



**ASSESSMENT OF SAFETY INDEX AND FUNCTIONAL POTENTIAL OF  
THE SHELLFISH *Cardiosoma armatum* IN RELATION TO SEX DIFFERENCES**

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**ABSTRACT**

This study analyzed the mineral safety index (MSI) and functional potential of *Cardiosoma armatum* with a focus on sex differences. Significant variations were observed between male and female crabs, with the shell consistently acting as a major mineral reservoir. In females, calcium (988.95 mg/100g) and magnesium (26.33 mg/100g) concentrations were significantly higher in the shell compared to the flesh, showing 92.67% and 87.08% differences, respectively. Similar trends were observed in males, where calcium (1210.32 mg/100g) and magnesium (19.22 mg/100g) exhibited 92.62% and 82.92% disparities between shell and flesh. The MSI indicated that the shell provides a critical mineral reserve, with calcium, magnesium, and phosphorus exhibiting notable deviations from the Recommended Allowance Intake (RAI). Functional properties also varied by sex, with males showing higher packed bulk density (0.52 g/ml), oil absorption (102.64%), and dispersibility (62.80%), whereas females exhibited higher solubility (21.24%). These findings highlight the sex-dependent differences in both mineral distribution and functional characteristics, which may inform their use in food processing and nutrition.

**Keywords:** Crab, Mineral, Safety, Index, Sex, Shellfish

**INTRODUCTION**

Shellfish, including various species such as crabs, shrimps, and molluscs, play a vital role in human nutrition, serving as a rich source of high-quality protein, essential amino acids, and micronutrients like iron, and omega-3 fatty acids, which contribute to overall health and well-being, particularly in coastal and estuarine communities where seafood forms a staple part of the diet (Lawal-Are *et al.*, 2021). Among these valuable aquatic resources, the African Land Crab (*Cardiosoma armatum*) stands out as a widely consumed species, not only because of its impressive nutritional profile, which includes substantial amounts of protein, vitamins, and minerals but also due to its significant economic contributions through small-scale fisheries, local markets, and commercial trade, making it an important species for both food security and livelihood sustenance in Southwest, Nigeria (Moruf *et al.*, 2021). The mineral content of shellfish plays a critical role in human nutrition, contributing to the development and maintenance of physiological functions such as enzyme activation, bone formation, and immune response (Moruf *et al.*, 2022). However, excessive consumption of certain minerals, including trace metals, can pose health risks, necessitating an evaluation of their safety indices. The Mineral Safety Index (MSI) serves as a quantitative measure to assess the potential risk associated with mineral intake from dietary sources. This index aids in determining whether mineral levels in food products exceed recommended dietary allowances (RDAs) and tolerable upper intake levels (TUILs) (FAO, 2021). Furthermore, the functional properties of shellfish proteins, including their water-holding capacity, emulsifying ability, and gelation characteristics, have garnered interest in food processing and value addition (Lawal-Are *et al.*, 2020).

Sexual dimorphism in crustaceans is known to influence their biochemical and mineral composition due to differences in metabolic rates, reproductive roles, and growth patterns (Farhadi *et al.*, 2021). In crustacean, males and females exhibit distinct physiological adaptations that may affect the bioavailability and distribution of essential minerals, potentially influencing their nutritional and

functional properties (Li *et al.*, 2021). Understanding these differences is crucial in determining the safety and functional potential of this species as a dietary resource.

Previous studies have indicated that shellfish accumulate varying concentrations of essential and non-essential minerals based on environmental factors, feeding habits, and sex-specific physiological differences (Jiang *et al.*, 2023; Guo *et al.*, 2024). Despite the growing awareness of seafood safety, limited studies have comprehensively analyzed the safety index and functional potential of *C. armatum*, particularly in relation to sex differences. Understanding these aspects is critical for public health risk assessments and for guiding sustainable consumption practices. This study, therefore, aims to evaluate the safety index and functional potential of *C. armatum* with a focus on sex-based variations, providing insights into its suitability for diverse food applications while ensuring that its consumption remains within safe mineral limits.

## MATERIALS AND METHODS

### Sample Collection and Preparation

A total of 120 specimens of *C. armatum* were collected during the 2024 wet season from the University of Lagos Lagoon Coast (6°31.228'N, 3°24.044'E) using baited traps and manual collection. The crabs, with lengths ranging from 51.89 to 62.54 mm and total weights between 21.39 and 44.47 g, were first sexed. The specimens were then placed in an ice chest for transport to the Marine Sciences Department, University of Lagos. Upon arrival, the crabs were thoroughly cleaned, measured, and deshelled. The shell and muscle tissues from each sex were homogenized separately. The homogenate samples were stored in sealed polythene bags and frozen at -20°C until further analysis.

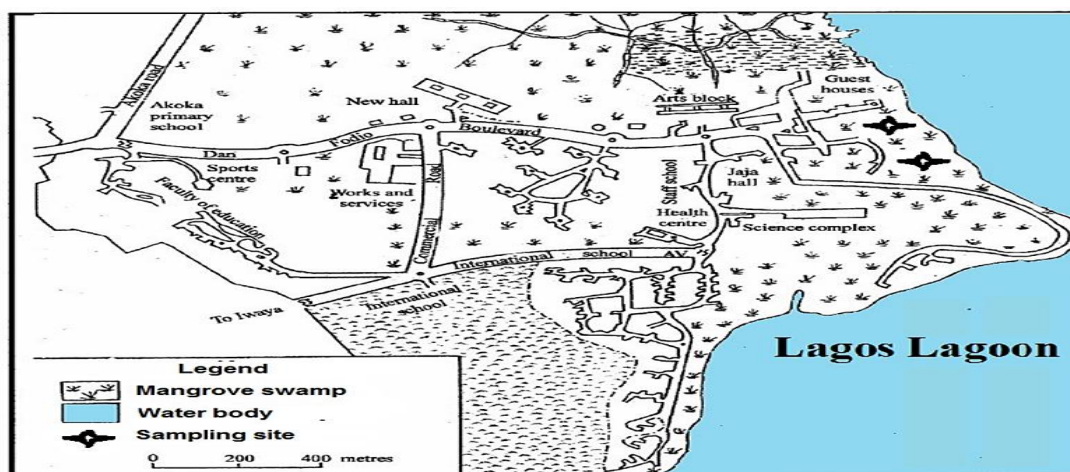


Figure 1: Map of Unilag Lagoon Front showing the study sites

### Samples Analysis

The samples were digested in HNO<sub>3</sub> / HCl for mineral determination. Calcium, phosphorus, magnesium, sodium and potassium were then determined by the Buck Scientific 210 GVP model of the Varian Spectra Atomic Absorption Spectrophotometer (Santoso, 2006). Mineral Ratios and Mineral Safety Index (Equation 1) were calculated according to Watts (2010) and Hatcock (1985), respectively.

$$\text{Calculated MSI} = [\text{TMSI (Standard)} / \text{RAI}] \cdot \text{Rr} \dots \quad (1)$$

Where: MSI - Mineral Safety Index;

TMSI - Tabulated MSI;

RAI - Recommended Adult Intake;

Rr – Research results.

Water absorption capacity (WAC) and oil absorption capacity (OAC) were determined following the method described by Brishti *et al.* (2017). The 0.25 g of specimen was mixed with 5 mL distilled water or oil in pre-weighed centrifuge tube for 30 secs using a vortex. Then, specimen was

allowed to stand at room temperature (20 - 25°C) for 15 min and centrifuged at 3000 rpm for 15 min. After centrifugation, the supernatant was decanted, and the centrifuge tubes + precipitate were re-weighed. The WAC and OAC were expressed as grams of water/oil absorbed per gram of the sample. The WAC and OAC were calculated by using the following equation:

Where W1 = weight of the dry sample (g)

W2 = weight of precipitate + centrifuge tube (g)

The modified methods reported by Souissi *et al.* (2007) were used to determine the emulsion stability. The foam formation and the foam stability were determined by optical measurements as described by Lawal-Are *et al.*, (2020). The foams were produced with a homogenizer for 2 min at 17 500 rpm, in 3 mL of solution (50 mMTris-HCl – 0.5 M NaCl, pH 7.5), which contained 1.5% protein. The initial height of the solution and the foam height were recorded at intervals of 0, 2, 10, 20 and 30 min, using a caliper. The foaming capacity was expressed as the proportion of foam height at 0 min to solution height. The foaming stability (FS) was conveyed by the percentage of foam height at some time to 0 min. The measurement of the height was rapid and accurate to three digits after the decimal point.

### Data Analysis

Results were expressed as means, standard deviations (SD) and coefficient of variation per cent (CV %). Each value was a mean of six (6) replications for mineral compositions. Data were analyzed using SPSS statistical software version 22.

## RESULTS AND DISCUSSION

### Mineral Concentration by Sexual Difference

The mineral concentrations in both the shell and flesh of female *C. armatum* show significant differences, with notably higher levels in the shell (Table 1). For instance, calcium is found at 988.95 mg/100g in the shell and 72.46 mg/100g in the flesh, a significant difference ( $P$ -value = 0.00) with a 92.67% disparity. Similarly, sodium, potassium, magnesium, and phosphorus concentrations are higher in the shell than in the flesh, with calcium (92.67%) and magnesium (87.08%) showing the highest percentage differences, highlighting the shell's role in mineral storage. The total mineral concentration is 2446.41 mg/100g in the shell, compared to 878.39 mg/100g in the flesh, marking a 64.09% difference. These findings align with similar studies on crustaceans, such as Vigneshwari and Gokula (2018), who reported significantly higher calcium concentrations in the exoskeleton of *Portunus pelagicus*. This supports species-specific patterns in mineral deposition, as also noted by Ikpe *et al.* (2022) in *C. sapidus*, further underscoring ecological and physiological influences on mineral distribution.

**Table 1:** Mineral Concentrations in the Shell and Flesh of Female *Cardiosoma armatum*

| Parameters (mg/100g) | Shell   | Flesh  | $P$ -Value | Standard Deviation | CV%    | Shell-Flesh | % Diff |
|----------------------|---------|--------|------------|--------------------|--------|-------------|--------|
| Calcium              | 988.95  | 72.46  | 0.00*      | 648.06             | 122.11 | 916.49      | 92.67  |
| Sodium               | 202.18  | 306.37 | 0.00*      | 73.67              | 28.97  | -104.19     | -51.53 |
| Potassium            | 297.56  | 211.46 | 0.00*      | 60.88              | 23.92  | 86.10       | 28.94  |
| Magnesium            | 702.15  | 90.75  | 0.00*      | 432.33             | 109.05 | 611.40      | 87.08  |
| Phosphorus           | 255.57  | 197.35 | 0.00*      | 41.17              | 18.18  | 58.22       | 22.78  |
| Total                | 2446.41 | 878.39 | 0.00*      | 1108.76            | 66.70  | 1568.02     | 64.09  |

\*- significant difference, %D – percentage difference, SD – standard deviation, CV% – coefficient of variation percentage

For male *C. armatum*, significant differences in mineral concentrations between the shell and flesh are evident, with the shell containing notably higher concentrations of all measured minerals (Table 2). For example, calcium in the shell is 1210.32 mg/100g, compared to 89.34 mg/100g in the flesh, resulting in a 92.62% difference. Similar trends are observed for sodium, potassium,

magnesium, and phosphorus, with the shell exhibiting higher levels. Magnesium and potassium show percentage differences of 82.92% and 31.70%, respectively. The total mineral concentration is 2485.18 mg/100g in the shell and 886.07 mg/100g in the flesh, reflecting a 64.35% difference. These results, confirmed by significant *P*-values, emphasize the shell's critical function as a mineral reservoir for male crabs. These findings align with studies on other crustaceans, such as *Portunus pelagicus* (Vigneshwari and Gokula, 2018) and *Scylla serrata* (Widnyani and Wijaya, 2024), where similar high concentrations of calcium and magnesium were found in the shell.

**Table 2:** Mineral Concentrations in the Shell and Flesh of Male *Cardiosoma armatum*

| Parameters (mg/100g) | Shell   | Flesh  | <i>P</i> -Value | Standard Deviation | CV%    | Shell-Flesh | % D    |
|----------------------|---------|--------|-----------------|--------------------|--------|-------------|--------|
| Calcium              | 1210.32 | 89.34  | 0.00*           | 792.65             | 121.98 | 1120.98     | 92.62  |
| Sodium               | 226.93  | 310.5  | 0.00*           | 59.09              | 21.99  | -83.57      | -36.83 |
| Potassium            | 316.38  | 216.09 | 0.00*           | 70.92              | 26.64  | 100.29      | 31.70  |
| Magnesium            | 512.64  | 87.58  | 0.00*           | 300.56             | 100.15 | 425.06      | 82.92  |
| Phosphorus           | 218.91  | 182.56 | 0.00*           | 25.70              | 12.80  | 36.35       | 16.60  |
| Total                | 2485.18 | 886.07 | 0.00*           | 1130.74            | 67.08  | 1599.11     | 64.35  |

\*- significant difference, %D – percentage difference, SD – standard deviation, CV% – coefficient of variation percentage

### Mineral Ratio by Sexual Difference

The mineral ratios in male and female *C. armatum* exhibit distinct variations, reflecting possible physiological and metabolic differences between sexes (Table 3). In both sexes, the Ca/Mg ratio falls below the reference value (7.0) and the acceptable range (3–11), with females (1.1) having a lower mean than males (1.69), indicating relatively higher magnesium content in females. The Ca/K ratio is lower in females (1.83) than in males (2.12), though both remain within the ideal range (2.2–6.2). The Ca/P ratio in females (2.12) is within the acceptable range (1.5–3.6), whereas males (3.01) exhibit a higher value, suggesting a greater calcium deposition in male exoskeletons. The Na/K ratio is nearly identical in both sexes (1.06 in females and 1.08 in males), yet both fall below the ideal range (1.4–3.4), implying a potassium-dominant balance. The Na/Mg ratio is also lower in females (1.83) than in males (1.99), both below the reference value (4.0) but within the acceptable range (2–6). The [K/(Ca + Mg)] ratio remains similar in both sexes (1.0 in females, 0.97 in males), indicating a relatively stable relationship between these minerals. High coefficients of variation (CV%) in both sexes, particularly for Ca/K and Ca/P, suggest significant fluctuations in mineral distribution.

The observed mineral ratios align with past findings on decapod crustaceans but also highlight species-specific differences. Plotnick and McCarroll (2023) reported Ca/Mg ratios ranging from 2.5 to 10.5 in cuticles, higher than the values recorded for *C. armatum* in this study, suggesting species-specific mineral deposition strategies. Similarly, Rangasamy *et al.* (2024) found that female edible crabs exhibited a lower Ca/P ratio than males, consistent with the trend observed in *C. armatum*. The lower Na/K ratio in both sexes of *C. armatum* compared to the 2.0–3.2 range reported for *Scylla paramamosain* (Wang *et al.*, 2021) may be linked to differences in habitat salinity and osmoregulatory adaptations. de Oliveira *et al.* (2022) observed a Na/Mg ratio of 3.5–5.0 in *Litopenaeus vannamei*, significantly higher than in *C. armatum*, suggesting variations in sodium uptake efficiency.



**Table 3:** Mineral Ratio in Female *Cardiosoma armatum*

| Parameter     | Ref. Value | Acceptable ideal range | Shell | Flesh | Mean | SD   | CV%    |
|---------------|------------|------------------------|-------|-------|------|------|--------|
| Ca/Mg         | 7.0        | 3 to 11                | 1.41  | 0.8   | 1.1  | 0.43 | 39.09  |
| Ca/K          | 4.2        | 2.2 to 6.2             | 3.32  | 0.34  | 1.83 | 2.11 | 114.99 |
| Ca/P          | 2.6        | 1.5 to 3.6             | 3.87  | 0.37  | 2.12 | 2.48 | 116.91 |
| Na/K          | 2.4        | 1.4 to 3.4             | 0.68  | 1.45  | 1.06 | 0.54 | 51.12  |
| Na/Mg         | 4.0        | 2 to 6                 | 0.29  | 3.38  | 1.83 | 2.18 | 119.19 |
| [K/(Ca + Mg)] | 2.2        |                        | 0.44  | 1.56  | 1    | 0.79 | 79.2   |

SD – standard deviation, CV% – coefficient of variation percentage

**Table 4:** Mineral Ratio in Male *Cardiosoma armatum*

| Parameter     | Ref. Value | Acceptable ideal range | Shell | Flesh | Mean | SD   | CV%    |
|---------------|------------|------------------------|-------|-------|------|------|--------|
| Ca/Mg         | 7.0        | 3 to 11                | 2.36  | 1.02  | 1.69 | 0.95 | 56.08  |
| Ca/K          | 4.2        | 2.2 to 6.2             | 3.83  | 0.41  | 2.12 | 2.41 | 113.83 |
| Ca/P          | 2.6        | 1.5 to 3.6             | 5.53  | 0.49  | 3.01 | 3.56 | 118.42 |
| Na/K          | 2.4        | 1.4 to 3.4             | 0.72  | 1.44  | 1.08 | 0.51 | 47.24  |
| Na/Mg         | 4.0        | 2 to 6                 | 0.44  | 3.55  | 1.99 | 2.19 | 110.03 |
| [K/(Ca + Mg)] | 2.2        |                        | 0.45  | 1.49  | 0.97 | 0.74 | 75.81  |

SD – standard deviation, CV% – coefficient of variation percentage

### Mineral Safety by Sexual Difference

The MSI results for both female and male *Cardiosoma armatum* reveal significant variations across the minerals, indicating differing levels of safety relative to the Recommended Allowance Intake (Tables 5 and 6). In females, calcium had a negative MSI calculated value (MSI<sub>cv</sub>) for both shell (-75.54%) and flesh (93.96%), suggesting an imbalance with calcium levels being low in the shell and high in the flesh. Magnesium also showed a highly negative shell value (-75.54%) but a high positive flesh value (77.31%), indicating significant variation in magnesium distribution. Phosphorus levels in females appear to be more stable, as both the shell (78.7%) and flesh (83.55%) show high positive percentages, with minimal fluctuation in the flesh. For sodium, the shell exhibited a high negative MSI<sub>cv</sub> (-59.56%), whereas the flesh showed a more moderate positive value (38.73%), indicating sodium's stronger concentration in the flesh. For males, calcium shows a more balanced MSI in the shell (92.56%) and flesh (121.98%), both with high positive values. Magnesium in males exhibits a moderately negative shell MSI (-28.16%) but a positive flesh MSI (78.11%). Phosphorus in males has a high positive MSI in both shell (81.76%) and flesh (84.79%), similar to females. Sodium in males also shows higher concentrations in the flesh (37.9%), though not as pronounced as in females. A study by Rangasamy *et al.* (2024) on *P. pelagicus* found calcium concentrations in the shell to be higher than in the flesh, which contrasts with the results in this study, where calcium was more concentrated in the flesh in both sexes. Similarly, the phosphorus values for both *C. armatum* sexes align with those reported by Moruf *et al.* (2021), where phosphorus concentrations in the soft tissue were higher than in the exoskeleton, reinforcing its biological role in energy storage and cellular function.

**Table 5:** Mineral Safety Index of Female *Cardiosoma armatum*

| Mineral | RAI (mg) | MSItv | Shell MSIcv | %D     | Flesh MSIcv | %D    | Mean  | SD    | CV%    |
|---------|----------|-------|-------------|--------|-------------|-------|-------|-------|--------|
| Ca      | 1200     | 10    | 8.24        | 17.59  | 0.6         | 93.96 | 4.42  | 5.4   | 122.11 |
| Mg      | 400      | 15    | 26.33       | -75.54 | 3.4         | 77.31 | 14.87 | 16.21 | 109.05 |
| P       | 1200     | 10    | 2.13        | 78.7   | 1.64        | 83.55 | 1.89  | 0.34  | 18.18  |
| Na      | 500      | 4.8   | 1.94        | 59.56  | 2.94        | 38.73 | 2.44  | 0.71  | 28.97  |

RAI – recommended adult intake, MSIsv – MSI standard value, MSIcv – MSI calculated value, % D – percentage difference, SD – standard deviation, CV% – coefficient of variation percentage.

**Table 6:** Mineral Safety Index of Male *Cardiosoma armatum*

| Mineral | RAI (mg) | MSItv | Shell MSIcv | %D     | Flesh MSIcv | %D    | Mean  | SD    | CV%    |
|---------|----------|-------|-------------|--------|-------------|-------|-------|-------|--------|
| Ca      | 1200     | 10    | 10.09       | -0.86  | 0.74        | 92.56 | 5.42  | 6.61  | 121.98 |
| Mg      | 400      | 15    | 19.22       | -28.16 | 3.28        | 78.11 | 11.25 | 11.27 | 100.15 |
| P       | 1200     | 10    | 1.82        | 81.76  | 1.52        | 84.79 | 1.67  | 0.21  | 12.8   |
| Na      | 500      | 4.8   | 2.18        | 54.61  | 2.98        | 37.9  | 2.58  | 0.57  | 21.99  |

RAI – recommended adult intake, MSIsv – MSI standard value, MSIcv – MSI calculated value, % D – percentage difference, SD – standard deviation, CV% – coefficient of variation percentage.

### Functional Potential by Sexual Difference

The functional properties of the edible portion of *C. armatum* showed notable variations between males and females, with significant differences in packed bulk density, oil absorption capacity, solubility, and dispersibility (Table 7). The packed bulk density was significantly higher in males (0.52 g/ml) than in females (0.41 g/ml) ( $P=0.01$ ), indicating that male tissues may have a more compact structure, which could affect processing and storage. Similarly, males exhibited a significantly greater oil absorption capacity (102.64%) compared to females (98.05%) ( $p=0.01$ ), suggesting that male tissues might have a higher lipid-binding potential, making them suitable for food formulations requiring fat retention. Solubility was significantly higher in females (21.24%) than in males (19.80%) ( $P=0.05$ ), implying a higher tendency for female-derived products to dissolve in aqueous systems, which could be relevant in food applications such as soups and sauces. Dispersibility, which indicates the ability to break down in water, was significantly higher in males (62.80%) than in females (60.68%) ( $P=0.02$ ), suggesting better rehydration potential in male tissue. Other functional parameters, including water absorption capacity, foam capacity, and emulsion properties, did not exhibit significant differences, implying that both sexes may have comparable applications in certain food formulations. Guo *et al.* (2024) reported that male crabs generally have higher oil absorption capacities, which was attributed to differences in muscle composition and fat-binding proteins. Similarly, Kobayashi and Naruse (2023) found that the higher dispersibility in male crab meat suggests better solubility and ease of incorporation into processed foods. Overall, these comparisons indicate that while *C. armatum* shares similar functional characteristics with other crustaceans, species-specific differences and habitat influences may contribute to the observed variations.

**Table 7:** Functional Potential of Edible Portion in Male and Female *Cardiosoma armatum*

| Parameters                  | Female      | Male        | P- value |
|-----------------------------|-------------|-------------|----------|
| Loose Bulk Density (g/ml)   | 0.4±0.01    | 0.41±0.07   | 0.87     |
| Packed Bulk Density (g/ml)  | 0.41±0.02   | 0.52±0.02   | 0.01*    |
| Water Absorption Capacity % | 90.34±1.16  | 90.08±0.40  | 0.84     |
| Oil Absorption Capacity %   | 98.05±1.01  | 102.64±0.25 | 0.01*    |
| Swelling Power %            | 210.34±1.05 | 214.27±1.23 | 0.07     |
| Solubility %                | 21.24±0.25  | 19.80±0.45  | 0.05     |
| Foam Capacity %             | 28.21±0.40  | 30.35±0.95  | 0.11     |
| Foam Stability %            | 25.64±0.25  | 25.90±0.06  | 0.38     |
| Emulsion Capacity (ml)      | 1.80±0.31   | 1.85±0.36   | 0.92     |
| Emulsion Stability (ml)     | 1.50±0.23   | 1.54±0.16   | 0.89     |
| Dispersibility %            | 60.68±0.48  | 62.80±0.25  | 0.02*    |

Keys: Mean±SE (Range), p<0.05 indicate significant difference (\*)

## CONCLUSION AND RECOMMENDATION

In conclusion, this study highlights the significant sex differences in both the mineral concentrations and functional properties of *Cardiosoma armatum*. The shell is confirmed as a major mineral reservoir, with both males and females exhibiting higher mineral concentrations in the shell compared to the flesh, emphasizing the shell's role in mineral storage. The MSI values further underscore the imbalance in the distribution of certain minerals, particularly calcium and magnesium, between the shell and flesh. Additionally, the functional properties of the edible portion of the crab show that males and females exhibit distinct characteristics, with males possessing a more compact structure and higher oil absorption capacity, while females show superior solubility.

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