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Nutritional and shelf-life studies of dry smoked and gamma irradiated shrimps (*Penaeus notialis*) from three different water sources in Ghana

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Abstract: Shrimps are mostly used in its dried state for several purposes in Ghana. They are food for several decades, used in many culinary dishes including baby foods as well as one of the main ingredients in the famous pepper sauce and can also be used in various foods to enhance flavor. Proximate composition of shrimps from three water sources: sea, lagoon and river was evaluated according to standard procedures of AOAC after exposure to gamma ionizing radiation from a Cobalt 60 source (SL 515, Hungary). Radiation doses used were 0, 4, 8 and 10 kGy at a dose rate of 1.7 kGy/h. Protein content ranged from 27.40 ± 1.30% to 34.35 ± 1.30%, ash 13.80 ± 0.09% to 15.42 ± 0.09%, fat 0.90 ± 0.01% to 1.72 ± 0.01% and moisture 9.36 ± 0.06% to 12.92 ± 0.06%. From the sea, river and lagoon, protein content ranged between 25.93 ± 1.13% and 34.42 ± 1.13%, ash 11.85 ± 0.08% and 18.25 ± 0.08%, fat 0.76 ± 0.01% and 1.83 ± 0.01% and moisture 9.22 ± 0.05% and 12.72 ± 0.05%. After 4 months of storage, there was a significant ($p < 0.05$) increase in protein and ash contents while fat and moisture contents

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PUBLIC INTEREST STATEMENT

Studies examining dietary habits have revealed the health benefits of shrimp consumption. Seafood (shrimp) contains functional components that are not present in terrestrial animals. Shrimp meat is popular and widely accepted in African and beyond according to FAO in 2010 due to its in-demand use in the preparation of several delectable dishes. Its nutrient contents are essential for bodily functions and are beneficial to growth, the brain and the nervous system; they also have anticancer properties. Shrimp has helped alleviate food crises and protein malnutrition in many developing countries, providing a valuable supplement to a diverse and nutritious diet. Studies on the nutritional attributes and its shelf-life extension vis-a-vis gamma irradiation interaction of shrimp are limited if not lacking.

decreased. The use of gamma irradiation technology in food processing should be encouraged as it does not affect nutrients.

Subjects: Agriculture & Environmental Sciences; Food Chemistry; Food Engineering

Keywords: Shrimps; *Penaeus notialis*; gamma irradiation; proximate composition

1. Introduction

Human nutrition interest and awareness has raised some worries about the high prevalence of diet-related chronic diseases in both developed and developing countries of the world. It has now become acceptable for consumers to actively select foods for health maintenance and disease prevention. Epidemiological studies have shown that those cultures that predominantly consume seafood have low incidence of heart attacks (Hu et al., 2002; Willet, 2007). According to the Institute of Medicine (IOM, 2006) report, seafood is nutrient rich and provides high-quality protein and could be used to improve the protein malnutrition problem in Sub-Saharan Africa especially. As reiterated by Akonor, Ofori, Dziedzoave and Kortei (2016), dried shrimps are popular and widely acceptable in Ghana because they are used (in whole or powdered form) in soups and sauces as a major protein source and for their delectable flavor.

Biologically, shrimps belong to a large group of crustaceans with extended abdomen. They represent one of the most important commercial seafood in the world (Oosterveer, 2006). In Ghana and Africa at large, they have gained so much popularity so is fished on both commercial and artisanal scale along the coastal regions of Africa (Entsua-Mensah, De Graft-Johnson, Atikpo, & Abbey, 2002). Shrimps are estimated to contain nearly 20% protein (wb) with well-balanced amino acids and significantly high amounts of other nutrients including micronutrients such as calcium and selenium. Lipids in shrimps are largely made up of polyunsaturated fatty acids which are essential for human health (Sriket, Benjakul, Visessanguan, & Kijroongrojana, 2007; Yanar & Celik, 2006). They have also been identified as rich in vitamin B12 and astaxanthin, a fat-soluble carotenoid which has antioxidant properties (Venugopal, 2008). The proximate composition of shrimps, crustaceans and other aquatic organisms has been found to be varied due to the seasonal factors such as climatic factors, geographic factors, habitat, developmental stage, sex and sexual maturation.

Owing to its high moisture content together with its high protein content, it predisposes them to rapid deterioration (Akonor et al., 2016); several drying techniques have been applied to process shrimps to extend its shelf-life. Some of these methods are freeze-drying (Donsi, Ferrari, & DiMatteo, 2001), superheated steam drying (Prachayawarakorn, Soponronnarit, Wetchacama, & Jaisut, 2002), jet-spouted bed drying (Niamnuy, Devahastin, & Soponronnarit, 2007) and heat pump drying (Zhang, Arason, & Arnason, 2008), among others.

In spite of these improved approaches to drying shrimps, gamma irradiation which is a preservation method has been in long standing use and has produced encouraging results (International Atomic Energy Agency [IAEA], 1995, IAEA-TECDOC, 2004, IAEA-TECDOC-1530, 2005, Odamtten et al., 1986, Kortei, 2015) and can augment these drying methods to enhance product shelf-life. The recommendation by the joint FAO/IAEA/WHO Expert Committee on the wholesomeness of irradiated foods in 1980 gave the impulsion for the acceptability of food irradiation as a means preserving food. Research by some scientists indicates that irradiation will not lead to chemical changes in food that would adversely affect human health (WHO, 1994).

The objective of this study was to assess the effect of gamma irradiation on the nutritional attributes of shrimps during storage at different periods obtained from three different water sources.

2. Materials and methods

2.1. Collection of samples

Samples were collected according to methods prescribed by Akuamoah, Odamtten and Kortei (2018) with some modifications. Smoked shrimp (*Penaeus notialis*) were purchased from the local market. The samples were dominated mainly by *P. notialis* although there were other few varieties found in the population, which were identified as *P. monodom* and *P. kerathucus*. The samples were then carefully sorted to ensure a homogenous population of *P. notialis*. They were then wrapped in a brown paper and then placed in a black polyethylene bag (main mode of packaging by the local producers) and then transported to the Department of Plant and Environmental Biology laboratory of the University of Ghana. The shrimps were poured into dense polypropylene containers and kept at a temperature (6–8°C) appropriate for storage and further studies.

2.2. Irradiation of shrimp samples and Dosimetry method

Irradiation was done according to Varanyanond et al. (2000) and Wang et al. (2010) with some modifications. The samples were packaged in a dense polypropylene bowls. This material was used because of its ability to resist piercing/puncture due to the antenna of the shrimp in accordance with the specific guidelines of the East African Standard (EAS, CD/K/512:2010: ICS 67.120.30) for dried shrimp packaging. The samples were treated with gamma irradiation (Cobalt-60 irradiator) in a Category Four (4) Wet Storage Irradiator at the Radiation Technology Centre at the Ghana Atomic Energy Commission. Doses applied were 0 kGy (control), 4, 8 and 10 kGy within the range used by for dried shrimp in East Asia. The dosimeter used was the Ethanol chlorobenzene Dosimetry system, which comprise of the Ethanol Chlorobenzene Dosimeter and the High Frequency Dosimeter Reader (HFDR). The dosimeter was calibrated against an International standard set by the International Atomic Energy Agency and read using the HFDR. To minimize variations in radiation dose absorption, the bags were turned at different angles halfway through the procedure. Samples were analyzed in triplicates for each source. The dose rate used was 1.7 kGy/h in air.

2.3. Determination of percentage moisture and fat content of shrimp samples

A Bench Top Pulsed Miniature Nuclear Magnetic Resonance facility (Oxford Instrument, United Kingdom, Model MQC-5) was used in the determination of both percentage (%) moisture and fat content of both irradiated and unirradiated samples simultaneously. The instrument also has the potential of determining the percentage moisture and fat content per dry weight as well as 9% moisture and fat content of the sample. The instrument was first auto-tuned using 100% paraffin oil as a tuning sample. The irradiated and unirradiated samples were blended (in order to reduce error and increase the total surface area) and poured into a tarred glass tube up to 4 cm of its height. The mass of the samples was recorded before being transferred into the sample embedment compartment of the NMR instrument to be analyzed. The moisture and fat percentage (%), percentage (%) moisture and fat content per dry weight as well as 9% moisture and fat content were recorded. Each reading was repeated three times and the values were average and recorded as moisture and fat content. The instrument was previously calibrated using rape seed.

2.4. Determination of ash content

According to methods described by AOAC (1995).

2.5. Determination of crude protein

According to methods described by AOAC (1995).

2.6. Statistical analysis

All experiments were performed in triplicates. Data were subjected to analyses of variance (multifactor ANOVA) and results presented in means and standard deviations. Significant differences were determined by *post-hoc* test using Duncan's multiple range test i.e. DMRT (Gomez & Gomez, 1984) with SPSS 16 (Chicago, USA).

3. Results and discussion

3.1. Crude protein

Table 1 summarizes results obtained from the effect of doses on the physicochemical properties of shrimps. Results for crude protein ranged between 27.40 ± 1.30% and 34.35 ± 1.30%. Irradiation up to 10 kGy did not significantly ($p \geq 0.05$) affect crude protein content, but at the end of 4 months storage, there were significant differences ($p \leq 0.05$) observed from treatment means (Table 3).

There were also significant ($p \leq 0.05$) differences between the crude protein of shrimp from the river, lagoon and sea (Table 2) and was highest (43.36%) (before irradiation) in riverine shrimp and least in (26.96%) in shrimp from the sea. Radiation is known to cause disintegration and subsequent aggregation of the protein molecules which has an effect on the protein composition (Kumta & Tappel, 1961). It is also known that gamma radiation affects a direct breakdown in protein or enhances the activity of lysozomal (proteolytic) enzymes, which help to aggregate the protein and decrease its solubility (Van Huystee & Verma, 1969). Furthermore, some scientists (Dogbevi, Vachon, & Lacroix, 1999; Rahma & Mostafa, 1988; Taha & Mohamed, 2004) suggested that the extent of denaturing is directly linked to the radiation dose used which is considered very important, since this dose could unfold protein to increase its size through the deamination of the protein. Again, aggregation of proteins during disintegration through the decrease of the sulphahydryl group, increase in the disulfide bond and the rearrangement of the small molecular weight to a high molecular weight protein (Afify & Shousha, 1988) could be some attributions of the change in protein contents. There was no interaction between dose, source of shrimp and storage period.

The average protein content (%) before irradiation was 35.25%. Ravichandran, Rameshkumar and Rosario (2009) also reported the protein content of flesh of white shrimp to be 41.3% whereas the shell contained 32.5%. Table 2 shows the treatment means for the effects of shrimp sources on protein content. Shrimp from the river recorded the highest amounts of

Table 1. Treatment means for the effect of dose obtained from a multifactor ANOVA of physicochemical indices of shrimps

Doses (kGy)	Treatment means ± standard error			
	Crude protein	Ash	Fat	Moisture
0	34.35 ± 1.30^{b}	15.42 ± 0.09^{d}	1.72 ± 0.01^{d}	12.92 ± 0.06^{d}
4	29.00 ± 1.30^{a}	14.94 ± 0.09^{c}	1.02 ± 0.01^{c}	10.32 ± 0.06^{c}
8	30.06 ± 1.30^{a}	14.31 ± 0.09^{b}	0.95 ± 0.01^{b}	9.73 ± 0.06^{b}
10	27.40 ± 1.30^{a}	13.80 ± 0.09^{a}	0.90 ± 0.01^{a}	9.36 ± 0.06^{a}

Means within each column with different letters are significantly different ($p \leq 0.05$).

Table 2. Treatment means for the effect of sources (lagoon, river and sea) obtained from a multifactor ANOVA of physicochemical indices of shrimps

Sources	Treatment means ± standard error			
	Crude protein	Ash	Fat	Moisture
Lagoon	30.26 ± 1.13^{b}	13.74 ± 0.08^{b}	0.85 ± 0.01^{b}	9.81 ± 0.05^{b}
River	34.42 ± 1.13^{c}	11.85 ± 0.08^{a}	0.76 ± 0.01^{a}	9.22 ± 0.05^{a}
Sea	25.93 ± 1.13^{a}	18.25 ± 0.08^{c}	1.83 ± 0.01^{c}	12.72 ± 0.05^{c}

Means within each column with different letters are significantly different ($p \leq 0.05$).

Table 3. Treatment means for the effect of months (initially and 4th month) obtained from a multifactor ANOVA of physicochemical indices of shrimps

Month	Treatment means ± standard error			
	Crude protein	Ash	Fat	Moisture
Initially	28.41 ± 0.92[a]	13.95 ± 0.06[a]	1.25 ± 0.01[b]	11.10 ± 0.04[b]
4 months after irradiation	32.00 ± 0.92[b]	15.28 ± 0.06[b]	1.04 ± 0.01[a]	10.06 ± 0.04[a]

Means within each column with different letters are significantly different ($p \le 0.05$).

protein content (43.36%) followed by shrimp from the lagoon (35.43%). Shrimp from the sea recorded the least amounts of protein content (26.96%). The differences observed in the protein content of shrimp from river, lagoon and sea were statistically significant ($p \le 0.05$) (Table 2). The discrepancies in protein content of shrimps used in these studies may be attributed to differences in species, growth stage, season and region waters in which they were shrimped (Karakoltsidis, Zotos, & Constantinides, 1995; Luzia, Sampaio, Castellucci, & Torres, 2003). Maghsoudloo, Marammazi, Matinfar, Kazemian and Paghe (2012) and Mente, Coutteau, Houlihan, Davidson and Sorgeloos (2002) also attribute this to feeding habits and dietary sources. Several studies conducted by scientists (Fenucci, Zein-Eldin, & Lawrence, 1980; Luzia et al., 2003) have affirmed a relationship between growth and diet quality for *Penaeus* sp. Protein synthesis rates are closely correlated with growth rates and RNA to protein concentration ratio (Houlihan, Hall, Gray, & Noble, 1988), and it is apparent that the rate of protein synthesis relative to the RNA concentration can be radically elevated after a meal (Houlihan, Waring, Mathers, & Gray, 1990).

The high protein content of shrimp meat makes it a good source of amino acids for human diets. Akonor et al. (2016) reported higher protein values of range 84.9–86.5% (db) of fresh meat as they studied the drying characteristics, physical and nutritional properties of shrimp meat as affected by different traditional drying techniques. In another study, Gopakumar (1997) reported protein values of 21.9% for *Peneaus indicus* from Indian waters. Deshpande (2002) suggested that an interaction of protein molecules and gamma radiation at high doses produces denaturation, and a host of reactions to the constituent's amino acid subunits. However, irradiation up to 10 kGy did not significantly ($p \ge 0.05$) influence the protein content (Table 1); 4 months storage showed marked differences (Table 3). Generally, results obtained in this study were comparable to the findings of some previous published studies (Adeyeye, Adubiaro, & Awodola., 2008; Sriket et al., 2007; Yanar & Celik, 2006).

3.2. Ash content

The ash content ranged between 11.85 ± 0.08% and 18.25 ± 0.08% (Tables 1–3). Increasing radiation doses up to 10 kGy significantly ($p \le 0.05$) reduced ash content (Table 1). At the end of 4-month storage, there were significant differences observed for the treatment means (Table 3). Clearly, the ash content of shrimp was significantly different ($p \le 0.05$) from one water source to another (Table 2). The highest ash content of the shrimp was 18.25 ± 0.08% in the sea samples and least was 11.85 ± 0.08% in the riverine samples. This observation could be attributed to reasons earlier stated by Luzia et al. (2003). There were highly significant interactions ($p < 0.001$) between the doses applied, source of the shrimp and storage period.

There were significant differences ($p \le 0.05$) in ash contents of the shrimp depending on the source (Table 2). Ash content was reduced with increasing dose up to 10 kGy (Table 1) such that at the end of 4 months storage, significant ($p \le 0.05$) differences were observed (Table 3). Shrimp from the sea recorded the highest amounts of ash content of 18.25% followed by shrimp from the lagoon (13.74%) and the least ash content of 11.85% from riverine. There were highly significant interactions ($p \le 0.05$) between dose, sources of shrimp and storage month.

Ash represents the total mineral content in food and is essential in maintaining several bodily functions. Shrimp meat was found to contain appreciable amounts of ash, totaling nearly 1.6 % (wb). This makes shrimp meat a good source of minerals in the diet. Due to moisture loss and concentration of chemical components, higher ash content was obtained after the drying process. The ash content of shrimp meat in the present study was greater than the ranges of 1–1.5% and 1.47% independently reported by Gunalan, Nina Tabitha, Soundarapandian, and Anand (2013) and Yanar and Celik (2006). Also, results obtained did not compare favorably well with results reported by Oksuz, Ozyilmaz, Gercek and Motte (2009) who reported 1.6 ± 0.3% and 1.01 ± 0.1% for *P. longirostris* and *P. martia*, respectively, and Sriket et al. (2007) who also reported values of 0.95% and 1.47% for black tiger and white shrimp, respectively.

3.3. Fat content

The fat content of the sea shrimp was highest to least 0.87% in the shrimp from the river; fat content of the shrimp from the lagoon was intermediate (0.96%). Increasing radiation dose significantly ($p \le 0.05$) reduced the fat content (Table 1). There was significant ($p \le 0.05$) interaction between dose, source of shrimp and the storage period. The effects of dose on fat content of shrimp depended largely on the source of shrimp and the storage time.

Fat content was highest in sea shrimp (3.98%) and least in the riverine (0.87%). The average percentage fat content of shrimp from the various sources before irradiation was 1.94%; after irradiation, it shifted to 0.92% at 10 kGy. The fat content decreased with increasing dose (Table 1). There was significant interaction ($p \le 0.05$) between dose applied, source of the shrimp and the storage period. Differences in fat content may be due to seasonal variation in nutrient in water, species and geographical location (Piggot & Tucker, 1990). Age and maturity of species may influence fat content. Ackman (1989) grouped fat content of fishes and shrimp into lean fish/shrimp with fat content less than 2%.

Generally, lipid acts as major food reserves along with protein and subjected to periodic fluctuations due to environmental variables like temperature (Gunalan et al., 2013). But this does not affect the lipid composition of muscle tissue to a greater extent. In this study, the average fat content of the shrimp ranged from 0.92% to 1.94% and could be categorized as lean fat. Wang et al. (2010) indicate that hexanal and 3-methylisobenzo-furanone content in shrimp increased significantly ($p \le 0.05$) after exposure to 9 kGy of gamma irradiation. Hexanal is the major volatile indicators of lipid oxidation and has strong correlations with 2-thiobarbituric acid reactive substances in meat. Woods and Pikaev (1994) reported that when lipids in shrimp absorb ionizing energy, they become reactive and form ions or free radicals which are capable of reacting to form stable radiolytic product. Similarly, sequences of biochemical reactions occur in our body which result in an imbalance between oxidants and antioxidant reactions (typically referred to as oxidative stress) but are usually checked by antioxidants.

Significant interactions ($p \le 0.05$) were found between dose, source of the shrimp and storage period. The implication is that the effect of dose applied on the fat content of the shrimp largely depended on the source and months of storage. Indeed, storage decreased fat content significantly ($p \le 0.05$) (Table 3). High doses of ionizing radiations according to Deshpande (2002) produce rancidity when stored for a period of time.

3.4. Moisture content

The moisture contents of the shrimp were significantly ($p \le 0.05$) affected by the radiation treatment. Moisture content ranged from 11.09% to 17.76% in the control. The moisture content differed significantly ($p \le 0.05$) depending on the source of the shrimp (Table 2). Analysis of variance of data showed that there was significant interaction between doses applied, source of the shrimp and storage time. Moisture content (mc) of food determines their susceptibility to spoilage by microorganisms. Food with moisture content higher than 13% is susceptible to decomposition by microorganisms (Moorthy, 2002). The average moisture content of shrimp before irradiation was 13.5%. This was significantly ($p \leq 0.05$) affected by radiation up to 10 kGy reducing it from 12.92% to 9.36%) (Table 1). This explains the high significant interaction ($p \leq 0.05$) between the dose applied, the source of shrimp and storage time. Garrido and Otwell (2007) stated that low or excessive moisture contents in shrimp could result in objectionable or inferior quality product after long storage. The nutritional value of micronutrients in food is little affected by radiation. Micronutrients including vitamins are rather more sensitive to radiation (Wilkinson & Gould, 1996).

4. Conclusion

Our results revealed that a maximum dose of 10 kGy is adequate for the preservation of our local shrimp since no deleterious effect was observed in our results. Hence, gamma irradiation technique could be used to enhance the shelf-life of commodities without significant alteration to nutrients. Its usage will help maintain the international standard acceptable for shrimp export as well as meet its high demand from local consumers.

Also, proximate composition of shrimps from various water sources did not show much variation. Lastly, owing to its adequate protein, low-fat content and essential mineral elements in shrimp from the different water source, shrimps should be made the choice nutrient supplement source for the populace.

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Competing interests
The authors declare no competing interests.

Author contributions
The principal author (Felicia Akuamoa) was the one who conducted the laboratory analyses. She also researched on the topic and came out with the relevant literature for the write-up. The second author (George Tawia Odamtten) supervised the study from start to finish and he was also responsible for all the necessary corrections in the write-up. The third author (Nii Korley Kortei) assisted in carrying out the experiment, assemblage of the write-up and making the needed corrections as well as submitting it to a suitable journal for publication. All authors read and approved the final manuscript.

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