | 9.82 | 1.28 | 0.29 | 0.18 |
| Carbohydrate | 1.20±0.47[a] | 0.26±0.20[b] | 2.30 | 0.63 | 1.07 | 5.06 | - | 0.37 | 10.02 |

Different superscript letters within the same row denote statistically significant differences between fresh and sun-dried *S. nudus*, as determined using an independent samples t-test ($p<0.05$);

[1]Salawati *et al.* (2024); [2]Silaban & Rieuwpassa (2019); [3]Nurhikma *et al.* (2017); [4]Rahayu *et al.* (2019); [5]Erliani (2021); [6]Fakhrurrozi (2011)

non-constant air temperature. The longer the drying process, the lower the water content trace and the higher the other chemical composition. Janetti and Janssen (2020) and Babiker *et al.* (2024) stated that the longer the drying time, the slower the moisture loss rate, but with much less water content remaining in the material. Tenyang *et al.* (2020) and Chibuezeh *et al.* (2022) observed that the loss of moisture content contributes to an increase in the relative concentrations of nutritional components, particularly ash, protein, and fat. Furthermore, Zhang *et al.* (2017) noted that the drying process significantly influences the nutrient profiles of materials. While an optimized drying process enhances nutrient stability by inhibiting enzymatic and microbial activities, improper methods, such as over-drying or high-temperature exposure, may lead to the degradation of heat-sensitive compounds, including specific amino acids and unsaturated fatty acids, thereby reducing the overall nutritional value of the product.

The moisture content of fresh *S. nudus* samples observed in the present study was comparatively higher than the values reported by Rahayu *et al.* (2019), who recorded a moisture content of 9.59% in fresh *S. australe* from the Wakatobi coastal region. Similarly, the values exceeded those reported by Fakhrurrozi (2011) for *Xenisiphon* sp. collected from the waters of Bangka Belitung, which had a recorded moisture content of 76.47% in fresh samples. Conversely, the moisture content of both fresh and dried peanut worms in this study was lower than that reported in several previously published studies. For instance, Salawati *et al.* (2024) reported a moisture content of 82.00% in fresh *S. nudus* specimens from North Minahasa, while Silaban and Rieuwpassa (2019) recorded 22.25% moisture content in dried peanut worms from Nusalaut. Likewise, Nurhikma *et al.* (2017) reported 82.25% moisture in fresh and 13.69% in freeze-dried *S. australe* collected from Konawe water. In a related study, Erliani (2021) found that fresh *S. robustus* specimens from Banda Naira contained 79.87% moisture content.

Variations in moisture content among species samples are attributed to differences in habitat, environmental conditions, species-specific characteristics, and the drying mechanisms employed. Furthermore, Fitri *et al.* (2022) noted that the age at harvest plays a significant role, as younger organisms typically exhibit higher water content owing to elevated metabolic activity and greater tissue hydration compared to older individuals. However, this pattern may vary across species, and environmental conditions remain the predominant influencing factors. Binalshikh-Abubkr *et al.* (2021) stated that the differences in the moisture content of marine biota are caused by the type and age of the biota, differences in environmental conditions (such as temperature, pH of dissolved oxygen, salinity, and seasons), and the metabolism of the biota.

Fresh peanut worms had 1.74% ash content, whereas dried ones had 7.34% ash content (Table 2). The increase in ash content is thought to be caused by drying, which Hossain *et al.* (2017) and Majumdar *et al.* (2017) mentioned was due to significant water evaporation from the dried material. The drying process of a material increases the calculated ash content, which is influenced by the type of material, ashing, and drying method (including time and temperature).

The ash content of fresh *S. nudus* specimens in the present study was higher than the values reported by Salawati *et al.* (2024), who found 0.74% ash content in the same species from North Minahasa waters, and Rahayu *et al.* (2019), who reported 0.64% ash content in fresh *S. australe from* Wakatobi. In contrast, the ash content observed in both fresh and dried samples in this study was lower than that reported in several other studies. Nurhikma *et al.* (2017) recorded ash contents of 3.03% in fresh and 15.08% in freeze-dried *S. australe* from Konawe, Indonesia. Similarly, Silaban & Rieuwpassa (2019) reported 27.85% ash in dried *S. nudus* from Nusalaut. More extreme values were noted by Erliani (2021), who documented an ash content of 82.00% in fresh *S. robustus* from Banda Naira, and by Fakhrurrozi (2011), who found 79.87% in fresh *Xenisiphon* sp. from Bangka, Belitung. The difference in ash content in peanut worms is thought to be due to the difference in the type and nutritional habitat of their food. This is aligned with studies by Erniati *et al.* (2023) and Zhong *et al.* (2024), who stated that differences in habitat, eating habits, geographic characteristics, or environmental substrate influence ash content.

The protein content of peanut worms is an important aspect of their nutritional value, recorded at 17.83% in fresh and 80.32% in sun-dried samples (Table 2). The increase in protein content in the dried samples does not indicate an absolute increase in protein content but rather a concentration effect due to the decrease in water content during the drying process. The loss of water content causes a higher proportion of dry matter components, including proteins, to be present in the total sample weight. Therefore, the percentage of protein measured in the dried samples increases as the water content decreases (Öztürk & Gündüz, 2018; Fitri *et al.,* 2024). The high protein content is related to the eating habits of peanut worms, which consume sediment rich in organic matter as the main source of nutrients in their habitat. This finding is consistent with that of Leiwakabessy *et al.* (2017), who noted that proteins, carbohydrates, and fats are organic materials deposited in sediments and consumed by peanut worms, contributing to their high protein content.

The protein content of both fresh and dried *S. nudus* observed in the present study was higher than that reported in several previous studies across various regions in Indonesia. For example, *S. nudus* from North Minahasa waters exhibited a protein content of 12.80% in fresh samples (Salawati *et al.,* 2024), whereas dried specimens from Nusalaut waters had 48.15% protein (Silaban & Rieuwpassa, 2019). Similarly, *S. australe* from Konawe waters contained 10.11% protein in fresh form and 56.35% when freeze-dried (Nurhikma *et al.,*2017). Other comparative data include fresh *S. australe* from Wakatobi waters, which showed 17.39% protein content (Rahayu *et al.,* 2019), and *S. robustus* from Banda Naira, which contained 17.61% protein content in the fresh condition (Erliani, 2021). Additionally, *Xenisifon* sp. from Bangka Belitung waters demonstrated a relatively low protein content of 10.61% in fresh samples (Fakhrurrozi, 2011). These findings also highlight that differences in protein content across various peanut worm species are influenced by biological and environmental factors such as diet, habitat characteristics, body size, and water content. Tamarit-Pino *et al.* (2019) and Liu *et al.* (2021) stated that variations in environmental conditions and nutrient availability can affect metabolic activity and protein assimilation efficiency, thus contributing to differences in protein content between species and habitats. Kazangeldina *et al.* (2022) explained that metabolism causes differences in protein levels in organisms, which are also affected by food types, habitats, species, body size, and moisture levels that vary between each type.

The fat content of fresh and dried peanut worms was 0.22% and 0.76%, respectively (Table 2). Dried peanut worms have a higher fat content than fresh peanut worms because drying is thought to be inversely proportional and simultaneously influences the decrease in moisture after drying (Silaban & Rieuwpassa, 2019), where the fat content increases during the drying process. The increase in lipid content after drying does not indicate an actual increase in lipid content but rather a concentration effect caused by the loss of water during the dehydration process. As moisture evaporates, the total weight of the sample decreases, resulting in a higher proportion of lipid components than the dry weight of the sample. Furthermore, the disruption of cellular structures during drying can enhance lipid extraction, making fat more readily detectable during proximate analysis (Bilgin & Tanrikulu, 2018; Banda *et al.,* 2023).

The fat content of both fresh and dried *S. nudus* in the present study was generally lower than that reported in previous studies. Salawati *et al.* (2024) recorded a fat content of 1.56% in fresh *S. nudus* from North Minahasa waters, whereas Silaban & Rieuwpassa (2019) reported 1.12% in dried samples of the same species from Nusalaut. For *S. australe*, Nurhikma *et al.* (2017) found higher fat levels, with 3.03% in fresh and 15.08% in freeze-dried samples from Konawe waters, respectively. Similarly, Rahayu *et al.* (2019) reported a fat content of 1.28% in fresh *S. australe* from Wakatobi. Interestingly, the fat content of dried *S. nudus* in the present study was higher than that reported by Silaban & Rieuwpassa (2019) for fresh samples of the same species, which had a fat content of only 0.63%. The difference in fat content of peanut worm flesh is thought to be influenced by water content, nutrition, species, and habitat. Lestaluhu *et al.* (2020) stated that the nutritional content of a marine organism varies depending on its nutrition, age, and species. Sánchez-Solís *et al.* (2021) and Karapanagiotidis *et al.* (2024) explained that habitat factors such as sediment type, organic matter content, temperature, and salinity can influence feeding activity and lipid accumulation in peanut worms. Furthermore, differences in metabolism, reproductive stage, body size, and nutrient assimilation efficiency contribute to variations in lipid content between species and habitats. The drying method also influences the measured lipid content, as a reduction in water content during the drying process increases the relative proportion of lipids in the sample.

The calculation results (by difference) of the carbohydrate content of fresh peanut worms were 1.20%, while the dried worms were 0.26% (Table 2). Changes in the moisture, ash, protein, and fat contents may influence the carbohydrate content of dry products. According to Rasul *et al.* (2021) and Kalita & Basumatari (2024), when the other nutritional content decreases, the carbohydrate content increases based on calculations using different methods. The lower the other nutritional components, the higher was the carbohydrate content, and vice versa.

The carbohydrate content of both fresh and dried *S. nudus* in the present study was lower than that reported in several previous studies. Salawati *et al.* (2024) reported a carbohydrate content of 2.30% in fresh *S. nudus* from North Minahasa waters, whereas Silaban & Rieuwpassa (2019) found 0.63% in dried samples of the same species from Nusalaut waters. In *S. australe*, Nurhikma *et al.* (2017) recorded a higher carbohydrate content of 5.06% in freeze-dried samples collected from Konawe, Indonesia. Likewise, *Xenisifon* sp. from Bangka Belitung showed a substantially higher carbohydrate level of 10.02% in fresh conditions (Fakhrurrozi, 2011). In contrast, the carbohydrate content of both fresh and dried *S. nudus* in this study was higher than that reported by Erliani (2021), who found only 0.37% fat in fresh *S. robustus* collected from Banda Naira waters. The species habitat, nutrient content, and different processing methods of peanut worms influence the differences in carbohydrate content. Rasul *et al.* (2021) explained that the carbohydrate content is influenced by nutrients in the worm diet, species, habitat, and drying process. Birie *et al.* (2025) mentioned that differences in the proportion of other nutritional contents, such as water, protein, fat, and ash, may also contribute.

## Mineral Content of Fresh and Dried Peanut Worms

The mineral composition of marine organisms is widely recognized as an important indicator of their nutritional value and plays a key role in assessing their potential as functional food resources (Mohanty *et al*., 2019). The results showed that dried peanut worms have a higher content of calcium (Ca), potassium (K), magnesium (Mg), sodium (Na), and phosphorus (P) compared to fresh peanut worms, showing that the drying process improves the mineral content of peanut worms. Statistical analysis using an independent samples t-test demonstrated that Ca, K, Mg, Na, and P differed significantly between fresh and sun-dried *S. nudus* ($p<0.05$). The mineral compositions of fresh and sun-dried peanut worms are presented in Table 3.

The analysis showed that sodium was the highest in both fresh (38,725 mg/kg) and dried peanut worms (56,820 mg/kg), whereas phosphorus was the lowest in both fresh (474 mg/kg) and dried peanut worms (3,8306 mg/kg). The sodium content found in the samples in this study was lower than that reported by Nurhikma *et al.* (2017), where fresh *S. australe* had 43,700 mg/kg and its freeze-dried product had 127,334 mg/kg sodium. The phosphorus content in the previous study also varied, being higher in fresh (1,500 mg/kg) but lower in freeze-dried peanut worms (3,722 mg/kg). The difference was due to differences in the sampling areas and environmental conditions. According to Barzkar *et al.* (2017) and Rahul *et al.* (2024), mineral content can be influenced by habitat and environmental conditions. Each aquatic environment can provide different mineral intakes for aquatic organisms. Rahman *et al.* (2018) also stated that differences in mineral levels in an organism can be caused by differences in the types of food and environmental conditions in which they live.

Peanut worms, being marine animals, inhabit an environment rich in sodium and chloride minerals, which significantly contributes to their high sodium levels (Huong *et al.,* 2019; Ba *et al.,* 2022). Sodium, a mineral crucially bound to proteins, including enzymes involved in metabolic processes, plays a vital role in maintaining cell osmotic pressure, regulating cell membrane permeability, forming salts, and healing wounds (Manullang *et al.,* 2016; Ardiansyah *et al.,* 2020; Rodrigues *et al.*, 2021).

## Fatty Acid Profiles of Fresh and Dried Peanut Worms

Fatty acids are classified into three types: saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA) (Guo *et al.,* 2022; Irnawati *et al.,* 2024). Statistical analysis using an independent samples t-test indicated significant differences in lauric, myristic, pentadecanoic, palmitic, heptadecanoic, stearic, behenic, palmitoleic,

Table 3 Mineral content of peanut worms

| Parameters | Mineral content (mg/kg) | | | |
|---|---|---|---|---|
| | *S. nudus* | | *S. australe** | |
| | Fresh | Sun-dried | Fresh | Freeze dry |
| Calcium (Ca) | 11,238±28.16[a] | 32,045±24.88[b] | 1,340 | 8,169 |
| Potassium (K) | 8,382±17.90[a] | 44,307±23.71[b] | 1,600 | 4,5084 |
| Magnesium (Mg) | 3,335±29.26[a] | 14,421±37.90[b] | 7,000 | 35,730 |
| Sodium (Na) | 38,725±48.22[a] | 56,820±25.71[b] | 43,700 | 127,334 |
| Phosphorus (P) | 474±20.10[a] | 3.8303±37.58[b] | 1,500 | 3,722 |

Different superscript letters within the same row denote statistically significant differences between fresh and sun-dried *S. nudus*, as determined using an independent samples t-test ($p<0.05$); *Nurhikma *et al.* (2017)

Table 4 Fatty acids compositions of peanut worm

| Fatty acids profile | *S. nudus* | | *S. australe** | |
|---|---|---|---|---|
| | Fresh (%) | Sun-dried (%) | Fresh (%) | Freeze dry (%) |
| Saturated fatty acids (SFA) | | | | |
| Lauric acid (C12:0) | 0.04±0.01[a] | 0.09±0.02[b] | 0.04 | 0.11 |
| Tridecanoic acid (C13:0) | 0.02±0.00[a] | 0.05±0.0[a] | 0.04 | 0.05 |
| Myristic acid (C14:0) | 0.33±0.01[a] | 0.77±0.02[b] | 0.75 | 0.92 |
| Pentadecanoic acid (C15:0) | 0.10±0.01[a] | 0.19±0.01[b] | 0.21 | 0.25 |
| Palmitic acid (C16:0) | 1.12±0.02[a] | 1.76±0.03[b] | 1.96 | 2.64 |
| Heptadecanoic acid (C17:0) | 0.06±0.01[a] | 0.15±0.02[b] | 0.77 | 0.78 |
| Stearic acid (C18:0) | 0.08±0.01[a] | 0.14±0.02[b] | 1.90 | 1.92 |
| Arachidic acid (C20:0) | n.d | n.d | 0.12 | 0.17 |
| Heneicosanoic acid (C21:0) | n.d | n.d | 0.21 | 0.18 |
| Behenic acid (C22:0) | 0.08±0.01[a] | 0.14±0.02[b] | 0.20 | 0.53 |
| Tricosanoic acid (C23:0) | n.d | n.d | 0.08 | 0.15 |
| Lignoceric acid (C24:0) | n.d | n.d | 0.12 | 0.15 |
| Total SFA | 1.82 | 3.29 | 6.40 | 7.70 |
| Monounsaturated fatty acids (MUFA) | | | | |
| Palmitoleic acid (C16:1) | 0.15±0.00[a] | 0.18±0.02[b] | 0.31 | 0.27 |
| Heptadecanoic acid (C17:1) | n.d | n.d | 0.12 | 0.05 |
| Oleic acid (C18:1n9c) | 0.05±0.01[a] | 0.22±0.01[b] | - | - |
| Eicosanoic acid (C20:1) | n.d | n.d | 0.05 | 0.02 |
| Nervonic acid (C24:1) | 0.01±0.01[a] | 0.05±0.02[b] | n.d | 0.03 |
| Total MUFA | 0.21 | 0.45 | 0.48 | 0.37 |
| Polyunsaturated fatty acids (PUFA) | 0.03±0.01[a] | 0.10±0.02[b] | 0.16 | n.d |
| Linolenic acid (C18:3n3) | 0.12±0.02[a] | 0.21±0.02[b] | 1.34 | 0.33 |
| Linoleic acid (C18:2n6c) | n.d | n.d | 0.06 | 0.02 |
| Erucic acid (C22:1n9) | 0.13±0.03[a] | 0.16±0.02[a] | 2.80 | 0.24 |
| Arachidonic acid (C20:4n6) | n.d | n.d | 0.52 | 0.09 |
| Eicosapentanoic acid (C20:5n3) | n.d | n.d | 0.15 | 0.02 |
| Docosahexaenoic acid (C22:6n3) | 0.28 | 0.47 | 6.26 | 1.80 |
| Total PUFA | 2.31 | 4.22 | 13.14 | 9.87 |
| Total Fatty Acids | 0.21 | 0.45 | 0.48 | 0.37 |

Different superscript letters within the same row denote statistically significant differences between fresh and sun-dried *S. nudus*, as determined using an independent samples t-test ($p<0.05$);
*Nurhikma *et al.* (2017); n.d (not detected)

oleic, nervonic, linolenic, and linoleic acids between the two treatments ($p$<0.05), whereas no statistically significant difference was detected in tridecanoic and arachidonic acids ($p$>0.05). The results of the fatty acid analysis are presented in Table 4. In fresh and dried peanut worms, 14 fatty acids were identified, including 8 SFA, 3 monounsaturated fatty acids (MUFA, and 3 polyunsaturated fatty acids (PUFA).

The highest amount of fatty acids in fresh and dried peanut worms was SFA at 1.82% and 3.29%, respectively, while the lowest was MUFA at 0.21% and 0.45%, respectively. However, a significant portion of the fresh and dried peanut worms, up to 97.69% and 95.78% of the total content, respectively, was unidentified. This high prevalence of unidentified fatty acids is thought to be due to the damage of several fatty acids during Soxhlet extraction, as suggested by Tonachella *et al.* (2025). Furthermore, Cascant *et al.* (2018) Zhukova (2022) reported that heating at high temperatures for a long time can damage unsaturated fatty acids, forming saturated fatty acids and various types of free radical groups.

Nurhikma *et al.* (2017) showed that the highest abundance of fatty acids in fresh *S. australe* is MUFA (35%), and the lowest is PUFA (2.4%). These differences can influence habitat and feed nutrition. According to Künili & Çolakoğlu (2019) and Kandyliari *et al.* (2020), fatty acid variations in aquatic organisms can be influenced by seasonal changes, geographical location, nutrition, environmental salinity, and living conditions, such as being free in its natural habitat or being cultivated. Pratama *et al.* (2018) and Rahman *et al.* (2023) stated that the fatty acid content of fish can vary depending on feed, location, species, sex, and environmental conditions.

In this study, the highest SFA fatty acid in dried peanut worms was palmitic acid (1.76%), while the lowest was tridecanoic acid (0.01 %) in fresh peanut worms. Palmitate is the most abundant SFA in marine organism fats compared to all other fatty acids (Inguglia *et al.,* 2020 & Irnawati *et al.,* 2023). Generally, palmitic acid is the most abundant SFA in food, consisting of 15-50% of all fatty acids (Gomes *et al.*, 2016). Nurhikma *et al.* (2017) showed that the highest fatty acid content in *S. australe* was palmitic acid in its fresh (1.96%) and freeze-dried (2.64) forms, while the lowest was tridecanoic acid in both fresh (0.04%) and freeze-dried (0.05%) forms. The difference in palmitic acid values can be caused by species, feed availability, age, and size (Wei *et al.,* 2018). Palmitic acid is the primary fatty acid in the sn-2 composition of breast milk (Durmus, 2019) and is known to induce changes in hepatocytes to the proinflammatory cytokine interleukin-8 (Chen *et al.,* 2016 & Truzzi *et al.*, 2018).

The highest MUFA and PUFA contents of dried peanut worms were oleic acid (0.22%) and linoleic acid (0.21%), respectively. According to Silaban (2019), the highest MUFA and PUFA contents in fresh *Sipunculus* sp. in Titawai, Indonesia, are palmitoleate (15.80%) and linoleate (5.33%), respectively. Nurhikma *et al.* (2017) explained that the highest MUFA and PUFA content in *S. australe* is palmitoleic acid, both fresh (0.31%) and freeze-dried (0.27%), and arachidonic acid in fresh (2.80%) and oleic acid in freeze-dried (1.97%) marine worms.

Oleic acid is an essential fatty acid. According to Jóźwiak *et al.* (2020) & Szczepańska *et al.* (2023), oleic acid is beneficial to human nutrition as a source of energy and antioxidants to inhibit cancer, lower cholesterol levels, and act as a solvent for vitamins A, D, E, and K. Similarly, Adawyah *et al.* (2020) & Xia *et al.* (2024) mentioned the health benefits of linoleic acid, including cancer growth inhibition and a reduced risk of heart disease and diabetes, while stimulating immune and anti-inflammatory responses in body cells to maintain their functions. Linoleic acid also plays a vital role in fat transport and metabolism.

## CONCLUSIONS

*Sipunculus nudus* from the waters of Konawe Islands Regency, Southeast Sulawesi, has morphometric characteristics with an average length of 13.52 cm, diameter of 1.69 cm, weight of 29.31 g, and meat yield of 31.42%. The sun-drying process reduces the water and carbohydrate content but increases the relative proportions of protein, fat, ash, minerals, and fatty acids owing to the concentration effect after water loss. Sodium had the highest mineral content in fresh and dried samples, whereas the fatty acid profile was dominated by saturated fatty acids. These findings confirm *S. nudus* as an alternative functional food sourced from local marine biota.

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