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ORIGINAL ARTICLE

Protein Digestibility and Mineral Bioavaliability of Some Selected Shellfish

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Abstract

In-vitro protein digestibility, total mineral and mineral bioavailability of periwinkle (rough and smooth), clam, whelk, and oyster were evaluated. Total ash content of clams and oysters were 2.87% and 2.92%, respectively. These value were significantly ($p<0.05$) higher than those of periwinkle (rough and smooth) and whelks. Percentage crude protein ranged from 12.01 - 18.84% with oyster and clams given significantly ($p<0.05$) higher values. Protein digestibility of the shellfish were 11.90, 8.62, 16.75, 16.64 and 13.88% for periwinkle rough, smooth, whelk, oyster and clam, respectively, with oyster and whelk showing significantly ($p<0.05$) higher value. A total of six essential minerals: Iron, calcium, magnesium, phosphorus, potassium, and sodium were determined. Potassium was significantly ($p<0.05$) higher in clam (1286.00 mg/100g) and low in periwinkle smooth (618.90 mg/100g). Whelk was significantly high in zinc and magnesium with values of 23.66 mg/100g and 721.60 mg/100g, respectively. Significantly ($p<0.05$) higher fraction of soluble Na (343.30mg/100g), K (1040.00 mg/100g), Fe (14.50 mg/100g) and Ca (185.60 mg/100g) were noticed in oyster, clam, periwinkle rough and periwinkle smooth, respectively. Whelk was significantly higher in soluble Zn (8.95 mg/100g) and Mg (718.00 mg/100g). Total calcium was found to be high in whelk (709.80 mg/100g) but only 58.80% was soluble after digestion with periwinkle rough recording the highest bioavailable calcium (84.30%).

Practical application

The knowledge of the mineral bioavailability, protein content and digestibility of some selected shellfish can give indication of the nutritional advantage of shellfish in fortifying carbohydrate based diets as a step towards alleviating the problem of protein energy malnutrition. Knowledge from this study presents shellfish as source of high quality protein with all the dietary essential amino acids and essential minerals necessary for maintenance and growth of the human body.

Keywords: Shellfish, Mineral bioavailability, Protein digestibility.

1. Introduction

Shellfish are excellent source of protein and a good source of minerals like calcium, sodium; phosphorus and iron (Kiin-Kabari *et al*., 2017). Shellfish are forms of sealife regarded as food by humans. They are classified into molluscs, crustaceans and echinoderms (Ponder & Lindberg, 2008). Mollusc's family includes shellfish such as oyster (*Crassosterea graser*), clam (*Anadora semillis*), periwinkle (*Tympanostomus fuscatus and Tympanostomus fuscatus var. radula*), and whelk (*Buccimum undatum*). Molluscs, to a large extent include gastropods (periwinkles, whelks, snails, slugs, and others), bivalves (clams, oysters, and others), cephalopods (squids), and other known subgroups which are similarly distinctive (Kiin-Kabari *et al*., 2017). Some mollusc inhabits the fresh water fauna and the terrestrial ecosystems, however, majority of species live in the oceans seashores and the abyssal zone (Ponder & Lindberg, 2008). Molluscs are extremely diverse in tropical and temperate regions, but can be found at all latitudes (Giribet *et al*., 2006). Most shellfish eat a diet composed primarily of phytoplankton and zooplankton (FAO, 2009). Molluscs occur abundantly in the brackish and fresh water, they are natural part of diet and contain high level of several important nutrients (Kiin-Kabari *et al*., 2017). Molluscs are excellent sources of protein to both riverine communities and the entire population at large (Tayo *et al*., 2008). Seafood is known to contain 12.00% - 18.58% of protein (Kiin-Kabari *et al*., 2017). Periwinkle had also been reported to contain as much as 60.93% protein (dry matter), when compared to whole hen's egg (Umoh & Basir, 1976). Shellfish are rich source of long-chain polyunsaturated fatty acids (omega-3) eicosapentaenoic and docosahexaonoic acids (Bresgen *et al*., 2010). Their ash content is about 5.84% (Obande *et al*., 2013), they are also rich in essential micronutrients such as calcium (129.18mg/100g), magnesium (31.19 mg/100g), potassium (71.13 mg/100g), phosphorus (60.52 mg/100g), iron (10.90 mg/100g), and zinc (1.31 mg/100g) as reported earlier by Obande *et al*. (2013). This makes molluscs a ready source of food for eradicating "hidden hunger" (Kiin-Kabari *et al*., 2017). Shellfish provide high quality protein with all the dietary essential amino acids for maintenance and growth of the human body. For this reason, shellfish is considered a low-fat, low saturated-fat, high-protein food that can be included in a low-fat diet (FNB, 2007). Shellfish meat, particularly clam meat has been recommended in several dietary regimes for their high protein content, low caloric values, low fat/cholesterol profile and lower proportions of saturated fat. The presence of omega-3-fatty acids, dietary essential amino acids, vitamin B12 and several important minerals such as iron, zinc and copper had been reported by many researchers (Dong, 2001). According to Wardlaw & Smith (2009), vitamin B-12 helps the body maintain sheathes around nerve fibers, to activate another B-vitamin called folic acid, and participates in many cellular processes. It is found exclusively in animal products and vitamin B-12-fortifiedplant products, such as meat replacements. A 100-gram serving portions of clam, oyster, mussel, crab and several other shellfish meats will provide more than the Dietary Reference Intake of this vitamin. Dietary Reference Intakes: Females and males, 19 to >70 years old: 0.9 µg/day (FNB, 2004).

Shellfish in general are low in fat, and some, notably squid, contain a high concentration of cholesterol. However, non-cholesterol sterols (also known as plantsterols or plant stanols) are found in herbivorous mollusks, such as clams and scallops. These non-cholesterol compounds are absorbed from the intestine and can actually decrease the absorption of cholesterol (Byrd-Bredbenner *et al*., 2009) and therefore have a positive effect on health. Kiin-Kabari *et al*. (2017) observed high protein values of 13.96%, 13.96%, and 13.31% in whelk, clams, and oysters, respectively and high ash content of 14.02% was shown in whelk, with corresponding higher magnesium, calcium, potassium and sodium. Oyster, with a value of 286.22 mg/100g was shown to be the richest in phosphorus (Kiin-Kabari *et al*., 2017). Studies have shown that increased consumption of oysters, clams, periwinkles, and whelks can address the serious problem of micronutrient deficiency. However, the usefulness of shellfish as a source of protein and minerals for human may be limited by the actual amount of these nutrients available for absorption and utilization. Digestion using simulated gastric and intestinal fluids provides valuable information and allows for the estimation of bioavailability. Having known that shellfish contains essential minerals and high protein, it becomes necessary to determine the bioavailability of these minerals as well as the digestibility of proteins present in shellfish.

2. Materials and Methods

Fresh periwinkle (smooth), periwinkle (rough), clams, whelk and oyster (Plate 1, 2, 3, 4 and 5, respectively) were obtained from "Nembe" seafood market in Port Harcourt, Rivers State, Nigeria. In February 2020

Plate 1: Periwinkle (Smooth)

Plate 2: Periwinkle (Rough)

Plate 3: Clams

Plate 4: Whelk

Plate 5: Oyster

2.1. Sample Preparation

The samples were prepared by using the traditional method of seafood processing in Rivers State, Nigeria (Kiin-Kabari *et al.,* 2017), as shown in Figure 1. The molluscs samples were washed properly, put into a stainless pot and boiled for 5min at 100°C. After boiling, the samples were poured into a perforated basket to drain and allowed to cool at room temperature (28±2°C). The edible portion (meat) was extracted from the shell with the aid of a sterile pin in the case of the periwinkle and whelk, and a sharp knife in the case of oyster and clam. The samples were frozen at -20°C until required for use.

2.2. Mineral Content

Mineral analysis was done by dry ashing according to procedure 14.013 of AOAC (2012). Muffle furnace (Model SKL, China) at temperature of 550 °C was used for ashing. After sample preparation, total mineral determination was done using Atomic Absorption spectrophotometer (AAS) (Hitachi Z-5300, polarized Zeaman, Hitachi Ltd; Japan). The light source was Hollow cathode lamp of each element, using acetylene and air combinations, with air pressure of 0.3 Mpa, and air flow rate of 6.5 L/min, acetylene pressure of 0.09 Mpa and a flow rate of 1.7 L/min was used. Other operating conditions such as wavelength and lamp current are given for each element as follows: Ca = 422.7 nm and 2 mA, Fe = 248.3 nm and 2 mA, K = 766.5 nm and 1 mA, mg = 285.2 nm and 1mA, Na = 589.0 nm and 1mA. Phosphorous was determined by molybdenum blue method and the absorbance read at 700 nm using a spectrophotometer UV-visible (CELiL model CE2021 U.K).

2.2.1 Mineral Bioavailability

Mineral Bioavailability was determined using method described by Chauhan & Mahjan (1988). One (1.0 g) was extracted using 10 ml of 0.03 N HCl with shaking at 37^{o}C for 3 h. Thereafter, the extract was filtered and a clear filtrate obtained was dried at 100^{o}C and then placed in a muffle furnace at 550^{o}C for 4 h, the sample was cooled and about 5 ml of 5 N HCl was added and boiled

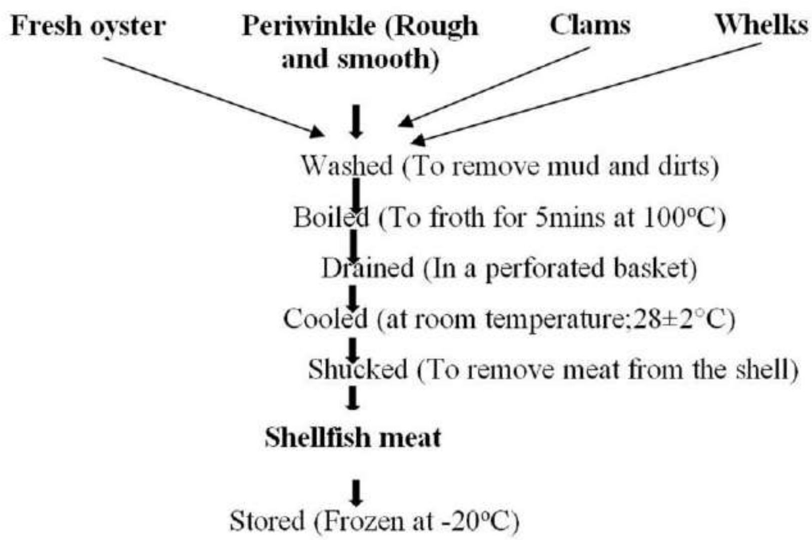

Figure 1: Flow chart for the processing of some selected shellfish (Kiin-Kabari *et al*., 2017)

gently for 10 min and then cooled and diluted with 100 ml of distilled water. The supernatant obtained was subjected to mineral analysis using atomic absorption spectrophotometer (AAS). The results obtained were used in calculating the percentage of minerals in the shellfish samples that are bioavailable in soluble fractions using the formula;

$$\text{X (mg/100g)} = \frac{(Concentration) \times 50 \times 1000}{104 \times Sample\ weight}$$

Mineral Balance was calculated by difference (Akusu *et al*., 2020).

$$\text{Mineral balance (\%)} = 100 - \text{Mineral Bioavailability (\%)}$$

2.2.2. Percentage Soluble Minerals

This was calculated from the total minerals and the soluble minerals after acid hydrolysis multiplied by 100.

$$\text{Mineral in soluble fraction (\%)} = \frac{X}{Y} \times \frac{100}{1}$$

Where X= Total minerals, Y= Mineral content after acid hydrolysis

2.3. Total Protein Determination

Protein content was determined using the AOAC (2012) standard method.

2.4. Protein Digestibility

In-vitro protein digestibility of the sample was determined by the method of Mertz *et al*. (1984) and modified by Monsour & Yusuf (2002). The sample (250 mg) was suspended in 15 mL of 0.1 N hydrochloric acid in a glass tube. Pepsin enzyme (1.5 mg) was introduced into the suspension and shake at 37 ^{0}C for 3 h. The solution was neutralized and 0.5 N sodium hydroxide and treated with 4 mg of pancreatic enzyme in 7.5 ml of 0.2 ml phosphate buffer (pH 8.0) containing 0.5 ml sodium azide. The mixture was shaken gently at 37^{o}C for 24 h. The solids were separated by centrifuging at 4000 rpm for 30 min and washed with water (5 x 30 mL) and filtered with whatman No. 1 filter paper. The residue was dried in the oven at 100 ^{o}C and analyzed for nitrogen by the kjeldahl method. The nitrogen content of the sample was analyzed. The invitro protein digestibility was calculated in accordance with the formula;

$$\% \text{ In-vitro protein digestibility} = \frac{\textit{Nitrogen of sample} - \textit{Nitrogen of residue}}{\textit{Nitrogen of samples}} \times 100$$

2.5. Statistical Analysis

All the analyses were carried out in triplicate. Data obtained were subjected to Analysis of Variance (ANOVA); differences between means were evaluated using Turkey's multiple comparison tests and significance accepted at p≤0.05 level. The statistical package in Minitab 16 computer program was used.

3. Results and Discussion

3.1. Total Ash and Protein Content of the Shellfish

The selected shellfish had high protein content ranging from 12.01-18.84% as shown in Table 1. These values were higher compared to the earlier work obtained on shell fish as reported by Kiin-Kabari *et al.* (2017) but lower than 19% protein content of shellfish reported by Venugopal & Shahidi (1996). This might be due to the feeding habit of the shell fish on rich protein source from the aquatic environment (Davies & Jamabo, 2016). Proteins are the source of dietary amino acids and are used for growth and maintenance of living systems (Sivasanka, 2011). The high protein content in the shell fish samples suggest that they could be used to fortify carbohydrate based diets as a step towards alleviating the problem of protein energy malnutrition. The Ash contents of oysters and clamp were significantly (p<0.05) higher than those of periwinkle (rough and smooth). The ash contents of the shell fish samples (1.32-2.92%) were observed to be lower than the findings of Kiin-Kabari *et al.* (2017) but compares well with previous reports on ash content (2%) of shell fish (Anthony *et al.*, 1983). This might also be due to the nature of the food they eat (Davies & Jamabo, 2016). The ash content of a food material gives an idea about the inorganic content of the sample and this gives an indication that they contain high mineral elements.

Table 1: Proximate Composition of Selected Shell Fish

Sample	Ash (%)	Protein (%)
Periwinkle(Rough)	1.55 ± 0.10^{bc}	13.86 ± 0.51^{b}
Periwinkle(Smooth)	1.32 ± 0.00^{c}	12.01 ± 1.02^{b}
Whelk	2.39 ± 0.70^{ab}	14.37 ± 1.03^{b}
Oysters	2.92 ± 0.70^{a}	18.84 ± 1.04^{a}
Clams	2.87 ± 0.00^{a}	18.74 ± 0.22^{a}

Values are means ± standard deviation of triplicate samples
Mean values bearing different superscripts in the same column differ significantly (p<0.05).

3.2. In-Vitro Protein Digestibility of Shell Fish Samples

Result for In-vitro protein digestibility of shellfish samples is presented in Figure 2. Protein digestibility of the shellfish sample range from 8.62-16.75% with oyster recording the highest while periwinkle (smooth) gave significantly lower protein content. Results showed no significant difference (p<0.05) between oyster and whelk. The protein digestibility of the shell fish was 11.9, 8.62, 16.75, 16.64 and 13.88 % for periwinkle rough, smooth, whelk, oyster and clam respectively. These showed that Oyster and whelk were more digestible than periwinkle smooth, periwinkle rough and clams. In vitro protein digestibility is useful in providing a suitable and reliable estimation of protein nutritional quality. The present in-vitro protein digestibility results provided a ranking of protein quality for the shellfish samples. Oyster and whelk were more digestible than periwinkle smooth, periwinkle rough and clams. The difference in digestibility could be attributed to action of enzymes in the shellfish involve in protein digestion (Sudip *et al.*, 2017). The digestibility of any protein depends on the ability of the fish to utilize ingested nutrients. The results of the protein digestibility of the shell fish samples agrees with the work of Ali *et al*. (2009) who reported a protein digestibility of 20.65% for shrimp meal. Protein digestibility of the shellfish was lower than the protein digestibility of Buffalo meat (90.79%) as reported by Babji *et al.* (2010). The nutritional quality of any protein relates to its amino acid composition, digestibility, and ability to supply the essential amino acids in the amounts required by the species consuming the protein (Endres, 2001). Protein is needed as building blocks for the body, necessary for growth and for the repair of damaged tissues (Wardlaw, 2004).

3.3. Total Mineral Content of the Shellfish

Calcium, iron, sodium, potassium, magnesium and zinc content of the shellfish ranged from 97.46-709.8, 31.08-36.60, 41.01-369.5, 618.5-1286, 1.04-721.6 and 8.89 - 23.66 mg/100g, respectively as shown in Table 2. All the shellfish samples differed significantly ($p<0.05$) in total mineral composition.

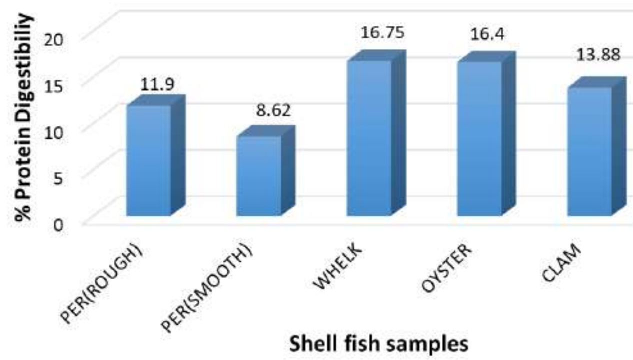

Figure 2: Percentage Protein Digestibility of some selected shellfish

Potassium was significantly ($p<0.05$) higher in clam (1286.00 mg/100g) and low in periwinkle smooth (618.90 mg/100g). Whelk was significantly high in zinc and magnesium with values of 23.66 and 721.60 mg/100g, respectively. The mineral results obtained from the study were in correlation with that reported by Kiin-Kabari *et al.* (2017) on the mineral composition of selected shell fish. The result showed that shellfish is a good source of essential minerals. Calcium and phosphorus are associated with each other for growth and maintenance of bones, teeth and muscles (Clarke, 2008). Calcium (Ca) is an important bone related macro element in human nutrition (Soetan *et al.*, 2010). Calcium in addition with other micro minerals and protein can help in bone formation with calcium acting as principal contributor (Kiin-Kabari *et al*., 2017). Calcium is important in blood clotting, muscles contraction and in certain enzymes in metabolic processes (Davis & Jamabo, 2016). Magnesium is an essential micronutrient needed for nervous system health (Abulude *et al*., 2006). Inadequate intakes of micronutrients (Zinc and Iron) have been associated with severe malnutrition, increased disease conditions and mental impairment (Mannay & Shadaksharaswany, 2005). Zinc is involved in normal functioning of immune system and is associated with protein metabolism (Hambidge & Krebs, 2007). Iron is an essential trace element for haemoglobin formation, normal functioning of central nervous system and in the oxidation of carbohydrate, protein and fats (Murray *et al*. 2000).

Table 2: Total Mineral Composition (mg/100g) of selected Shell Fish

Samples	Sodium	Iron	Potassium	Zinc	Calcium	Magnesium
Oysters	$369.50^{a}\pm0.70$	$32.10^{b}\pm0.62$	$695.00^{d}\pm0.75$	$9.19^{c}\pm0.07$	$251.00^{c}\pm1.01$	$1.04^{e}\pm1.04$
Clam	$355.23^{b}\pm1.00$	$24.99^{d}\pm0.04$	$1286.00^{a}\pm0.14$	$11.07^{b}\pm0.04$	$181.00^{e}\pm0.11$	$205.86^{b}\pm0.05$
Periwinkle rough	$255.00^{d}\pm0.56$	$19.044^{e}\pm0.07$	$958.20^{b}\pm0.09$	$9.11^{e}\pm0.61$	$97.46^{d}\pm0.20$	$9.13^{d}\pm0.14$
Periwinkle smooth	$240.10^{c}\pm0.94$	$36.60^{a}\pm0.01$	$618.90^{e}\pm0.00$	$8.90^{d}\pm0.49$	$260.60^{b}\pm0.33$	$38.88^{c}\pm0.44$
Whelk	$41.01^{e}\pm0.86$	$31.08^{c}\pm0.00$	$760.00^{c}\pm0.74$	$23.66^{a}\pm0.02$	$709.80^{a}\pm0.84$	$721.60^{a}\pm0.02$

Values are means ± standard deviation of triplicate samples.
Mean values bearing different superscripts within the same column differ significantly (p<0.05)

3.4. Soluble Mineral Composition (mg/100g) of Selected Shell Fish

The soluble mineral composition of oyster, clam, periwinkle and whelk is shown in Table 3. Soluble sodium ranged from 9.01-343.30 mg/100g, with oyster and whelk given significantly ($p<0.05$) higher value. The most soluble fractions of calcium and iron were recorded in periwinkle (smooth) while the least soluble fraction of calcium was shown in periwinkle rough. Soluble iron ranged from 8.79-14.50 mg/100g however, there was no significant ($p>0.05$) difference in the soluble iron fractions of periwinkle rough and smooth. The least soluble fraction of iron (8.79 mg/100g) was recorded in clam. The soluble component of zinc and magnesium in whelk were significantly ($p<0.05$) higher than other selected shellfish. Lower proportions of mineral in soluble forms after digestion of food products is a suggestion that not all the minerals are bioavailable, and absorbed by the intestinal cells (Kiin-Kabari *et al*., 2015). Although; the total iron (Fe) content of the shell fish were high, the proportion of Fe in soluble forms ranged from 8.79 mg/100g in clams to 14.50 mg/100g in periwinkle (smooth and rough), reduction in soluble iron (Fe) could be due to present of calcium (Ca) in the shell fish, calcium has been implicated to play an inhibitory effect on Iron absorption (Benkhedda *et al*., 2010), decreasing its availability.

3.5. Percentage Mineral Bioavailability of Selected Shellfish

The bioavailability of calcium, iron, sodium, zinc, magnesium and potassium ranged from 58.80-84.30, 33.85-47.87, 21.90-96.60, 31.45-62.06, 69.00-99.50 and 80.80-97.40%, respectively, with periwinkle smooth recording the highest value and clam the lowest. Bioavailable magnesium was; 96.40, 93.20 and 94.80%, respectively for Periwinkle rough, whelk and oyster.

Table 3: Soluble Mineral Content of Selected Shell Fish

Shellfish	Na	Fe	K	Zn	Ca	Mg
Oyster	$343.30^a\pm0.01$	$13.10^b\pm0.00$	$659.00^d\pm0.01$	$2.89^e\pm0.10$	$155.00^c\pm0.32$	$0.72^e\pm0.07$
Clam	$343.30^a\pm0.02$	$8.79^d\pm0.04$	$1040.00^a\pm0.01$	$6.87^b\pm0.03$	$96.00^d\pm0.04$	$204.00^b\pm0.94$
Periwinkle rough	$235.00^b\pm0.04$	$14.50^a\pm0.02$	$924.00^b\pm0.23$	$4.21^c\pm0.04$	$82.20^e\pm0.12$	$7.37^d\pm0.56$
Periwinkle smooth	$219.00^c\pm0.09$	$14.50^a\pm0.00$	$603.00^e\pm0.11$	$3.70^d\pm0.01$	$185.60^a\pm0.54$	$37.80^c\pm0.21$
Whelk	$9.01^d\pm0.00$	$10.52^c\pm0.05$	$708.00^c\pm0.52$	$8.95^a\pm0.08$	$411.70^b\pm0.22$	$718.00^a\pm0.64$

Values are mean ± standard deviation of triplicate samples. Mean values bearing different superscript within the same column differ significantly ($p<0.05$)

Na=sodium, Fe= Iron, K= potassium, Zn= zinc, Ca= calcium, Mg= magnesium

Consistently, lower concentrations of bioavailable sodium (21.90%) and iron (33.90%) were observed in whelk while higher bioavailable calcium (84.30%) was observed in periwinkle rough as presented in Table 4. Clams were high in bioavailable sodium (96.60%) and zinc (62.10%) while periwinkle smooth was high in bioavailable iron (47.90%) and potassium (97.40%). The shellfish in general had high mineral bioavailability except for iron and zinc which was below 50%. The low bioavailability of zinc and iron in the shell fish samples could be attributed to interactions of the iron with proteins and/or other food components thereby hindering its absorption. The bioavailability of iron, which is the amount absorbed from food can be less than one percent to over 50%. Iron is found in food in two different forms, either as heme iron, found in the haemoglobin and myoglobin of meat, poultry and fish, or as non-heme iron found in plant products. Heme iron is better absorbed (about 15 to 40%) than non-heme iron (1 to 15%) (Roughead & Hunt, 2000). Thus, although heme iron contributes only about 10 to 15% of total iron intake but may provide substantial amount of total iron absorbed (EFSA, 2010). The bioavailability of minerals in the shellfish (except for zinc) were higher as compared to other foods such as plantain as reported by Kiin-kabari & Agoha (2018). Bioaccessibility has been defined as the fraction of a compound that is released from its matrix in the gastrointestinal tract and thus becomes available for intestinal absorption (i.e., enters the blood stream) (Benito & Miller, 1998). Bioaccessibility includes the entire sequence of events that take place during the digestive transformation of food into material that can be assimilated by the body, the absorption/ assimilation into the cells of the intestinal epithelium, and lastly, the presystemic metabolism (both intestinal and hepatic) (Ting & Loh, 2016). Bioavailability is the technical term used to convey the fact that not 100% of nutrients ingested will be absorbed, irrespective of whether consumed in the form of food or supplements. Similarly, meat, fish and poultry, while containing highly bioavailable iron themselves, are also known to enhance the absorption of iron from other foods ingested at the same time. Low bioavailability diets (5% of the total iron absorbed) are based mainly on cereals and root vegetables with only very small quantities of meat, fish or vitamin C- containing foods (Baech *et al*., 2003). Such diets often contain foods that inhibit iron absorption (maize, beans, whole-grain flour) and are dominant in many developing countries. Intermediate bioavailability diets (10% of the iron absorbed) consist mainly of cereals and root vegetables but contain some meat and some foods containing vitamin C. High bioavailability diets (15% of the iron absorbed) contain regular intakes of meat, poultry and fish (Baech *et al*., 2003). Result for mineral balance of selected shellfish as presented in Table 5, showed Sodium ranging from 3.40 – 78.10%, with significantly ($p<0.05$) higher percentage noticed in whelk. Significantly High Zinc balance (68.50%) was noticed in oyster. shellfish that presented with high mineral balance in any particular mineral, is an indication of its low bioavailability. Increased percentage mineral balance is probably due to presence of anti-nutritional factors. As noted earlier by Akusu *et al.* (2020), anti-nutritional factors are shown to cause complexing, binding and inhibition of minerals, thereby decreasing their bioavailability and increasing the mineral balance. The mineral balance in a food substance is the insoluble mineral that is unavailable and cannot be absorbed (Akusu *et al*., 2020).

Table 4: Percentage Mineral Bioavailability of Selected Shellfish

Shellfish	Na	Fe	k	Zn	Ca	Mg
Oyster	$92.90^{b}\pm0.01$	$40.80^{c}\pm0.04$	$94.80^{c}\pm0.06$	$31.50^{e}\pm0.15$	$61.80^{c}\pm0.43$	$69.00^{e}\pm0.00$
Clam	$96.60^{a}\pm0.15$	$35.20^{d}\pm0.11$	$80.80^{e}\pm0.04$	$62.10^{a}\pm0.00$	$53.00^{e}\pm0.08$	$99.00^{b}\pm0.01$
Periwinkle (rough)	$92.10^{c}\pm0.00$	$42.60^{b}\pm0.02$	$96.40^{b}\pm0.02$	$46.20^{b}\pm0.11$	$84.30^{a}\pm0.04$	$80.70^{d}\pm0.03$
Periwinkle (smooth)	$91.20^{d}\pm0.02$	$47.9^{a}\pm0.21$	$97.40^{a}\pm0.10$	$41.60^{c}\pm0.07$	$71.20^{b}\pm0.03$	$97.20^{c}\pm0.02$
Whelk	$21.90^{e}\pm0.01$	$33.90^{e}\pm0.02$	$93.20^{d}\pm0.04$	$37.90^{d}\pm0.09$	$58.80^{d}\pm0.00$	$99.50^{a}\pm0.01$

Values are mean ± standard deviation of triplicate samples. Mean values bearing different superscript within the same column differ significantly ($p<0.05$)

Na=sodium, Fe= Iron, K= potassium, Zn= zinc, Ca= calcium, Mg= magnesium

4. Conclusion

The protein digestibility of the shellfish was 11.9%, 8.62%, 16.75%, 16.64% and 13.88% for periwinkle rough, smooth, whelk, oyster and clam, respectively. These showed that Oyster and whelk were more digestible than periwinkle smooth, periwinkle rough and clams.

Table 5: Percentage Mineral Balance of Selected Shellfish

Shellfish	Na	Fe	k	Zn	Ca	Mg
Oyster	$7.10^{d}\pm0.01$	$59.20^{c}\pm0.04$	$5.20^{c}\pm0.06$	$68.50^{a}\pm0.15$	$38.20^{c}\pm0.43$	$31.00^{a}\pm0.00$
Clam	$3.40^{e}\pm0.15$	$64.80^{b}\pm0.11$	$19.20^{a}\pm0.04$	$37.90^{e}\pm0.00$	$47.00^{a}\pm0.08$	$1.00^{d}\pm0.01$
Periwinkle (rough)	$7.90^{c}\pm0.00$	$57.40^{d}\pm0.02$	$3.60^{d}\pm0.02$	$53.80^{d}\pm0.11$	$15.70^{e}\pm0.04$	$11.30^{b}\pm0.03$
Periwinkle (smooth)	$8.80^{b}\pm0.02$	$52.10^{e}\pm0.21$	$2.60^{e}\pm0.10$	$58.40^{c}\pm0.07$	$28.80^{d}\pm0.03$	$2.80^{c}\pm0.02$
Whelk	$78.10^{a}\pm0.01$	$66.10^{a}\pm0.02$	$6.80^{b}\pm0.04$	$62.10^{b}\pm0.09$	$41.20^{b}\pm0.00$	$0.50^{e}\pm0.01$

Values are mean ± standard deviation of triplicate samples. Mean values bearing different superscript within the same column differ significantly ($p<0.05$)
Na=sodium, Fe= Iron, K= potassium, Zn= zinc, Ca= calcium, Mg= magnesium

The protein digestibility in whelk and oyster was significantly higher compared to other samples. Whelk recorded the highest bioavailable magnesium (99.50%) followed by clam (99.00%). Clam also showed significant high zinc bioavailability. Low concentrations of bioavailable sodium (21.90%) and iron (33.90%) were observed in whelk while higher bioavailable calcium (84.30%) and potassium (96.40) were observed in periwinkle rough. Clams were high in bioavailable sodium (96.60%) and zinc (62.10%) while periwinkle smooth was high in bioavailable iron (47.90%) and potassium (97.40%). Although the shellfish studied have good amount of total minerals, not all the minerals were available for absorption after digestion.

Conflict of interest

The authors declare that there are not conflicts of interest.

Ethics

This Study does not involve Human or Animal Testing.

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