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INTERRELATIONSHIPS BETWEEN PROXIMATE COMPOSITIONS AND MINERAL CONTENTS IN THE COMMON CUTTLEFISH (*Sepia officinalis*)

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Abstract: *This study assessed the proximate composition, energy value, mineral profile, and inter-component correlations of different anatomical regions (head, mantle, and bone) of the common cuttlefish (Sepia officinalis) using standard methods. Results revealed higher moisture (73.55%) and protein (20.33%) contents in the mantle, while the head showed greater fat (4.15%) and ash (6.55%) levels. Energy contribution was predominantly protein-based, with protein energy proportion ranging from 20.9–23.1%, while energy from fat remained below 10.3%. Carbohydrates were negligible (<0.15%) across samples. Mineral analysis indicated the bone had significantly higher levels of sodium (1.14 mg/100g), calcium (2.51 mg/100g), potassium (1.67 mg/100g), magnesium (3.68 mg/100g), and phosphorus (112,968.56 mg/100g) compared to head and mantle tissues (p<0.05). Correlation analysis revealed strong negative associations between moisture and protein, fat, and ash in both head and mantle, and positive associations between crude protein and ash (r = 1.00). Minerals such as phosphorus and magnesium showed perfect positive correlations, particularly in head tissues. These findings underscore the nutritional richness of S. officinalis and its potential for value-added utilization in functional food and nutraceutical development.*

Keywords: *Biochemical profile, Nutritional quality, Mineral element, Mollusks, Proximate*

1. Introduction

Cephalopods, particularly cuttlefish (*Sepia officinalis*), have garnered significant scientific interest in recent years due to their multifaceted ecological roles and notable nutritional contributions. As a class of molluscs, cephalopods are known for their adaptability, intelligence, and diverse feeding strategies, which position them as essential components of marine food webs. *Sepia officinalis*, in particular, stands out for its high-quality lean protein, low lipid content, and abundance of vital minerals, including calcium, phosphorus, and magnesium, making it a nutritionally superior seafood option. These attributes are especially valuable in regions where protein deficiency is a public health concern. In Nigeria, especially within the Lagos coastal waters, cuttlefish form part of the artisanal fisheries sector and are harvested both for home consumption and for local markets. This fishery contributes to livelihoods and sustains a critical source of animal protein. Consequently, a comprehensive understanding of the species' biochemical properties is pivotal for improving post-harvest utilization, enhancing dietary planning, and bolstering food and nutrition security strategies [1].

The concentrations of these nutrients in marine species are influenced by a complex interplay of factors such as species differences, geographic location, feeding habits, reproductive stage, and ambient water conditions [2]. Past studies have underscored the variability and interdependence of proximate and mineral constituents across various fish and shellfish species, which suggests that fluctuations in one nutrient could reflect broader biochemical changes [3-4].

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Understanding these relationships is therefore critical to accurately assess the nutritional quality and optimize the processing and preservation of seafood products. The investigation of statistical correlations among proximate and mineral components in marine species holds immense practical relevance for both research and applied nutrition. From a scientific standpoint, these correlations can highlight possible nutrient synergies or antagonisms that can be leveraged to formulate balanced diets-particularly for aquaculture, where feed cost and nutritional efficacy are primary considerations. From an industrial and regulatory perspective, identifying these interrelationships aids in standardizing nutritional labeling, setting dietary recommendations, and guiding quality control processes. Prior research has demonstrated that in finfish and shellfish, certain proximate elements, such as protein and fat, often correlate with mineral content, which can serve as indicators of overall nutritional health or environmental exposure [5]. However, while such studies are relatively abundant for bony fishes and crustaceans, there remains a notable gap in data for cephalopods-especially those inhabiting West African coastal regions. As a result, there is a need for more detailed exploration of how these biochemical factors interact within *S. officinalis*, to fill this critical knowledge gap and provide a basis for informed utilization.

In light of the increasing global demand for alternative and sustainable protein sources, it is vital to reassess the nutritional potential of lesser-exploited marine species like *S. officinalis*. Cephalopods not only offer nutritional benefits but also possess favorable biological traits-such as rapid growth and short life cycles-that make them attractive for aquaculture development. Examining the interrelationships among their nutritional constituents provides insight into their suitability for human diets and animal feed formulations, thereby contributing to broader food system resilience. Additionally, such research supports evidence-based policymaking, resource management, and public health initiatives focused on combating malnutrition. The Lagos coastal environment, shaped by diverse hydrodynamic conditions and nutrient inflows, offers a distinctive context for studying the compositional dynamics of *S. officinalis*. This study, therefore, aims to evaluate the proximate and mineral composition of *S. officinalis* harvested from the Lagos coast and to assess the internal correlations among these nutritional elements. The outcomes are expected to enhance current understanding of the species' nutritional profile and its relevance for both human diets and aquafeed formulations.

2. Materials and methods

2.1 Collection and Preparation of Specimens

Samples of common cuttlefish were monthly collected from the coastal waters of Lagos, Nigeria, with the sampling range extending across Badagry to Ibeju-Lekki Local Government Areas. This stretch represents a significant portion of the southwestern Nigerian coastline, geographically situated between longitudes 2°50′ and 4°50′ East and latitudes 6°18′ and 6°21′ North. These coordinates cover a diverse estuarine and marine environment, influenced by both oceanic and anthropogenic factors, which could affect the biological and chemical composition of marine organisms in the region. The sampling was conducted using artisanal fishing gear, and the freshly caught specimens were promptly washed with distilled de-ionised water to eliminate any surface debris, slime, or adhering contaminants that could interfere with subsequent analytical procedures. After cleansing, the specimens were thoroughly drained and taxonomically identified using morphological keys and anatomical features as outlined in the Food and Agriculture Organization (FAO) species identification guide by Schneider [6]. Following identification, the cuttlefish were carefully placed in insulated containers filled with crushed ice to maintain freshness and prevent biochemical degradation during transport. Upon arrival at the laboratory, the samples were immediately stored in a deep freezer at a temperature of -20 °C to preserve the integrity of their proximate and mineral composition until laboratory analysis commenced.

2.2 Laboratory analysis

Upon removal from frozen storage, the cuttlefish samples were subjected to a controlled thawing process by allowing them to equilibrate at ambient room temperature (approximately 25 °C) for about one hour. This gentle defrosting approach was employed to preserve the structural integrity of the tissues and prevent moisture loss or nutrient degradation that could result from rapid or uneven thawing. Once thawed, the samples were meticulously dissected into three distinct anatomical components-head, mantle and bone-each representing a different tissue type with potentially unique nutritional properties. These separated parts were individually dried using a hot air oven set at a constant temperature of 105 °C until a stable, moisture-free weight was achieved. This drying step ensured consistency in weight measurement and facilitated accurate assessment of dry matter. The dried tissues were then finely ground and homogenised to yield a uniform texture suitable for subsequent chemical analyses, thereby minimizing variability between replicates and ensuring analytical accuracy. Proximate composition analysis was conducted according to the validated and widely accepted protocols of the Association of Official Analytical Chemists [7]. This included quantification of key nutritional parameters-moisture, ash, crude protein, crude fat, and carbohydrate content-each providing insight into the overall nutritional value and biochemical makeup of the cuttlefish tissues.

In addition to proximate analysis, the study extended to the determination of essential mineral elements, critical for assessing the micronutrient quality of the samples. The dried and homogenised cuttlefish components underwent acid digestion using a carefully prepared mixture of nitric acid (HNO_3) and hydrochloric acid (HCl), a method known for its effectiveness in breaking down organic matrices and releasing bound mineral content into solution. This digestion process was crucial in preparing the samples for accurate instrumental analysis. The resulting clear digests were then analysed for key mineral elements, including calcium, phosphorus, magnesium, sodium, and potassium, which are vital for physiological functions and dietary adequacy. Elemental quantification was performed using a Varian Spectra Atomic Absorption Spectrophotometer (AAS), specifically the Buck Scientific Model 210 VGP, a reliable instrument known for its sensitivity and precision in trace element analysis. The procedure followed was in accordance with the methodology described by Santoso et al. [8], ensuring methodological consistency and facilitating comparison with previous studies on marine organisms.

2.3 Statistical analysis

The data obtained were analyzed to compute the mean and standard error for each variable. To determine significant differences among treatment groups, the data were subjected to one-way analysis of variance (ANOVA). Relationships between variables were further examined using the Pearson Correlation Coefficient.

All statistical tests were conducted at a 95% confidence level, with significance accepted at $p \leq 0.05$.

3. Results

3.1 Energy Value Contributed by Nutrients

The proximate composition of the Common Cuttlefish, as presented in Table 1, revealed significant variations between the head and mantle regions. Moisture content was slightly higher in the mantle (73.55%) compared to the head (70.44%), with a mean value of 72.00 ± 2.20 g/100g, resulting in a modest coefficient of variation (CV%) of 3.05%. The negative difference (D = -3.11) and percentage difference (%D = -4.42%) suggest greater water retention in the mantle. Protein levels were also higher in the mantle (20.33%) than in the head (18.71%), with a mean of 19.52 ± 1.15 g/100g and a %CV of 5.87%. The negative difference in protein content (D = -1.62; %D = -8.66%) indicates higher protein concentration in the mantle.

In contrast, fat and ash contents were more pronounced in the head. Crude fat content was higher in the head (4.15%) compared to the mantle (3.67%), with a positive difference of 0.48 g/100g, equating to an 11.57% increase. Total ash content in the head was 6.55% compared to 3.35% in the mantle. The ash content showed a standard deviation of 2.26 and a high CV% of 45.71, indicating large variability. The nitrogen-free extract (NFE) was negligible in both portions but slightly higher in the head (0.14%).

Table 1

Proximate composition (g/100g) of the Common Cuttlefish, *Sepia officinalis* on wet basis

Parameters	Head	Mantle	$p < 0.05$	SD	CV%	D	% D
Moisture	70.44	73.55	0.11	2.20	3.05	-3.11	-4.42
Protein	18.71	20.33	0.09	1.15	5.87	-1.62	-8.66
Crude Fat	4.15	3.67	0.09	0.34	8.68	0.48	11.57
Total Ash	6.55	3.35	0.12	2.26	45.71	3.20	48.85
NFE	0.14	0.12	0.08	0.01	10.88	0.02	14.29

Keys: Nitrogen-Free Extract (NFE), Standard deviation (SD), Coefficient of variation per cent (CV%), Difference between shell and flesh (D), Percentage difference (D). No significant Difference

Table 2 shows the nutritional energy contributions from macronutrients in the head and mantle portions of *S. officinalis* show that the total energy (TE) values for both portions are quite similar, with the mantle (483 kJ/100g or 115 kcal/100g) slightly higher than the head (474 kJ/100g or 113 kcal/100g), resulting in a low coefficient of variation (CV%) of 1.39% and 1.29%, respectively.

This indicates a relatively uniform energy density across the edible portions. Further breaking down the total energy, the proportion contributed by fat (PEF) is relatively low, ranging from 9.1-10.1% in kJ and 9.3–10.3% in kcal. Conversely, protein is the major contributor to energy, with PEP values between 20.9–23.1% (kJ basis), indicating the mantle provides a slightly higher protein-derived energy than the head. The proportion of energy from carbohydrates (PEC) is minimal, averaging 0.15% (kJ) and 0.14% (kcal).

The UEDP% values range between 12.52–13.85 kJ and 12.4–13.74 kcal, with a coefficient of variation of approximately 7.2%.

Table 2

Energy value contributed by nutrients in the Common Cuttlefish, *Sepia officinalis*

Parameter	Unit	Head	Mantle	Mean	SD	CV%
Total energy	kJ 100g-1	474	483	478.72	6.68	1.39
	kcal 100g-1	113	115	113.79	1.47	1.29
PEF	% (kJ 100g-1)	10.1(154)	9.1(136)	9.57	0.71	7.42
	% kcal 100g-1	10.3 (37)	9.3 (33)	9.81	0.72	7.3
PEC	% (kJ 100g-1)	0.2 (2)	0.1 (2)	0.15	0.01	9.62
	% kcal 100g-1	0.2 (1)	0.1 (0)	0.14	0.01	9.51
PEP	% (kJ 100g-1)	20.9 (318)	23.1 (346)	21.98	1.57	7.13
	% kcal 100g-1	20.7 (75)	22.9 (81)	21.79	1.58	7.25
UEDP%	kJ	12.52	13.85	13.19	0.94	7.13
	Kcal	12.4	13.74	13.07	0.95	7.25

Keys: Proportion of total energy due to fat (PEF), Proportion of total energy due to carbohydrate (PEC), Proportion of total energy due to protein(PEP), utilization of energy value due to protein (UEDP%), Standard deviation (SD), Coefficient of variation per cent (CV%)

3.2 Macro elements in common cuttlefish

The mineral content of *S. officinalis* presented in Table 3 reveals a marked variation among the head, mantle, and bone tissues. The bone segment recorded significantly higher concentrations of all minerals assessed, particularly sodium (1.14 ± 0.00), calcium (2.51 ± 0.00), potassium (1.67 ± 0.00), and magnesium (3.68 ± 0.00), compared to the mantle and head, which exhibited relatively lower and statistically similar levels. These differences ($P < 0.05$) underscore the mineral-rich nature of cuttlefish bone. Notably, phosphorus concentration was remarkably high in the bone (112,968.56 ± 0.00), dwarfing the values in the head (2,203.36 ± 0.00) and mantle (925.57 ± 0.00).

Table 3

Macro elements in the Common Cuttlefish, *Sepia officinalis*

Minerals	Head	Mantle	Bone
Sodium	0.61±0.00^{a}	0.45±0.00^{a}	1.14±0.00^{b}
Calcium	0.03±0.00^{a}	0±0.00^{a}	2.51±0.00^{b}
Potassium	0.14±0.00^{a}	0.42±0.00^{a}	1.67±0.00^{b}
Magnesium	0.10±0.00^{a}	0.21±0.00^{a}	3.68±0.00^{b}
Phosphorus	2203.36±0.00^{a}	925.57±0.00^{b}	112968.56±0.00^{c}

Keys: Mean±Standard Error; values with different superscripts across row are significantly different at ($p < 0.05$)

3.3 Relationship between proximate and mineral contents

The correlation matrix presented in Table 4 offers valuable insights into the interrelationship between proximate compositions and mineral contents in the head of *S. officinalis*. A strong negative correlation exists between moisture and crude protein ($r = -0.96$), ash ($r = -0.93$), and nitrogen-free extract (NFE) ($r = 0.89$), suggesting that as moisture increases, the concentration of these proximate components decreases, and vice versa. Furthermore, NFE shows an almost perfect negative correlation with crude protein ($r = -0.98$) and ash ($r = -0.99$). A strong positive correlation is observed between ash and protein (r = 1). Among the minerals, magnesium (Mg) and phosphorus (P) display a perfect positive correlation (r = 1). Crude fat shows a near-perfect correlation with both Mg (r = 0.98) and P (r = 1). Calcium (Ca) is positively correlated with NFE (r = 0.94) but negatively correlated with protein and ash.

Table 4

Correlation coefficient between proximate and minerals in the head of *S. officinalis*

	Moisture	Crude Protein	Crude Fat	Ash	NFE	Na	Ca	K	Mg	P
Moisture	1									
Crude Protein	-0.96	1								
Crude Fat	0.06	-0.33	1							
Ash	-0.93	1	-0.42	1						
NFE	0.89	-0.98	0.51	-0.99	1					
Na	-0.86	0.69	0.46	0.62	-0.53	1				
Ca	0.69	-0.86	0.77	-0.90	0.94	-0.22	1			
K	-0.87	0.69	0.45	0.63	-0.55	1	-0.24	1		
Mg	-0.14	-0.13	0.98	-0.22	0.32	0.63	0.62	0.62	1	
P	-0.07	-0.21	1	-0.30	0.40	0.57	0.68	0.55	1	1

The correlation matrix in Table 5 illustrates the relationships between proximate composition and mineral content in the mantle of *S. officinalis*. A strong and negative correlation (r = -0.99) exists between moisture content and crude protein, crude fat, and ash, indicating that an increase in moisture tends to dilute other proximate constituents. Conversely, a perfect positive correlation (r = 1.00) is observed between crude fat and moisture, as well as between crude protein and ash, suggesting an interdependent biosynthetic relationship during the organism's physiological development. Furthermore, the negative correlation between ash and fat content (r = -1.00) implies that as ash content increases, fat concentration decreases.

In terms of mineral composition, significant positive correlations are seen between phosphorus (P) and nitrogen-free extract (NFE) (r = 0.98). Notably, calcium (Ca) exhibits strong negative correlations with NFE (r = -0.87), sodium (Na) (r = -0.84), and potassium (K) (r = -0.86). The high intercorrelation among Na, K, and Mg (r = 1.00 between Na and Mg; r = 1.00 between K and Mg) is also evident.

Table 5

Correlation coefficient between proximate and minerals in the mantle of *S. officinalis*

	Moisture	Crude Protein	Crude Fat	Ash	NFE	Na	Ca	K	Mg	P
Moisture	1									
Crude Protein	-0.99	1								
Crude Fat	1	-0.99	1							
Ash	-0.99	1	-1	1						
NFE	0.46	-0.50	0.49	-0.49	1					
Na	-0.58	0.54	-0.54	0.54	0.46	1				
Ca	0.04	0.00	0.01	-0.01	-0.87	-0.84	1			
K	-0.56	0.52	-0.53	0.53	0.48	1	-0.86	1		
Mg	-0.54	0.50	-0.51	0.51	0.50	1	-0.87	1	1	
P	0.29	-0.33	0.32	-0.32	0.98	0.62	-0.94	0.64	0.65	1

4. Discussion

Aquatic animal-derived foods possess superior proximate composition, featuring highly digestible proteins that are richer in essential amino acids and diverse bioactive peptides compared to terrestrial meats [9]. The higher moisture and protein levels in the mantle may be due to its muscle structure and active role in locomotion, as supported by Holst et al. [10], who reported elevated moisture and protein in cephalopod mantles for similar reasons. The greater fat and ash contents observed in the head could be attributed to the presence of fatty organs such as the brain and eyes, and mineralized structures, respectively. This aligns with the findings of Griesshaber et al. [11], who noted higher ash concentrations in cephalopod heads. These compositional differences offer strategic opportunities for utilization: the mantle may be better suited for high-protein food applications, while the head could serve as a source for lipid and mineral extraction in value-added seafood processing. The similarity in TE values between the head and mantle portions suggests a consistent energy profile, which may support uniformity in dietary applications. The low variability further affirms a stable macronutrient composition within edible tissues. The low fat contribution to energy is typical of lean seafood, supporting findings by Lamarre et al. [12], who reported lipid energy contributions in Sepia species rarely exceed 11%. The Proportion of total energy due to protein reinforces the classification of cephalopods as protein-rich seafood. The negligible carbohydrate content corroborates earlier reports [13], which emphasized the limited role of carbohydrates in cephalopod nutrition. Additionally, the moderate UEDP% values highlight efficient protein utilization, underlining the biological and nutritional significance of protein in cephalopod metabolism. Furthermore, the present energy values align closely with those reported by Zavadlav et al. [14], who observed energy content in raw cephalopods ranging between 460–510 kJ/100g. This consistency confirms the reliability of the current findings within the broader context of cephalopod nutritional studies.

The significantly higher mineral levels in the bone likely reflect its physiological role in structural support and buoyancy regulation via the cuttlebone. This finding aligns with the known biochemical makeup of cephalopod cuttlebone, which is largely composed of calcium carbonate and phosphate minerals [15]. Comparable findings have been reported in earlier studies on cephalopod species. For instance, Ahmed et al. [16] observed elevated levels of calcium and phosphorus in the skeletal structures of *Sepiella inermis*, affirming the bone as a critical site of mineral concentration. Similarly, the works of Nadarajah et al. [17] on *Loligo vulgaris* documented higher mineral contents in cartilage and hard parts than in the soft tissues, supporting the pattern observed in the present study. The relatively modest sodium, potassium, and magnesium levels in the head and mantle are consistent with their role in soft tissue metabolism and osmoregulation rather than structural storage. These observations not only validate the nutritional potential of *S. officinalis* bones as mineral-rich by-products but also reinforce their established relevance in nutraceuticals and feed formulations.

The negative correlation between moisture and major proximate components such as protein and ash align with previous findings by Moruf et al. [18], who reported similar inverse relationships in *Panulirus regius*. This phenomenon is attributed to the water-replacement effect during biochemical composition shifts post-mortem or under storage. The strong negative correlation between NFE and both protein and ash reinforce the competitive accumulation

among macronutrients during metabolic processes. The perfect positive correlation between ash and protein may indicate mineral-bound protein interactions or co-depositional mechanisms during physiological development in the cuttlefish's head tissues. Similarly, the Mg–*p* correlation reflects their likely co-regulation or co-localization in biochemical pathways, as reported by Hu et al. [19] in cephalopod muscle. The association of Mg and P with crude fat could suggest the presence of phospholipids or other mineral-bound lipid forms. The contrasting correlation of Ca with NFE versus protein and ash suggests a possible trade-off in mineral allocation between structural and energy roles. These observed correlations support the hypothesis that nutrient distribution in cephalopod tissues is tightly regulated and may be influenced by environmental factors, physiological states, or post-harvest changes [12]. The observed negative correlation between moisture and other proximate constituents is consistent with previous findings by Schmidt et al. [20], who reported that increased moisture in cephalopod tissues is often associated with reduced protein and fat levels due to the inverse compositional balance. The perfect positive correlation between crude protein and ash, and between crude fat and moisture, suggests a coordinated physiological regulation in *S. officinalis*.
Additionally, the inverse relationship between ash and fat content may reflect metabolic trade-offs in nutrient allocation. The significant positive correlation between phosphorus and NFE supports the idea that carbohydrate-like components may influence phosphorus accumulation in tissues, as similarly reported by Lawal-Are et al. [15]. The strong negative correlations involving calcium suggest regulatory or competitive interactions among minerals. The perfect correlations between Na, K, and Mg may indicate shared transport or storage mechanisms, supporting the mineral balance theory proposed by Chouvelon et al. [21]. Collectively, these findings offer insights into the nutritional physiology of *S. officinalis*, which can inform its dietary evaluation and post-harvest management strategies.

5. Conclusion

The findings from this study demonstrate statistically significant nutritional differences among the anatomical parts of *Sepia officinalis*. The mantle and head exhibited distinct biochemical profiles, with the mantle containing significantly higher moisture and protein levels, underscoring its role as a premium source of lean marine protein. Conversely, the head segment showed a significantly greater fat and ash content, indicating its suitability as a source of marine lipids and minerals. The calculated energy distribution further confirmed *S. officinalis* as a protein-rich, low-fat organism with negligible carbohydrate content, aligning with consumer demand for low-calorie, high-protein seafood. Mineral profiling revealed the bone portion to be significantly enriched in key elements such as phosphorus, calcium, magnesium, and sodium, affirming its viability for use in bio-fortification and nutraceutical formulations. Correlation analyses revealed strong inverse relationships between moisture and other proximate components, indicative of a dilution effect, while perfect positive correlations between protein and ash, as well as among select minerals, suggest tightly regulated physiological mineral-nutrient interactions.
These statistically significant relationships enhance our understanding of nutrient dynamics in marine tissues and may inform processing, preservation, and functional product development. Collectively, *S. officinalis* proves to be a nutritionally potent marine species with established utility in food, pharmaceutical, and functional ingredient applications.

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