Synergistic effect of gamma irradiation and proper packaging for the control of insects in smoked shrimps (Penaeus notialis) from three different water bodies in Ghana

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Synergistic effect of gamma irradiation and proper packaging for the control of insects in smoked shrimps (Penaeus notialis) from three different water bodies in Ghana

Felicia Akuama¹, George Tawia Odamten² and Nii Korley Kortei³*

Abstract: Damage caused to stored dried shrimps by insect pests is problematic and are often underestimated. The incubation, identification, and control of these insect pests which infest shrimps from three water sources; sea, lagoon, and river were evaluated according to standard procedures of the Entomological Society of Canada. Exposure to gamma ionizing radiation was undertaken from a Cobalt 60 source (SL 515, Hungary) and radiation doses of 0, 4, 8, and 10 kGy at a rate of 1.7 kGy/hr were used. The hidden insects identified were Necrobia rufipes (Copra beetle), Derestes maculatus De Geer (Hide beetle), and a mite Lardoglyphus sp. belonging to the family Acaridae in the mite group Astigmata. An after-feeding test on shrimps by insects revealed a weight reduction by 17%, 14%, and 26% for sea, lagoon, and riverine shrimps respectively. These observations were statistically significant at p ≤ 0.05 level. After 2 months of storage there was generally a 43.0 % reduction in weight which was significantly different (p ≤ 0.05) from the initial

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PUBLIC INTEREST STATEMENT

Shrimp meat consumption is extensively accepted (globally) according to FAO in 2010 due to its enormous nutritional as well as health benefits. Shrimp is in high demand owing to its use in the preparation of several scrumptious dishes. Shrimp has helped alleviate food crises and protein malnutrition in many developing countries, providing a valuable supplement to a diverse and nutritious diets. Shrimp meat acquisition and consumption has not been widely studied. Studies investigating the preservation of these shrimps using an effective monitoring of the moisture absorbed by the shrimps stored in air-tight polypropylene packages which is anticipated to discourage the growth of microorganisms and larval infestations was carried out. Gamma irradiation which is a non-thermal means of preservation of food, with ionizing radiations was also employed to augment the preservation and shelf life extension of the shrimps in the polypropylene packaging material.
weight. Moisture sorption isotherms of dehydrated shrimps were also checked at 20, 55, 65, 75, 85, and 95% of Effective Relative Humidity (EHR) and revealed a general trend of sigmoid shape. The prescribed dose of 8–10 kGy was able to kill all insects and rendered the product insect-free in airtight dense polypropylene containers used in these investigations.

**Subjects:** Agriculture & Environmental Sciences; Agriculture and Food; Food Packaging

**Keywords:** insects; dried shrimps; Penaeus notialis; gamma irradiation; moisture isotherms; Ghana

1. **Introduction**

The term fish includes shellfish, such as molluscs, crustaceans, and echinoderms. Fish are mostly consumed as food by many species, humans included. The importance of fish to the human beings is in the supply of an essential source of protein; 113 g of shrimp a day provides the human body with 24 g of protein which represents 47.4% of the daily needs of the human protein and could be considered as a supplement for meat protein (Akonor et al., 2016).

Several techniques have been reported for their preservation including fermentation, drying, addition of chemicals, etc (Aktar et al., 2009; Akonor et al., 2016; Akuamoa et al., 2018. Many medicinal plants and spices such as leaves of *Borcia senegalensis*, *Capsium frutescens* L., *Dennettia tripetala* Baker F., *Myrcianthes fragrans* (Sw.) McVaugh, *Eugenia aromatic* O. Berg, *Monodora myristica* (Gaertn.) Dunal and *Piper guineense* Schumach. & Thonn., have also been noted as pest control agents for the preservation of shrimps. Furthermore, many insecticides such as Malathion®, Gamoxine®, and Endrine® have been reported by Khan and Khan (2001) to be used as preservatives on dried fishes for protection from infestation. Insecticides are potential sources of chemical hazards causing blurred vision, dizziness, and vomiting (Aktar et al., 2009; Kpoclou et al., 2013; Odeyemi et al., 2000; Okonkwo & Okaye, 2001).

In Ghana and some other African countries, cottage smoking is the main technique used for shrimp preservation for local markets and consumption (Akuamoa et al., 2018; Bordoloi & Muzaddadi, 2015). More than 67% of fresh shrimp produced each year is processed in the cottage industry (Degnon et al., 2013). Smoked shrimp is stored for 2.5–6 months and sold later during the shortage period, to maximize the profit (Kpoclou et al., 2013). Infestation by insects and molds are the main spoilage problems linked with the storage of smoked shrimp in the cottage industry (Kpoclou et al., 2013; Akuamoa et al., 2018). These factors subsequently affect consumer acceptability, commercial value, and income of shrimp producers and sellers.

Although natural sun drying and smoking are done at a low cost, it has limitations such as the control of the drying process and other parameters such as prevailing weather uncertainties, large drying area, insect infestation, mixing with dust, and other foreign materials (Jain & Pathare, 2007). To reduce product degradation and enhance the quality of the dried shrimps, researchers have focused on the development of various alternative drying techniques for shrimps such as superheated steam drying (Pronyk, 2007; Tang, 2002), jet-spouted bed (Devahastin et al., 2006), drying and heat pump drying (Namsangluang, 2004).

In most of Africa, the means of shrimp processing, predisposes it to insect larvae as well as adult infestation because they are often laid bare on surfaces without any well-mounted structures dedicated to the drying purpose and also storing them in infested containers. They are further sold in our open markets, where they are exposed to aero- microflora contamination without any quality control measure. Thus its production and marketing methods are not hygienically full proof, thereby resulting in high contamination by microorganisms (Varanyanond et al., 2000) and infestation by insects. Losses in a large number of dried fishes due to insects are mainly
due to infestation by earwig, hide beetles, and copra beetles during storage. The most destructive insect of dried shrimp during storage is *Necrobia rufipes* (De Geer) of the family Cleridae as reported by Bello- Olusoji et al. (2006).

The World Health Organization/IAEA Joint Committee on Food Irradiation (JECFI) in 1980, concluded that irradiation of any food commodity up to 1 Mrad (10kGy) causes no toxicological hazards, and therefore needs no further toxicological testing of such foods (Varanyanond et al., 2000). Gamma irradiation also introduces no nutritional or microbiological problems (Farkas, 2006). Irradiation treatment of foods may cause certain changes in flavor, odor, and color which could affect the product and cause problems with consumer acceptance (Egan & Wills, 1985). However, improvement of the hygienic quality of food by irradiation studied by some researchers (Akuamoah et al., 2018; Kortei et al., 2014, 2017; Odamten et al., 2018) showed that doses of 3kGy—10kGy caused a reduction of a 2–4 log cycles reduction in microbial load. Irradiation can, therefore, be an added means of extending the shelf-life of smoked shrimps in Ghana. The use of proper packaging material and storage practices of shrimp after irradiation has been studied by Varanyanond et al. (2000). They showed that microbial load decreased during storage in different packing material depended on moisture permeability, gas permeability, and gas composition inside the packaging.

Moisture sorption isotherms are an important tool when formulating food to achieve specific qualities and attributes (Bell & Labuza, 2000). There is hardly any published information on the effect of the combined influence of packaging and gamma irradiation in reducing insect load on smoked shrimp to extend the shelf life and boost its economic value. No extensive work has also been carried out on the insect infestation of shrimp in Ghana not excepting the effect of gamma irradiation on the infesting insect and evaluation of moisture content with sorption isotherms during post-irradiation storage of shrimps.

2. Materials and methods

2.1. Sample

Dehydrated-smoked shrimps were purchased from three different areas, and sources. The sources were Sea, Lagoon, and River. 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 which is main mode of packaging by the local producers, and then transported to the laboratory of the Department of Plant and Environmental Biology, University of Ghana. The shrimps were poured into dense polypropylene containers and kept at a temperature (6–8°C) appropriate for storage. These were considered the population from which the samples were collected for further analysis.

3. Gamma irradiation of shrimp samples and dosimetry method

A packaging material that is strong enough to resist puncture by the antenna of the shrimp was considered. The samples were packaged in dense polypropylene bowls that were able to satisfy this condition and following the East African Standard (EAS, CD/K/512:2010: ICS 67.120.30) for dried shrimp packaging (Plate 5, a-d). 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 kGy, 8 kGy, and 10 kGy within the range used by Varanyanond et al. (2000) and Wang et al. (2010) for drying shrimp in East Asia. The dosimeter used was the Ethanol-chlorobenzene (ECB) Dosimetry system, which comprises of the Ethanolchlorobenzene 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 made in triplicates of each source and irradiated at the same target dose. The dose rate used was 2.17 kGy/hour in the air. Entomological and physicochemical analyses were carried out before and after irradiation. Plate 5a-d illustrate the packaging material (dense polyethylene bowls) used in these investigations.
4. Insect incubation and identification
Numerous methods for detecting stored-product insects, particularly food pests, have been investigated. The technique employed in this study was the product incubation procedure. Fifty (50) grams of each sample were wrapped in a low-density black polyethylene bag (to maintain the temperature in the bag) and kept for 1 month. Samples were held in a temperature cabinet, at a temperature and humidity that would optimize insect development and growth. Insects that appeared on the sample in the polyethylene bags were poured into storage bowls in a confined area (which will ensure that insects do not escape). The bowl was then agitated to allow free mobility of insects. Insects that were in motion on the surface were trapped into a disposable petri-dish and then identified at the Entomology laboratory at the University of Ghana. Immature insects (larvae) were allowed to reach the adult stage before identification was carried out accurately. Insects in petri-dish were kept at freezing temperature for about five (5) seconds to halt mobility before pictures were taken with the Radical Stereo Zoom Microscope (Model, 8) at the Radiation Entomology and Pest Management Centre at Biotechnology and Nuclear Agriculture Research Institute (B.N.A.R.I.) at Ghana Atomic Energy Commission (G.A.E.C.).

5. Insect degradation of shrimps
Freshly dehydrated-smoked shrimps from sea, river or lagoon free from insect infestation were weighed using Electronic Balance, 69 ADAM, ACB plus-300. Ten (10) grams of each sample was weighed into six glass containers. The containers were assigned to the three different sources, each in duplicate. They were then covered with muslin netting material, bounded with a rubber band to enhance ventilation, and prevent the escape of insects and kept standing on spent oil at room temperature of 28.5°C as spelled out in the method of Bello- Olusoji et al. (2006). The samples were kept for observation for 8 weeks. At the end of the 8th week, the samples were observed for in-product infestation and re-weighed to access how much has been degraded by insects using an Electronic Mesh (Retsch, Bie and Berntsen A. S., Model VS 1000).

6. Statistics analysis
Replicates were averaged ± standard deviation and percentage losses were calculated. The data were analyzed using Microsoft excel and analysis of variance (one way ANOVA) using Statgraphics software (centurion XVI.I) to test to assess the significant difference of losses and assess whether the 2 independent variables thus radiation dose at the different levels and sources of shrimps had any effect on the variable been measured (various parameters). Differences among mean values were processed by Fisher’s Least Significant Difference (LSD) procedure. Mean difference values were reported and significance was defined at P < 0.05.

7. Results
The hidden insects resident in the dry and smoked shrimp from the different water sources fed on the shrimp and reduced the weight by 17.0 %; those feeding in the shrimp from the river decreased weight by 14.0 % while the weight of the lagoon shrimp was reduced by 26.0 % (Table 1). These observations were statistically significant at p ≤ 0.05 levels. After 2 months of storage there was generally a 43.0 % reduction in weight which was significantly different (p ≤ 0.05) from the initial weight (Table 2).

| Sources of shrimp | Initial weight before incubation (g) | Average weight after incubation (g) | Average weight loss after incubation (g) | Percentage loss | Treatment means± SD |
|------------------|------------------------------------|------------------------------------|------------------------------------------|-----------------|---------------------|
| Lagoon           | 10                                 | 8.6                                | 1.4                                      | 14              | 8.7 ± 0.004a        |
| River            | 10                                 | 7.4                                | 2.6                                      | 26              | 9.3 ± 0.004b        |
| Sea              | 10                                 | 8.3                                | 1.7                                      | 17              | 9.1 ± 0.004b        |

Means within each column with different letters are significantly different (P ≤ 0.05)
The hidden insects were *Necrobia rufipes* (Copra beetle), *Dermestes maculatus* DeGeer (Hide beetle), and a mite *Lardoglyphus* sp. belonging to the family Acaridae in the mite group Astigmata. Plates 2 and 3 (a-c) shows the external and dorsal portion of the larvae and adult of these insects.

Insect infestations of smoked shrimp during storage have increased the need for the application of appropriate packaging and preservation techniques. The hidden insects infecting the dry smoked shrimp were *Necrobia rufipes*, *Dermestes maculatus*, and a mite *Lardoglyphus* sp. (Plates 2 and 3). Those found in the riverine shrimp decreased weight by 26%; insects in the lagoon shrimp decreased weight by 14% and that of the sea by 17%. These observations were statistically significant (p ≤ 0.05). There was generally a 43.0% decrease in weight after incubation.

Table 2. Weight changes in shrimp samples kept under laboratory conditions for two months at 30°C

| Storage (months) | Initial weight before incubation (g) | Average weight after incubation (g) | Average loss after incubation (g) | Percentage Loss | Treatment (means±SD) |
|------------------|--------------------------------------|------------------------------------|----------------------------------|----------------|----------------------|
| Initial          | 10                                   | -                                  | -                                | -              | 10.0 ± 0.003b        |
| 2 months         | -                                    | 8.1                                | 1.9                              | 43             | 8.1 ± 0.003a         |

Means within each column with different letters are significantly different (P ≤ 0.05)

![Plate 1](image1.png) Plate 1: A: photograph showing dehydrated-smoked shrimp placed in dense polypropylene bowl with lid eccentrically placed on top of the bowl (x 1/5).

![Plate 2](image2.png) Plate 2: A: Dorsal view of Larva of *Necrobia rufipes* (Red-Legged Ham Beetle), B: Dorsal view of an adult *Necrobia rufipes* (Red-Legged Ham Beetle), C: The ventral view (underside) of the abdomen of an adult *Necrobia rufipes* (Red-Legged Ham Beetle)

![Plate 3](image3.png) Plate 3: A: Dorsal view: (larva of *Dermestes maculatus* DeGeer (Hide Beetle), B: Dorsal view: (Adult *Dermestes maculatus* DeGeer (Hide Beetle), C: The vertical view (Adult *Dermestes maculatus* DeGeer (Hide Beetle))
reduction in weight after 2 months of incubation (Table 2). This constitutes a huge loss in economic terms. The prescribed dose of 8–10 kGy was able to kill all insects and rendered the product insect-free in airtight dense polypropylene containers used in these investigations.

8. Moisture sorption isotherms
The moisture sorption/desorption isotherms of the shrimp from the lagoon river and sea are presented in Figures 1–3 respectively.

8.1. Shrimp from the lagoon
Moisture sorption/desorption isotherms of shrimp from lagoon followed a sigmoid curve (Figure 1). Dehydrated-smoked shrimp kept at 65, 75, 85 and 95 % ERH gained weight and equilibrated with its surrounding after 6–8 days, whereas those kept at 20 and 55 % ERH lost an insignificant amount of moisture and also equilibrated after 6–8 days of incubation. Samples incubated at 95 % became moldy after 8 days and continued rising in weight. The moisture sorption curves were characteristically sigmoid (Figure 1).

8.2. Shrimp from the river
The moisture sorption/desorption isotherms of shrimp from the river followed the same sigmoid curve trend as those from the lagoon. There was a gain in weight at ERH's 55, 65, 75, 85, and 95 %.

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**Figure 1.** Moisture sorption isotherm of dehydrated shrimp from lagoon source at 30°C for 20 days.

**Figure 2.** Moisture sorption isotherm of shrimp from riverine source at 30°C for 20 days.
At 95 %, the moisture continued rising. The equilibration period at 55–85 % was 6–8 days. There was rather a marginal loss in moisture content at 20 % ERH. Shrimp became moldy after 10 days at 95 % ERH (Figure 2).

### 8.3. Shrimp from the sea

The moisture sorption isotherms again followed a sigmoid curve in smoked shrimp harvested from the sea (Figure 3). There was an increase in weight at ERH's 85 and 95 %. Nonetheless, desorption occurred in samples held at 75, 65, 55, and 20 % ERH. Equilibration in samples held at ERH's 85, 75, 65, 55, and 20 % occurred after 4–6 days of incubation, and thereafter weight remained the same (Figure 3). At 95 % ERH, the moisture content continued rising.

It was noticeable that in all instances of sorption and desorption, the weight gained/lost was rather marginal (≤ 0.07–2.0 %).

### 9. Discussion

The moisture sorption and desorption isotherms, which tells the relationship between water activity and equilibrium moisture content of the shrimp at a constant (Ahmed et al., 2005) temperature were assessed. This was to help us identify the critical moisture content of the shrimp which will support the growth of spoilage micro-organisms. Water activity determines the shelf-life of food products and most bacteria do not grow at water activities below 0.91, including pathogenic bacteria such as *Clostridium botulinum*. Below 0.75, most molds cannot grow and below 0.60aw no microbiological growth possible. However, between the ranges of 0.8–0.6, some food spoilage microbes can grow. Kpoclou et al. (2017) and Akuamoah et al (2018) indicated that storage fungi on shrimps (species of *Aspergillus and Penicillium*) are usually encountered when shrimp is stored after harvest at moisture levels of 13–20% or in equilibrium with RH between 70–90%. An increase in aw results in an increase in the water content, but in a nonlinear trend. The knowledge base of moisture adsorption and desorption behaviors are useful for production design such as drying process, selecting appropriate equipment and packaging material, and predicting in shelf-life stability during storage and transportation (Chowdhury et al., 2005; Kaymak- Ertekin & Gedik, 2004; Tunc & Duman, 2007).

According to Rohvein et al. (2004), moisture sorption isotherms are sigmoidal in shape for most foods. At high relative humidities, there is an increase in water activity of a product which avoids water for microbial growth and spoilage (Isengard, 2001). Ekechukwu and Norton (1999) reiterated that the combined effect of warm temperatures and high moisture content results in accelerated food product deterioration and promotes the growth of insects and fungi. To maintain
good quality shrimps during storage, shrimps must be protected from changes in moisture content and growth of insects and microorganisms such as fungi.

Gamma irradiation was conjectured to have caused some deleterious effects on the larvae of insects hidden in the crevices of the shrimp. Functional changes observed in irradiated shrimps could due to the adsorption of energy released during gamma radiation (Farkas, 1998). Several hypotheses attempted to explain the mechanism of gamma rays-induced cell injury (Al-Zahrani & Al-Sewaidan, 2017; Kuefner et al., 2015; Sage & Shikazono, 2017): increased permeability of the cellular membrane, dysfunction of enzymes and generation of radiotoxins (Al-Zahrani & Al-Sewaidan, 2017; Ibragimova et al., 2008; Rendic & Guengerich, 2012). Notwithstanding, these hypotheses are well documented and now widely accepted, based on the significant number of experimental pieces of evidence, that damage of deoxyribonucleic acid (DNA) is mainly responsible for the detrimental effects of gamma radiation. Gamma rays either deconstruct DNA helix directly, or generate free radicals that disrupt chemical bonds within DNA (Kuefner et al., 2015; Sage & Shikazono, 2017).

Results obtained in this work agreed with published findings of Ajani et al. (2006) and Bello-Olusoji et al. (2006) as they isolated adult and larval forms of Demestes maculatus, Lardoglyphus sp. and Necrobia rufipes in some shrimp species in Nigeria. Odeyemi et al. (2000) also reported Demestes maculatus and Necrobia rufipes as insect pests of dried fish.

Khan and Khan (2001) recorded similarly, these insects species and further assessed damage done by infestation on non treated samples (25.4%) while a lower proportion was recorded for treated products. Likhoy et al. (2018) in a related study, reported a range of 7–1273 adults/kg grains caused by Sitophilus zeamais and Protephanus truncates populations of insects.

10. Conclusion

Findings from this study indicate that the prescribed dose of 8–10 kGy was able to kill all insects and rendered the product insect-free in airtight dense polypropylene containers used in these investigations. There are no organized structures for the sale of the shrimp after smoking. The packaging materials (light polyethylene, brown paper) used by the traders were not strong enough to resist piercing by the antenna of the shrimp. For this reason, holes created on these packaging materials by shrimp antenna serve as avenues for cross infestation by insects and other organisms onto uninsected ones. Insects infesting the local shrimp are Necrobia rufipes, Demestes maculatus DeGeer, and mites (Lardoglyphus sp.). Though spoilage or contamination of shrimp is likely to occur at any time from harvesting to storage, microbiological contamination by fungi and bacteria can be accentuated by insects’ metabolic activities and other environmental factors. The act of storing different fishes and shrimp together by traders should be discouraged in the marketing system.

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Competing Interests
The authors declares no competing interests.

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Author statement
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Authors’ contributions
The principal author (Felicia Akumoa) 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 Odamten) 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.

Cover Image
Caption: A photograph showing dehydrated-smoked shrimp placed in dense polypropylene bowl with lid eccentrically placed on top of the bowl (x 1/5).
A: Dorsal view: (larva of Derrnests maculatus DeGeer (Hide Beetle). B: Dorsal view: (Adult Deremest maculatus DeGeer (Hide Beetle)). C: The vertical view (Adult Derrmest maculatus DeGeer (Hide Beetle)).

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