Review Article

A Review on the Physicochemical Properties of γ-irradiated Copra (*Dried Cocos nucifera* L.)

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Abstract
Copra or dried coconut kernel is a primary product of coconut and is known to be a source of coconut oil. It is found to be highly susceptible to *Aspergillus flavus* that can cause aflatoxin contamination during pre- and post-harvesting processes. Therefore, researchers have been looking for a method to reduce aflatoxins in copra to a safe level while positively affecting its properties. The γ-irradiation is found to induce growth inhibition of *A. flavus* in copra at low irradiation doses (0 to 3 kGy) using a semi-commercial irradiator. This result is supported by other food samples having a high reduction of aflatoxins. Currently, no studies examined the influence of γ-irradiation on the physicochemical properties of copra. Hence, this study used the properties of different γ-irradiated commodities that are similar to copra to justify the need of investigating properties in irradiated copra. Gamma irradiation has the potential to increase the fat and ash content, decrease protein and crude fiber content at higher absorbed doses, and expected no changes in moisture content of the irradiated copra. In addition to this, the effect of the irradiation on carbohydrate content, phytochemical profile, and water activity may vary in significant findings until further investigations have been made on irradiated copra. However, the researchers recommended that the microbial activity of *A. flavus* and characterization of the physicochemical properties of irradiated copra were necessary for future experimentations.

Keywords: Aflatoxin, Copra, Degradation, Fungal contamination, Irradiation, Physicochemical properties

1 Introduction

Coconut (*Cocos nucifera*) is a well-known perennial and essential crop used for food, drink, clothing, and shelter [1]. Coconut meat or kernels are used to make products such as cake, cream, oil, milk, and copra. Due to the high demand for coconut-based products for food and beverage applications, the market size was estimated at $11.5 billion in 2018 and expected to attain $31.1 billion in 2026 [2]. Its cultivation has played a significant part in developing the Philippines' economy in the last few generations with around 80% of the products consumed locally, while the remaining 20% are distributed worldwide [3], [4]. Until now, the Philippines were regarded as the world's second-largest producer of coconut, after Indonesia [5]. One of its valuable parts, copra has a composition of 6% moisture, 60–65% oil, 27% carbohydrates, 20% proteins, fiber, and ash [1], [6].

Since the coconut products are classified as perishable goods with very high moisture content from 40 to 50%, postharvest losses are expected during storage periods, which puts pressure on its profitability and raises serious concerns on global demands [7]. For consumer safety, regular inspections, and surveillances for possible contamination have been undertaken by the Bureau of Food and Drugs (BFAD) in compliance with the toxin limitation levels of coconut products implemented by the USFDA and the European Union. Several studies indicate that the contamination of food commodities is linked to the mycotoxins produced by highly toxigenic fungi [8]. Characterized by their low molecular weight and very high thermal stability, they are found to be difficult to remove by conventional thermal technologies [9].

Aspergillus flavus is a well-known species of molds and is classified as an opportunistic pathogen since it has many susceptible hosts, especially coconuts [10]. Environmental conditions that would favor the fungal growth in coconut kernels are the following: 1) humidity levels ranging from 80–90% and 50–70% in the wet and dry seasons, respectively; 2) low temperatures from 10 to 12 °C; and 3) and high temperatures from 50 to 55 °C. However, the optimal temperature is relatively close to 33 °C [11]. As xerophilic microbes, they can thrive in conditions with low water availability. Quantitatively, the water activity for the growth of this fungal strain can reach the minimum value of 0.78 and obtain the optimum of 0.99 [11].

As recognized by the IARC, aflatoxins (AF) belong to group 1 carcinogens, and the contamination can cause various health effects on humans and animals [12], [13]. The United States and other countries in Latin America and Africa frequently used the maximum limit of 20 µg kg^{-1}. However, European countries currently follow the maximum concentration limit of aflatoxins at 4 µg kg^{-1} for other commodities [14]. Because of this, food irradiation is the preferred treatment for copra, as it gives promising results in sterilization and decontamination of food products. Moreover, it is reported that the aflatoxin levels can be reduced by the free radicals' ability to attack the toxins' furan rings [15].

There are numerous advantages to using irradiation such as improving shelf life and eradicating the presence of microbial contaminants in food commodities without rendering residual effects on the food quality [16]. With the lack of research on the sterilization of copra using food irradiation, this study will contribute to future experimentations and provide sufficient knowledge to the public by focusing on the impact of gamma irradiation on the physicochemical properties of the food material.

2 Microbiological Analysis

2.1 *Aspergillus flavus in copra*

In Figure 1, Asis *et al.* examined the microbial activity of γ-irradiated copra [17]. The molds and yeast count (MYC) of the irradiated copra decreased with increasing absorbed dose but the concentration is slightly higher than the FDA limit represented by broken lines. This indicated that there was a positive relationship between

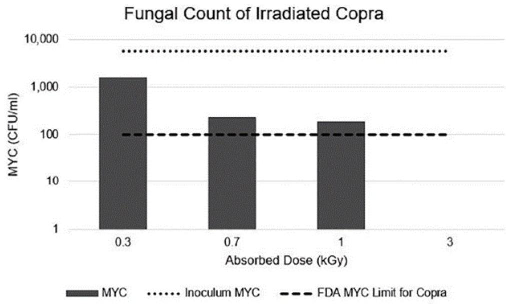

Figure 1: Molds and yeast count in copra at different absorbed doses [17].

the absorbed dose and the degradation of fungal spores. Moreover, they pointed out that the cellular wall of the mold facilitates the attenuation of the low-dose radiation (LDR) as mentioned by Aquino *et al.* [18]. However, the radiation sensitivity of the mold was not emphasized in the study and more research was needed on physicochemical properties of the irradiated copra samples and the possible breakdown products from irradiation.

Makari *et al.* reported that the gamma irradiation has reduced the viable spore count of the strain on pistachio nut at absorbed doses of 4 and 6 kGy with an overall percent reduction of 73.26% and 83.36%, respectively [19]. In Table 1, Markov *et al.* observed the impact of the treatment on the microbial activity of the *A. flavus* in maize samples with irradiation doses between 1–5 kGy [20].

Table 1: Microbial activity of Aspergillus strains at different absorbed doses [20]

Fungi	Activity	Absorbed Dose (kGy)				
		0	1	2	3	5
A. flavus 305	G	+	+	–	–	–
	S	+	+	+	+	–

*Legend: G – germination; S - sporulation

No germination of spores was spotted starting from 2 kGy while the sporulation only rendered negative at 5 kGy after an incubation period of 7 days. The post-irradiation effect further facilitated the colony growth inhibition by 90%. Therefore, the treatment is effective in inhibiting fungal activity in irradiated maize samples. On the other hand, Calado *et al.* [21] described the mechanism of the inactivation of the pathogenic microorganism during irradiation. The free radicals generated are responsible for the prevention of cell proliferation due to the indirect damage to the DNA, which can induce radiolysis [21].

This area must be investigated further to determine the effect of gamma irradiation on microbiological activity and radiosensitivity of the *A. flavus* strain in a certain incubation period and post-irradiation period. Automated cell counting may be considered for accurate analysis of fungal germination and sporulation in a certain size range [22].

2.2 *Aflatoxin concentration*

Currently, there is no previous study reported on the inactivation of aflatoxins contaminated in irradiated copra. This allowed the researchers to review other studies that have reported their findings on the effectiveness of the treatment on inactivating aflatoxins brought by *A. flavus*, in which the mostly detected type is aflatoxin B1 (AFB1).

In Figure 2, Sera *et al.* utilized the Fisher's Least Significant Difference method ($\alpha = 0.05$) to determine the percentage reduction of AFB1 in irradiated corn at different absorbed doses (0–10 kGy) [23]. On the other hand, the determination of the aflatoxin concentration in the food samples was conducted by using the Veratox® Aflatoxin Kit for mycotoxin testing. From the results, there is no significant difference observed between 6 and 10 kGy and the recorded percentages in the reduction of AFB1 are 89.59% and 95.47%, respectively. Similar findings were observed by Ghanem and Shamma in their study on irradiated food and feed crop including barley, bran, and corn with percentage reductions of 89.86, 86, and 84.23%, respectively with an absorbed dose of 10 kGy [24]. The high reduction of AFB1 indicated that the irradiation facilitates the production of hydrogen ($H\cdot$) and superoxide ($O_2\cdot^-$) radicals, and hydroxide ion (OH^-), responsible for mycotoxin degradation [25]. Free radical addition targets the terminal furan (lactone) ring of the AFB1, yielding breakdown (radiolytic) products with low biological activity and cytotoxicity [26]. Moreover, Domijan *et al.* described that free radicals attack the double-bonded carbon (C8 = C9) of the furan ring by addition reaction after gamma irradiation, which transforms into radiolytic products, such as aldehydes and ketones upon testing by using methanol-water solution [27]. This area must be

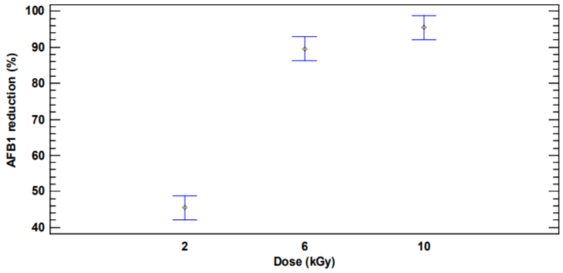

Figure 2: Degradation efficiency of aflatoxins in irradiated peanut samples [23].

investigated in γ-irradiated copra to determine if the involved modification has an impact on the concentration of aflatoxin B1 contained in the sample. Furthermore, the measurement chart of the degradation efficiency of AFB1 should be provided as well as the toxicity analysis of the samples after gamma irradiation.

3 Physicochemical Properties

3.1 *Fat and protein content*

Previous studies on peanut (*Arachis hypogaea*) and copra conducted by Liu *et al.* and Ghosh *et al.* found that the characterization of the fat content can be done by conducting solvent extraction [28], [29]. For copra, the crude fat was investigated by employing the Soxhlet extraction wherein the solvent used was petroleum ether. The extraction method was suitable for extracting oil from the solid material – the dried coconut kernel and the solvent was not sensitive to the presence of moisture in the material [30]. On the other hand, the Kjeldahl method was used to estimate the crude protein content of the irradiated peanut samples based on the total nitrogen content.

In Figure 3, Liu *et al.* studied the influence of the treatment on the fat and protein contents of the exposed peanut samples with absorbed doses from 1 to 10 kGy at room temperature and then stored at –20 °C before monitoring [28]. From the results, there were no significant differences observed in the first four absorbed doses. However, there was a gradual decrease detected in the fat content at 10 kGy. Meanwhile, the amount of protein did not differ significantly at low irradiation doses but the decrease in amount was observed at a higher dose.

Similar findings were reported by Khan *et al.*,

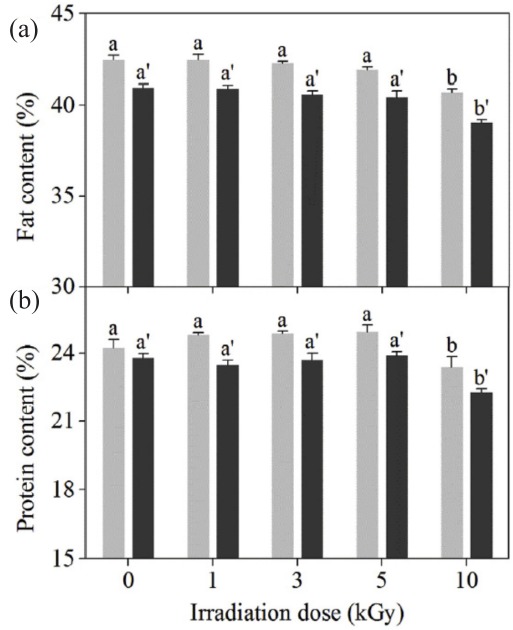

Figure 3: Fat and protein contents of irradiated peanut samples at different irradiation doses [28].

Anwar *et al.*, and Bamidele and Akanbi that the fat and protein contents decreased significantly from 0–30 kGy [31]–[33]. Contrary to the reported negative correlation that a higher irradiation dose decreases the fat and protein content of the food sample, Chumwaengwapee *et al.* studied the influence of gamma irradiation on crude fat and protein of fish coconut meal expressed on a dry matter basis [34]. It is observed that the fat and protein contents increased when the raw coconut meal samples are subjected to treatment using an absorbed dose of 30 kGy in a JS-9000 IR-155 γ-irradiator, while the other treatments yielded less amount of the involved constituents.

In Table 2, the slight increase of the total lipid content of the sample indicated that the unsaturated fats present in the sample are converted into saturated fats during γ-irradiation, which result in the occurrence of rancidity as described by Chen *et al.* and Fan *et al.* [35], [36]. On the other hand, there were no significant differences observed in the protein content between the non-irradiated and irradiated coconut meal samples. Future studies should report on the characterization to confirm if increasing of the irradiation dose may induce lipid oxidation, responsible for the deterioration of fat and protein contents in the food material.

Table 2: Chemical composition of irradiated coconut meal samples (in percentages) [34]

Parameter	Control	Treatment		
		Microwave	Gamma	Electron
Protein	4.63 ± 0.05	4.70 ± 0.05	4.68 ± 0.05	4.46 ± 0.04
Crude lipid	31.00 ± 0.01	30.08 ± 0.05	32.14 ± 0.25	31.44 ± 0.22
Ash	1.03 ± 0.00	1.09 ± 0.04	1.17 ± 0.01	1.17 ± 0.02
Crude fiber	36.89 ± 0.05	28.74 ± 0.0	24.38 ± 0.61	25.49 ± 0.61
Nitrogen free extract	26.45 ± 0.07	35.39 ± 0.12	37.63 ± 0.66	37.44 ± 0.41

3.2 *Crude fiber and ash content*

In Table 2, Chumwaengwapee *et al.* observed that the crude fiber of the coconut meal samples decreased in all treatments and the lowest amount of fiber is reported from the gamma-irradiated sample [34]. The degradation involves the cleavage of glycosidic bonds in which the free radicals weaken the van der Waals forces, resulting in the breakdown of the cell wall components [37], [38]. Additionally, the formation of carbonyl groups in the components with the presence of oxygen also contributes to lignocellulosic degradation. Another study conducted by Orozco *et al.* stated that the lignocellulosic components were cellulose, hemicellulose, and lignin [37]. In Figure 4, they found out that the first two constituents were partially degraded by the irradiation at a higher irradiation dose, while lignin was found to be resistant to the treatment due to its ability to absorb and scatter gamma rays. On the other hand, the ash content increased in all treatments with the highest amount reported from using gamma irradiation. The trend implied that more mineral content is present in an irradiated sample than in a non-irradiated sample. These minerals are high in sodium, magnesium, phosphorus, iron, and zinc [39]. Another related study by Akuamoa *et al.* on irradiated shrimps (Penaeus notialis) suggested that the increase in ash content may be related to the loss of moisture content after gamma irradiation [40]. Similar findings by Nour *et al.* and Bamidele and Akanbi reported that there are significant differences observed in crude fiber and ash content between the original groundnut sample and the irradiated groundnut [32], [41]. This area must be investigated in γ-irradiated copra to determine if the involved modification has an impact on the crude

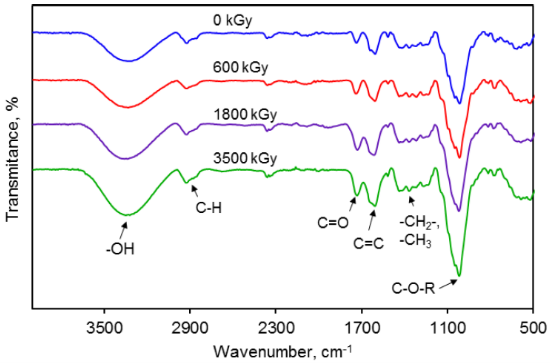

Figure 4: FTIR analysis of irradiated orange peel at high absorbed doses [37].

fiber and ash content of the sample. Furthermore, characterization of the functional groups of the irradiated food allows for further investigation of the irradiation effect on the lignocellulosic components.

3.3 *Carbohydrate content*

Ghosh *et al.* reported that the copra contained 6.90% carbohydrates [29]. The carbohydrate content in coconut meal samples after irradiation increased significantly at a high dose (30 kGy) [34]. The result indicates that the physical barrier of coconut meals was destroyed during irradiation. Also, irradiated coconut meals have higher carbohydrates than unirradiated coconut meals. The previous researchers correlated the increase in carbohydrates with the decrease in crude fiber. The mechanism behind the trend is the breakdown of cell wall constituents by glycosidic bond cleavage, providing more available carbohydrates [34]. Costa *et al.* reported similar results using CEASA peanut samples, demonstrating a significant increase in carbohydrate content at 12 kGy irradiation doses, but no difference at 6 and 15 kGy (Figure 5) [42]. In addition, Petrolândi peanut samples significantly decrease at all irradiated doses. Additionally, Nguyen *et al.* observed that the carbohydrate content of peanut samples increases between 0 and 10 kGy [43]. This is due to polysaccharides being disrupted by gamma irradiation, leading to the breakage of glycosidic bonds. This phenomenon should be investigated further if this can be applied to coconut fiber cell walls. Polysaccharide structures must be broken down to increase the amount of carbohydrate content.

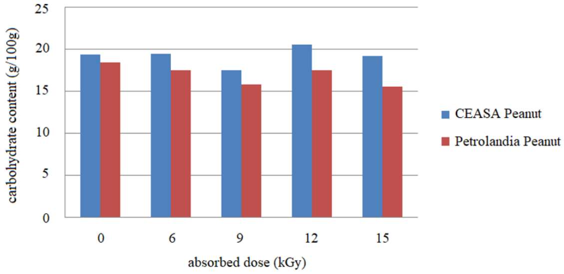

Figure 5: Carbohydrate content of peanut samples from CEASA and Petrolândia [42].

However, the polysaccharide degradation is not linearly proportional to irradiation doses. The degree of degradation of polysaccharides was found to be higher at low doses of irradiation than at high doses. Further studies should be considered to determine the carbohydrate content from low to high doses of gamma irradiation. Hence, additional research is needed to determine the influence of γ-irradiation on the amounts of carbohydrates in irradiated copra.

3.4 *Phytochemical profile*

Ghosh *et al.* carried out the characterization of the bioactive profile based on the revised screening technique used by Odenigbo and Otisi, wherein the copra samples are subjected to both polar and nonpolar extraction [29], [44]. On the other hand, several related studies described the impact of γ-irradiation on the phytochemical contents of food materials.

Ghosh *et al.* found that the antioxidant activities for the copra aqueous and n-hexane extracts are 1.96 mg/mL and 49.98 mg/mL, respectively [29]. Gamma irradiated samples of copra may result in a significant increase of antioxidant activity at doses up to 6 kGy using the ferric reducing antioxidant power (FRAP) method, whereas the DPPH method at 6 kGy significantly decreased the activity [45]. The mechanism behind the increase in the antioxidant activity is the scavenging ability of radicals, wherein it can minimize the impact of free radicals that causes nutrient oxidation on the food material. Moosavi *et al.* discovered the same result using the DPPH method that 2 kGy slightly increased almond hull's antioxidant activity and 10 kGy yielded the lowest values (highest IC50 value) [46] (Table 3). If a crop is exposed to radiation, its antioxidant content will either increase or decrease, and this will depend on the exposure period, material, and assimilated dose [47]. As for FRAP values of almond hull extracts, Moosavi *et al.* reported a significant decrease at 2 kGy, whereas the extracts remained unchanged at 6 and 10 kGy [46]. This demonstrates that there was no reduction in the antioxidant activity, even after irradiation to higher doses. Moreover, the antioxidant activity of irradiated samples may vary at different irradiation doses, as suggested by Khattak *et al.*, possibly because of varying extraction solvents [48].

Table 3: Antioxidant activity of irradiated samples using FRAP (mg $FeSO_4$) and DPPH methods (IC_{50} values, mg/mL) [46]

	Irradiation Dose (kGy)			
	0	2	6	10
DPPH	74.8	72.4	77.5	113.3
FRAP	16.3 ± 0.25	14.9 ± 0.25	16.6 ± 0.08	16.3 ± 0.02

Based on the study by Ghosh *et al.* using copra extract, the phenolic content obtained for aqueous extract was 0.08 mg/g, whereas none was detected in the n-hexane extract [29]. The value of phenolic content obtained in copra can be assumed to be negligible. These findings are similar to the Nigerian coconut extracts that contained alkaloids, glycosides, saponins, and resins [44]. However, there were no tannins or terpenoids in the extracts, which is contrary to the same report. Moreover, according to previous studies, there were no acids and flavonoids in either extract [44], [49]. As a result, further research should be done regarding the phenolic compounds available in copra extracts since there is a possibility of tannins being observed. The presence of tannins can affect the phenolic content during irradiation. Researchers have found that when tannin levels are reduced through exposure to ionizing irradiation, phenolic content increases [50], [51]. However, other studies found an increase in tannin content when phenolic is reduced through irradiation [50], [51]. Gamma irradiation may significantly decrease the phenolic content of copra at doses 0–10 kGy. Behgar *et al.* obtained the same result using pistachio hull [52]. This study found that absorption of 10 kGy reduced total phenolics, doses greater than 10 kGy (20–60 kGy) led to an increase in total phenolics compared to controls (Table 4). On the other hand, a study found that irradiated soybean grains at the dose of 8 kGy contained more phenolics than control samples [53].

The effect of gamma irradiation on phenolic content might vary due to irradiated samples and are more likely to have phenolic compounds that can be extracted because of changes in cell compounds and the release of bound or insoluble phenolics at high irradiation dose [52].

Table 4: Phenolic content of irradiated pistachio samples [52]

Irradiation Dose (kGy)	Total Phenolics (mg/mL)
0	7.86 ± 0.38
10	6.49 ± 0.77
20	8.10 ± 0.58
30	8.13 ± 1.03
60	8.45 ± 0.59

The reducing power of copra aqueous and n-hexane extracts were found to be 4.05 mg/g and 1.51 mg/g, respectively [29]. Kavintha *et al.* found that the reducing power of ber fruits after irradiation at doses less than 1 kGy significantly declined (Table 5) [54]. The same result was found in black pepper when using higher irradiation doses at 5 and 30 kGy [55]. However, irradiated zinger and clove at the same doses resulted in unchanged reducing power [56]. It shows that irradiation maintains or reduces the activity of reducing power. A decrease in reduction could significantly decrease in reducing power activity [54]. The antioxidant activity, phenolic content, and reducing power reported by previous studies may vary at different irradiation doses.

Table 5: Reducing power (in terms of absorbance units) of irradiated ber fruit samples [54]

Irradiation Dose (kGy)	Reducing Power (AU)
0	3.51 ± 0.05
0.25	1.82 ± 0.07
0.50	1.68 ± 0.01
1.0	1.20 ± 0.06

3.5 *Fatty acid profile*

The characterization of fatty acids in copra is necessary to determine the quality attributes of the fat contained in coconut kernel and its products. From a recent study conducted by Adoyo *et al.*, the fatty acids present in coconut varieties were caproic acid, caprylic acid, lauric acid, myristic acid, palmitic acid, stearic acid, oleic acid, linoleic acid, and arachidic acid [39]. Moreover, coconut has the highest amount of lauric acid, which constitutes 50% of the fats [57]. Usually, gas chromatography (GC) is the preferred method for the characterization of the fatty acid profile after conversion into fatty acid methyl esters (FAMEs) due to its high accuracy and replicability as mentioned by Browning *et al.* and Cao *et al.* [58], [59].

In Figure 6, Ghosh *et al.* presented their generated GC of the fatty acid profile of copra. Based on the results, it can be observed that lauric acid has the highest peak among the fatty acids detected in the chromatogram. For the characterization of the graph, the peaks represent the following: 1) caproic acid; 2) caprylic acid; 3) capric acid; 4) lauric acid; 5) myristic acid; 6) palmitic acid; 7) linoleic acid; 8) oleic acid, and 9) stearic acid. Based on the results, it can be observed that lauric acid has the highest peak among the fatty acids detected in the chromatogram. Lauric acid with over 45–50% has the highest amount among the fatty acids in selected coconut kernel varieties, while the component with the least amount was arachidic acid with over 0.17–0.19%. These findings coincided with the study conducted by Boateng *et al.* [29], [57]. Since there were significant changes observed in the fat content of most food commodities after subjecting to physical modification, the researchers also discussed about the influence of gamma irradiation on the fatty acids, which are also found in coconuts for justification.

In Table 6, Murata *et al.* reported that there are no observable changes in the fatty acid compositions between non-irradiated and irradiated samples with absorbed doses of 10, 40, and 80 kGy [60]. It can be noticed that the saturated fatty acids present in soybeans (*Glycine max* L.) are palmitic acid and stearic acid. While the unsaturated fatty acids observed were oleic acid and linoleic acid. As described by Idowu *et al.*, no detection of changes in fatty acids indicated that the food material consisted of very high antioxidant content attributed to resistance to irradiation due to its scavenging ability of radicals [61]. Contrary to the reports of no changes in fatty acids, there are studies reported by Mexis *et al.*, Gecgel *et al.*, and Anwar *et al.* that found observable changes in the fatty acid composition of several groundnuts. For cashew nuts (Anacardium occidentale), myristic acid does not differ

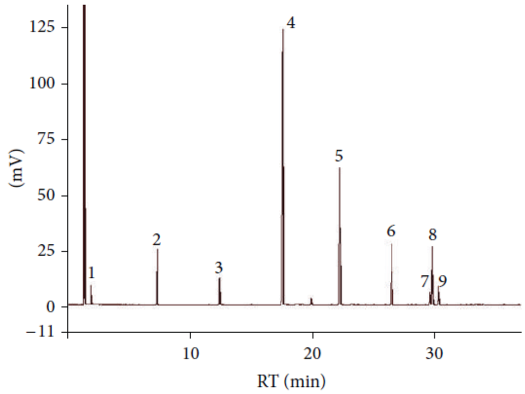

Figure 6: Gas chromatography of FAME of extracted oil from copra [29].

significantly but the other saturated fatsincreased, such as palmitic acid and stearic acid, while there is a decrease detected in oleic acid and linoleic acid after gamma irradiation with irradiation doses between 0–7 kGy [62]. This is also supported by similar findings from several food samples, including hazelnut, walnut, almond, and pistachio [63]. The reported changes in the fatty acid content after irradiation indicated that the unsaturated fatty acids are converted into saturated ones attributed to the interactions of free radicals. As described by Sinanoglou *et al.*, the high levels of unsaturated fat in food samples are more susceptible to lipid oxidation after irradiation resulting in the formation of off-flavor products, such as aldehydes and ketones [64]. This area must be investigated in γ-irradiated copra to determine if the involved modification has an impact on the fatty acid composition and shelf-life of the coconut oil.

Table 6: Fatty acid profile of soybean samples [60]

FAME	Irradiation Dose (kGy)			
	0	10	40	80
C16:0	10.1 ± 0.2	10.4 ± 0.1	10.7 ± 0.6	10.0 ± 0.2
C18:0	1.2 ± 0.6	1.0 ± 1.6	1.3 ± 0.5	1.6 ± 0.1
C18:1	44.8 ± 0.5	44.3 ± 1.4	40.4 ± 3.1	43.5 ± 0.3
C18:2	38.4 ± 0.3	38.8 ± 0.9	41.4 ± 2.9	38.9 ± 0.3

3.6 *Moisture and water activity*

Moisture determines the amount of water available in the commodities, whereas water activity measures unbound water [65]. Ghosh *et al.* reported that copra

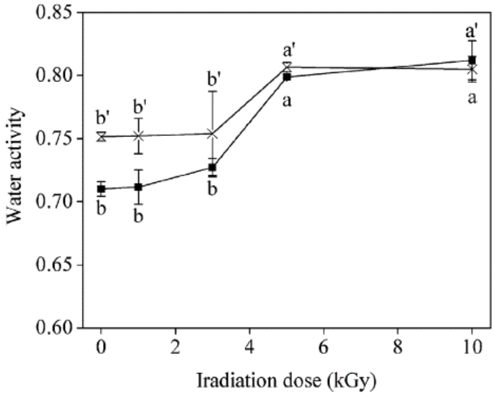

Figure 7: Water activity of irradiated peanut samples at different absorbed doses [28].

contained 3.94% moisture [29]. Gamma irradiation of copra at doses 0–10 kGy may result in unchanged moisture content. Based on the study of Liu *et al.*, irradiated two peanut cultivars had moisture contents of 3.65% and 4.05% [28]. Doses of 0–10 kGy have no discernible impact on peanut moisture content in either of the two cultivars tested. Other than peanuts, other commodities, such as irradiated hazelnut and walnut, had the same findings [66], [67]. In addition, a similar finding by Al-Bachir was reported that low moisture content stimulates the action of free radicals [68]. This clearly shows that low moisture content indicates a higher percentage of oil content, better quality, and longer shelf life of copra [69].

After irradiation with absorbed doses from 5 to 10 kGy, the water activity of both peanut cultivars significantly increased, as depicted in Figure 7 [28]. However, a study on irradiated in-shell peanuts shows that the water activity was lower at 10 kGy [70]. The water activity in commodities can be kept relatively balanced if the right conditions are present. The physical structure of a material can be altered by irradiation in which moisture of commodities can be increased and the water activity changes [28]. However, maize that was irradiated up to 2 kGy reported maintaining its water activity [71]. A similar finding was reported when hazelnut at an irradiation dose up to 1.5 kGy [66]. An increase in aflatoxin production is due to the high moisture and high-water activity. Based on the studies presented, the low moisture content reduces the risk of fungal growth, such as *A. flavus* that produces aflatoxins. On the other hand, the water activity from different reports were contradicting each other's results. Hence, the effect of radiation on moisture and water activity in copra should be further studied.

4 Conclusions

Evaluation of the physicochemical properties of irradiated copra is necessary to increase the volume of production of coconuts without worrying about the contamination of aflatoxin produced by the invading fungi during postharvest operations. However, some studies discussed only the influence of γ-irradiation on aflatoxin decontamination in copra. Moreover, the researchers noted that these are the following parameters to be monitored in microbial activity: fungal germination, sporulation, and fungal growth at different incubation periods to determine if growth inhibition is achieved in irradiated copra. On the other hand, the researchers included a brief discussion on the influence of the γ-irradiation physicochemical profile of copra. This study found that irradiation has the potential to increase the fat and ash content, decrease protein and crude fiber content at higher absorbed doses, and expected no changes in moisture content. While, the effect of the irradiation on carbohydrate content, phytochemical profile, and water activity may vary in significant findings. This conclusion is based on the results from different commodities that compared the irradiated to non-irradiated samples at different doses. Thus, more research is needed in the characterization of the irradiated copra for future experimentations that can benefit the coconut industries to prioritize more on food safety and food quality improvements. Also, the researchers recommended the influence of gamma irradiation on copra in terms of sensory properties and appearance in future experimentations.

Authors Contribution

M. J. L. D.: conceptualization of research topic, data collection and analysis, reviewing and editing, writing and revising contents; F. C. D. V.: journal article advising, reviewing and editing.

Conflicts of Interest

The authors declared no conflict of interest.

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