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Combined Gamma Irradiation and Hydrothermal Treatments did not adversely affect the Nutritional Characteristics of African Bush Mango (*Irvingia gabonensis*) Seeds and the Oil Quality

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Abstract

The need to preserve the nutrients in a food sample while ensuring microbiological safety has led to researches on different hurdle techniques. To this end, this study aimed at evaluating the effect of gamma irradiation and hydrothermal treatment in a hurdle arrangement on the physicochemical and functional properties of bush mango (*Irvingia gabonensis*) seed, as well as investigation of its impact on quality attributes of the oil. The *Irvingia gabonensis* samples were divided into raw, cooked, cooked and irradiated at 10 kGy, and irradiated at 5 kGy and 10 kGy, respectively. Proximate composition, minerals, antinutritive factors, oil quality and amino acid profile were determined in the differently treated samples. It was observed that increase in gamma irradiation dose, as well as the hurdle treatment, reduced the protein content of the samples. Tannins, iodine value and free fatty acid were all reduced with increased irradiation dose and additional hydrothermal treatment. On the other hand, no significant difference was observed in water and oil absorption capacities and foaming stability of the seed samples. The amino acid profile indicated various increases in isoleucine, valine, threonine, glutamic acid, alanine, and tyrosine as irradiation dose increased, while lysine, glycine, leucine, phenylalanine and methionine showed decreases. It could be deduced from the findings that, apart from increased saturation of the seed oil, the hurdle arrangement of gamma irradiation and cooking did not adversely affect the nutritional status of the bush mango seed.

Keywords: *Gamma irradiation; hydrothermal treatment; African mango seeds; chemico-functional properties; oil quality*

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1. Introduction

Rural dwellers in developing countries like Nigeria hardly afford animal products which are rich sources of protein, because they are either too expensive or simply unavailable. This has led to various research efforts being directed towards utilization of unconventional plant protein sources either through product development applications for production of value-added food products (Enujiugha, 2000; Olagunju *et al*., 2018a), or through process modifications and enrichment formulations for healthier and more productive human populations (Enujiugha *et al*., 2008; Oyedokun *et al*., 2016; 2020). The current reality is that majority of staple diets in developing countries consist mainly of cereal grains or monotonous starchy roots and tuber crops thus leading to various health problems associated with protein and vitamin/mineral deficiencies (Enujiugha, 2005; 2020). In the

search for plant protein and vitamin-enriched substitutes, underutilized oilseeds, nuts and legumes, which are largely obtained in the wild and mostly uncultivated, have received considerable research attention (Talabi *et al.*, 2023; Enujiugha *et al*., 2023a; Olagunju *et al.*, 2018b) culminating in increased awareness of their rich nutrient potentials and bioactive properties. Among the various oilseeds that are attracting research attention, the African mango (*Irvingia gabonensis*) seeds have found very popular use especially in their application as soup base and thickener, when mashed. This sticky, sour, cheesy solid is rich in protein, vitamins, and food energy, and even in the tropical heat it keeps well without refrigeration. It is also known to be rich in basic macro- and micro-nutrients (Sanusi *et al*., 2017; Stadlmayr *et al.*, 2010).

Food irradiation is the process of exposing food to a controlled source of ionizing radiation for the purposes of reduction of microbial load, destruction of pathogens, extension of product shelf life, and/or disinfestation of produce (Enujiugha *et al*., 2012). The irradiation process involves exposing the food, either prepackaged or in bulk, to a predetermined level of ionization radiation. Ionization radiation interacts with an irradiated material and ionizes molecules by creating positive and negative ions through energy transference in the electron (Asunni *et al*., 2024). The reactive ions produced by irradiating foods injure or destroy microorganisms by altering the cell membrane structure and affecting metabolic enzyme activity. Like thermal processing, irradiation is a first-order reaction, in which theoretically, a logarithmic reduction in microbial numbers with increasing dose is expected (Campbell-Platt and Grandison, 1990). Among the common types of irradiation, application of gamma rays as a processing and preservation technique has gained considerable attention (Olotu *et al*., 2014a,b), and has been found quite useful at low to medium doses for disinfestation and decontamination of tropical and sub-tropical underutilized and non-conventional legumes and oilseeds (Asunni *et al*., 2024; Oyinloye *et al*., 2023).

The nature of food materials requires that essential nutrients be preserved during processing and handling (Adejobi *et al*., 2024). To achieve the twin objectives of disinfestation/disinfection and nutrients retention, introduction of hurdle effect becomes imperative so as to minimize damage to innate nutrients while at the same time ensuring effective processing and preservation treatments (Enujiugha *et al*., 2023b). Applying gamma rays in a closed chamber at low to medium doses, combined with cooking has been confirmed to favour amino acid retention (Olotu *et al*., 2014b) and reduction in rancidity parameters (Enujiugha *et al*., 2012) in oilseed-based food products. The objective of the present study was to apply gamma rays at 5 kGy and 10 kGy in combination with hydrothermal treatment (cooking in water at 100 ^{o}C) to monitor the effect on the nutritional and functional characteristics of African bush mango seeds. It was also necessary to monitor the progressive increase in irradiation doses and its effects on the quality of the seeds.

2. Materials and Methods

Materials collection and sample preparation

Fresh African bush mango (or dikanut) (*Irvingia gabonensis*) seeds were obtained from a local market (Oja Oba) in Akure, Ondo State, Nigeria. Upon receipt and subsequent authentication at the CSP botanical laboratory, the *Irvingia gabonensis* seeds were visually inspected and defective seeds were discarded. The seeds were then transported to the FST processing laboratory and kept in airtight polyethylene containers in a dry and cool environment until ready for use.

Gamma irradiation was carried out at the irradiation laboratory at Sheda Science and Technology Complex (SHESTCO), in Abuja, Nigeria using cobalt-60 irradiation facility, as outlined previously (Enujiugha et al., 2023b). The samples were subjected to different processes and were divided into the following: Raw seed; Cooked, non–irradiated seed; Irradiated and cooked seed at 5 kGy and 10 kGy; and single treatment Gamma irradiation at 5 kGy and 10 kGy, respectively. They were subsequently grinded into flour in preparation for further analysis. All the chemicals and reagents used in the study were of analytical grade.

Determination of proximate chemical composition

The dtermination of quantitative composition was carried out on each of the samples using the following analytical methods: Moisture content was according to the air oven method (AOAC, 2012), whereby drying was done to constant weight; crude protein was determined using the micro-Kjeldhal method and the total nitrogen in the sample was multiplied by a factor 6.25 (AOAC, 2012); crude fat was extracted overnight in a Soxhlet extractor with n-hexane and quantified gravimetrically; ash content was determined in the sample by dry ashing in a muffle furnace at 550 ^{o}C for 8 hours (AOAC, 2012); crude fibre was determined after digesting five grams (5 g) of fat-free sample in mixture of refluxing 1.25% sulphuric acid and 1.25% sodium hydroxide; and total available carbohydrates were determined by the difference method (subtracting the percent crude protein, crude fibre, crude fat, and ash from 100% dry matter). All analyses were carried out in triplicates. The energy values of the samples were obtained by multiplying crude protein, crude fat and carbohydrate contents by factors of 4, 9 and 4, respectively (Enujiugha and Ayodele-Oni, 2003).

Mineral analysis

Analysis of sodium (Na) and potassium (K) contents of the samples was carried out using digital flame photometer (Jenway PFP7; Jenway Ltd, Fested Dunmow, Essex, England), while phosphorus (P) was determined by the phosphovanado-molybdate (yellow) method (AOAC, 2012) and the absorbance was measured at 470 nm. The other elemental concentrations (Ca, Mg, Fe and Zn) were determined, after carrying out wet digestion of extracted sample ash with a mixture of nitric and perchloric acids (1:1 v / v), using Atomic Absorption Spectrophotometer (AAS, Buck Model 20A, Buck Scientific, East Norwalk, CT06855, USA). All the determinations were carried out in triplicates.

Determination of antinutritional factors

The modified method of Reddy *et al.* (1982) was used for phytic acid and phytate-phosphorus determinations. Phytic acid was extracted from each 3 g flour sample with 3% trichloroacetic acid (TCA) by shaking at room temperature followed by high-speed centrifugation (30,000 x g for 5 min). The phytic acid in the supernatant was subsequently precipitated as ferric phytate, and iron in the sample was then

estimated. Phytate-phosphorus (phytate-P) was calculated from the iron results, assuming a 4:6 iron:phosphorus molecular ratio according to AOAC (2012) analytical procedures. The phytic acid in the sample was estimated by multiplying the amount of phytate-phosphorous by the factor 3.55 based on the empirical formula $C_6P_6O_{24}H_{18}$ (Enujiugha and Olagundoye, 2001).

Tannin contents were determined by the modified vanillin-HCl method (Burns, 1971; Price *et al.*, 1978). Two grams (2 g) of sample was extracted with 50 ml of 99.9% methanol for 20 min at room temperature (28 ± 2 ºC), with constant agitation. After centrifugation for 10 min at 653 x g, 5 ml of vanillin – HCl (2% vanillin, 1% HCl) reagent was added to 1 ml aliquots, and the colour developed after 20 min at room temperature was read at 500 nm. Correction for interference from natural pigments in the sample was achieved by subjecting the extract to the conditions of the reaction, but without vanillin reagent. A standard curve was prepared using catechin (Sigma Chemical, St. Louis, MO) after correcting for blank, and tannin concentration was expressed in g/100 g.
Determination of oxalate was by the AOAC (2012) method. One gram (1 g) of finely ground sample was dissolved in 75 ml of 1.5 N H_2SO_4. The solution was carefully stirred intermittently with a magnetic stirrer for about 1 h and filtered using Whatman no. 1 filter paper. Twenty five millilitres (25 ml) sample of the filtrate (extract) was collected and titrated hot (80 – 90 ºC) against 0.1 N $KMnO_4$ solution to the point when a faint pink colour appeared that persisted for at least 30 seconds. The concentration of oxalate in each sample was got from the calculation: 1 ml 0.1 N permanganate = 0.006303 g oxalate. All procedures were carried out in triplicates.

Analysis of functional properties
The determination of water and oil absorption capacities followed a slight modification of the method of Prinyawiwatkul *et al.* (1997), as carried out by Enujiugha and Akanbi (2005). Each flour sample (5 g) was thoroughly mixed, without pH adjustment, with 25 ml of deionized water or oil in 50-ml centrifuge tubes. Suspensions were stirred intermittently over a 30 min period at room temperature (28 ± 2 ºC) and then centrifuged at 12,000 x g for 30 min at 25 ºC. The volume of decanted supernatant was measured, and the water and oil absorption capacities were then calculated. Triplicate samples were analyzed for each flour sample category.

For the least gelation concentration, triplicate suspensions of 1 - 20% seed flour sample (dry w/v, at 1% increment) were prepared in 10 ml of deionized water and mixed thoroughly without pH adjustment. The slurries were heated in 125 x 20 mm screw- capped test tubes in a water bath with in-built magnetic stirrer (Julabo Model SW22, Julabo Labortechnik GMBH, Seelbach, Germany) at 95 ± 2 ºC. After 1 h of heating, tubes were immediately cooled in tap water for 30 s and then in ice water for 5 min to accelerate gel formation. All tubes were then held at 4 ºC for 3 h. Least gelation concentration (percent) was determined as the concentration above which the sample remained in the bottom of the inverted tube (Enujiugha *et al.*, 2003).

The foaming properties of the samples were determined using the modified procedure of Enujiugha and Akanbi (2005). Exactly 2 g of sample was weighed into 60 ml distilled water in a 100-ml cylinder. Solid material was dispersed with spatula and the suspension was whipped for 5 min using ultra-Turax T25 mixer at a high speed. Volumes before and after whipping were noted and volume increase due to whipping was then calculated. The volume of foam in the standing cylinder was also recorded for foam stability studies at 1, 5, 10, 20, 30, 60, 90, 120 and 180 min after whipping. The results were expressed in percentages.
Emulsifying properties were determined using a modification of the method described by Ige *et al.* (1984), as reported by Enujiugha *et al.* (2003). A measured quantity (1.8 g) of sample was dispersed in 25 ml distilled water, and 25 ml vegetable oil (pure soybean oil) was added. The 50 ml mixture was emulsified at high speed using ultra-Turax T25 mixer for 1 min. Emulsion was filled into centrifuge tubes and centrifuged for 5 min at 1,300 x 6 rpm. Percentage emulsion was then expressed as

$$\% \, Emulsion = \frac{100x}{y}$$

where: x = height of emulsified layer
y = height of whole solution in centrifuge tube.
The results were expressed in percentages, as for the foaming properties.

Determination of Amino Acids Profile
The amino acids profile in the sample was determined using the methods described by Olotu *et al.* (2014b) and Asunni *et al.* (2024), with slight modifications. The samples were dried to constant weight, exhaustively defatted, acid-hydrolyzed (or alkaline hydrolyzed, in the case of tryptophan), evaporated in a rotatory evaporator and loaded into the Technicon sequential multi sample amino acid analyzer (TSM). Briefly, five grams (5 g) of sample powder was weighed into extraction thimble and any remaining fat was extracted with chloroform/methanol (2:1) using Soxhlet extraction apparatus as described by AOAC (2012); the extraction lasted for 15 hours. Two hundred milligrams (200 mg) of the defatted sample was then weighed into glass ampoule. Exactly 7 ml of 6 N HCL (or 6 N KOH, for tryptophan) was added and oxygen was expelled by passing nitrogen into the ampoule in order to avoid possible oxidation of some amino acids (such as methionine and cysteine) during hydrolysis. The glass ampoule was then sealed with Bunsen burner flame and put in an oven preset at 105 ± 5 ºC for 22 hours. The ampoule was allowed to cool before broken open at the tip and the content was filtered to remove the residues. The filtrate was evaporated to dryness at 40 ºC under vacuum in a rotary evaporator. Subsequently, the residue was dissolved with 5 ml of acetate buffer (pH 2.0) and stored in plastic specimen bottles, which were kept in the freezer. The amount of hydrolysate loaded into the TSM analyser was between 5 to 10 microliters. This was dispensed into the cartridge of the analyzer. The TSM analyser is designed to separate and analyze free acidic, neutral and basic amino acids of the hydrolysate. The period of an analysis lasted for 76 minutes. All determinations were carried out in triplicates.

Determination of seed oil characteristics
The seed oils of the samples were extracted using Soxhlet apparatus (Talabi and Enujiugha, 2014; Oyinloye and Enujiugha, 2017) and the rancidity indices (peroxide value, iodine value, free fatty acids content and acid value) were determined according to the standard methods of AOAC (2012). The oils were extracted from the samples with 95% n-hexane as the extracting solvent. After extraction, the solvent was removed *in vacuo* and the extracted oils were then kept till utilized in subsequently analyses. The peroxide values were expressed as miliequivalents of peroxide oxygen per kg of sample (mEq/kg) while the free fatty acids were expressed as g oleic acid per 100 g of sample (g/100 g). Free fatty acids were determined by titrating ethanol-sample-solution against 0.1 M potassium hydroxide solution. The iodine value was determined by the AOAC (2012) method using Wij's iodine solution.

Statistical analysis
Data collected from the study were subjected to analysis of variance (ANOVA) as described by Steel and Torrie (1980). Differences among means were separated using Duncan's multiple range test; significances were accepted at 5% level ($P \geq 0.05$). The statistical software used was SPSS 10.0 for windows.

3. Results

Proximate chemical composition of the samples
The results obtained from the analysis of proximate chemical composition of the seed samples are presented in Table 1. Cooking relatively increased moisture content of the oil seed, while gamma irradiation had little or no effect on the hydro-structure of the oil seed. However, combined 10 kGy irradiation and cooking increased the moisture content from 2.66 g/100g to 3.61 g/100g. Ash content was observed to increase with higher doses of irradiation while no significant difference ($p<0.05$) was experienced with cooked raw sample and cooked irradiated (10 kGy). The highest protein content (17.77 g/100g) was recorded for the cooked sample, while the lowest value (12.23 g/100g) was reported in the 5 kGy irradiated sample.

Antinutritive factors in the samples
The results of the analysis of antinutritional factors in the treated and untreated samples are presented in Table 2. Generally, all the antinutritional factors determined were affected by the processing treatments, with reduced concentrations corresponding to higher irradiation doses and combination treatments (10 kGy gamma irradiation with subsequent hydrothermal in hurdle arrangement). Oxalate content decreased with hydrothermal treatment due to solubility of oxalate in water. Tannin content was also observed to decrease with increase in radiation dose and cooking as single treatments, with a further decrease occasioned by hurdle arrangement of combined 10 kGy gamma irradiation and cooking. Both hydrothermal and irradiation treatments affected phytate content, which decreased with increase in irradiation from 5 kGy to 10 kGy (from 1.11 to 1.07 mg/g, respectively) with a further significant decrease to 0.82 mg/g under combination treatment.

The quality of Irvingia gabonensis seed oil
Table 3 shows the seed oil characteristics of raw and processed *Irvingia gabonensis* seeds. Iodine value of the raw seed oil was 55.01 mg/100g which decreased significantly with seeds irradiated at 5 kGy. There was no significant difference ($p>0.05$) in the iodine value between the raw seed sample and the sample from 10 kGy irradiation. The combination treatment significantly ($p<0.05$) reduced the iodine value of the seed oil. Peroxide value registered increases with increased irradiation of the samples. The seeds that were subjected to hydrothermal treatment as a single processing operation had the highest peroxide value of 72.00 mEq./kg. Free fatty acid value increased with higher radiation dose.

Functional properties of the seed flour
The results presented in Table 4 indicate that irradiation had no apparent significant effect on water absorption capacity; the same trend was also observed with oil absorption capacity. Gamma irradiation brought about decreases in the emulsion properties of *Irvingia gabonensis* seeds. The cooked seed flour had the highest emulsion capacity of 40%. Cooking and 10 kGy gamma irradiation both as single and combined treatments did not significantly affect the least gelation concentration of the seed flour samples. The foaming stability results indicated that all the samples became stable from 120 minutes up to 24 hours as shown in Table 5.

Minerals composition of the samples
The low dose gamma irradiation applied to I*rvingia gabonensis* seeds indicated no substantial change in minerals composition as presented in Table 6. The Na/K ratio was generally less than 1, which is desirable in terms of blood pressure control; except for the sample irradiated at 10 kGy and the sample from the combined treatment of cooking and 10 kGy irradiation that were exceptionally high in sodium, reflecting in very high Na/K ratios. Calcium to magnesium ratios were also within recommended levels of >1, except for the high magnesium content of the 10 kGy irradiated sample.

Amino acids profile of the African mango seed flour samples
Amino acids profile of *Irvingia gabonensis* seeds in Table 7 shows increase and decrease with differently applied gamma irradiation dose, with no clear trend of change. For these samples, isoleusine, valine, threonine, glutamic acid, alanine, and tyrosine showed increases as irradiation dose increased; while lysine, glysine, leucine, phenylalanine, and methionine showed decreases as irradiation dose increased. Generally eight amino acids are especially regarded as essential for humans, namely phenylalanine, valine, threonine, tryptophan, isoleucine, methionine, leucine and lysine, and additionally, cysteine (a sulphur-containing amino acid), tyrosine (an aromatic amino acid), histidine and arginine are required by infants and growing children. All these amino acids were found to be present both in the raw and treated *Irvingia gabonensis* seeds.

Aspartic acid was significantly reduced with increase in irradiation dose from 5 kGy to 10 kGy, and this could be due to loss of free radical. On the other hand, glutamic acid gave the highest value probably indicating its level of unsaturation by free radical. Compensating for lysine loss after cooking,

there was increased lysine content after irradiation both in 5 and 10 kGy respectively. Generally, the most abundant amino acid in African mango seed from this study is glutamic acid, which recorded increase with combined irradiation and cooking, but was reduced with cooking and irradiation as single treatments.

The ratio of total essential amino acids (TEAAs) to total non-essential amino acids (TNEAAs) was >1, which is considered positive for all the treatments (Table 8). The predicted protein efficiency ratio (PER) was highest in the 5 kGy irradiated sample. There were no differences in the total aromatic essential amino acids among all the seed samples (both raw and treated).

Table 1: Proximate Nutrient Composition of *Irvingia gabonensis* Seeds (g/100g dry weight)

	TREATMENTS				
PARAMETER	**Raw**	**Cooked**	**10 kGy**	**C+I**	**5 kGy**
MC	2.66±0.05^{b}	2.96±0.02^{b}	3.43±0.01^{b}	3.61±0.03^{a}	2.11±0.02^{c}
ASH	1.83±0.02^{d}	2.53±0.02^{b}	3.34±0.03^{a}	2.83±0.05^{b}	2.24±0.03^{c}
FAT	35.99±1.3^{b}	34.12±0.07^{b}	36.94±0.06^{a}	35.34±1.1^{b}	30.25±0.04^{c}
CRUDE FIBER	4.88±0.01^{b}	3.99±0.06^{c}	5.00±0.14^{a}	4.88±0.5^{b}	5.08±0.03^{a}
PROTEIN	12.88±0.05^{c}	17.55±0.05^{a}	13.69±0.07^{b}	16.29±0.05^{a}	12.23±0.01^{c}
CHO	41.77±0.09^{a}	29.05 ±1.02^{c}	37.41 ±0.07^{b}	37.23±0.09^{b}	44.09±0.05^{a}

Keys: C+I: Cooked plus Irradiated @ 10 kGy, 10 kGy: irradiated @ 10 kGy, 5 kGy: Irradiated @5 kGy

Table 2: Antinutritive Factors in *Irvingia gabonensis* Seed

SAMPLE	**Oxalate (mg/g)**	**Tannin (%)**	**Phytate (mg/g)**
Raw	0.11±0.03^{a}	0.10±0.02^{a}	1.83±0.02^{a}
Cooked	0.04±0.01^{c}	0.08±0.01^{b}	1.44±0.01^{a}
10 kGy	0.08±0.01^{b}	0.06±0.01^{c}	1.07±0.03^{b}
C+I	0.07±0.01^{b}	0.05±0.01^{c}	0.82±0.02^{c}
5 kGy	0.08±0.02^{b}	0.06±0.01^{c}	1.11 ±0.03^{b}

Keys: C+I: Cooked plus Irradiated @ 10 kGy, 10 kGy: irradiated @ 10 kGy, 5 kGy: Irradiated @5 kGy

Table 3: Quality Indices of Oil Extract of Dikanut (*Irvingia gabonensis*) Seed

SAMPLE	**Iodine Value (**mg/100g**)**	**Peroxide Value (**mEq./kg**)**	**Free Fatty Acid (**%**)**
Raw	55.01±1.02^{a}	25.20±1.08^{e}	5.85±0.04^{b}
Cooked	31.00±1.01^{b}	72.00±1.02^{a}	6.35±1.01^{a}
10 kGy	51.40±1.04^{a}	62.00±1.05^{b}	6.75±1.03^{a}
C+I	27.20±1.03^{c}	36.00±2.60^{d}	6.45±0.70^{a}
5 kGy	25.60±1.30^{d}	52.00±1.04^{c}	5.80±0.05^{b}

Keys: C+I: Cooked plus Irradiated at 10 kGy, 10 kGy: irradiated at 10 kGy, 5 kGy: Irradiated at 5 kGy

Table 4: Functional Properties of *Irvingia gabonensis* Seed

SAMPLE	WAC (ml/100g)	OAC (ml/100g)	Emulsion (%)	Least gelation
Raw	3.00±0.01	0.83±0.02	38.00±0.11	8.00±0.13
Cooked	2.80±0.11	0.73±0.01	40.00±1.62	8.00±1.01
10 kGy	3.15±0.07	0.65±0.01	36.00±1.02	8.00±1.02
C+I	3.13±0.02	0.71±0.02	36.00±1.03	8.00±1.01
5 kGy	3.20±0.02	0.84±0.03	36.90±0.12	2.00±0.03

Keys: C+I: Cooking and Irradiated at 10 kGy, 10 kGy: irradiated at 10 kGy, 5 kGy: Irradiated at 5 kGy

WAC -water absorption capacity OAC –oil absorption capacity

Table 5: Foaming Stability of *Irvingia gabonensis* Seed Flour Samples

Sample	1min	5min	10min	20min	30min	60min	90min	120min	8h	24h
Raw	62	62	62	62	62	62	61	60	60	60
Cooked	68	68	68	68	68	67	67	67	67	67
10 kGy	73	73	73	73	72	70	71	68	68	68
C+I	64	64	64	64	64	64	63	62	62	62
5 kGy	70	70	70	70	70	70	68	68	68	68

Keys: C+I: Cooking and Irradiated at10 kGy, 10 kGy: irradiated at 10 kGy, 5 kGy: Irradiated at 5 kGy

Table 6: Minerals profile of *Irvingia gabonensis* Seed (mg/100g)

Sample	K	Na	Ca	Mg	Zn	Fe	P
R	17.57±0.09	2.46±0.01	28.32±0.10	5.97±0.03	4.64±0.02	2.71±0.01	4.29±0.02
C	24.60±0.20	2.04±0.01	28.22±0.40	5.87±0.02	4.92±0.01	2.53±0.01	4.32±0.02
10 kGy	18.27±0.30	98±0.02	24.51±1.00	75.12±0.70	4.02±0.01	1.98±0.01	3.66±0.01
C+I	24.79±0.50	83±0.07	28.36±0.30	5.84±0.02	4.53±0.02	2.83±0.01	4.25±0.03
5 kGy	24.60±0.90	2.04±0.01	28.22±0.70	5.87±0.03	4.92±0.01	2.53±0.02	4.33±0.02

Keys: R = raw seed; C = cooked seed

C+I: Cooking Irradiated @ 10 kGy; 10 kGy: irradiated @ 10 kGy; 5 kGy: Irradiated @ 5 kGy

Table 7: Amino acid profile of *Irvingia gabonensis* seed

Amino Acid	Raw	Cooked	C+I	5 kGy
Lysine	3.87±0.10^{b}	3.01±0.01^{c}	4.54±0.01^{a}	3.28±0.02
Histidine	2.29±0.02^{c}	7.23±0.10^{b}	8.34±0.10^{a}	2.63±0.03^{c}
Arginine	8.85±0.02^{a}	7.23±0.05^{d}	8.34±0.02^{c}	8.68±0.10^{b}
Aspartic Acid	9.66±0.01^{b}	8.63±0.02^{c}	8.91±0.00^{c}	11.25±0.00^{a}
Threonine	3.55±0.10^{b}	2.30±0.02^{c}	3.36±0.01^{a}	3.11±0.02
Serine	2.78±0.05	2.05±0.02^{c}	3.40±0.01^{a}	8.68±0.10^{b}
Glutamic Acid	13.91±0.20^{b}	12.07±0.10^{c}	15.75±0.20^{a}	11.62±0.10^{c}
Proline	3.72±0.01^{a}	3.08±0.04^{c}	3.50±0.02^{b}	3.50±0.01^{b}
Glycine	4.52±0.02^{b}	4.01±0.01^{c}	4.89±0.01^{a}	4.08±0.03^{c}
Alanine	4.21±0.02^{a}	3.71±0.01^{c}	4.02±0.03^{b}	3.94±0.03^{c}
Cystine	1.46±0.01^{a}	1.19±0.01^{c}	1.32±0.01^{b}	1.32±0.01^{b}
Valine	4.53±0.02^{b}	4.04±0.03^{c}	4.65±0.01^{a}	4.21±0.04^{b}
Methionine	1.54±0.01^{a}	1.30±0.02^{b}	1.22±0.01^{a}	1.28±0.01^{b}
Isoleucine	3.80±0.01^{b}	3.01±0.01^{c}	4.14±0.07^{a}	3.51±0.03
Leucine	5.79±0.02^{c}	6.20±0.04^{b}	6.20±0.01^{b}	6.64±0.04^{a}
Tyrosine	3.06±0.01^{a}	2.25±0.01^{c}	3.06±0.02^{a}	2.74±0.01^{b}
Phenylalanine	3.63±0.02^{c}	4.14±0.02^{a}	3.39±0.01^{b}	3.89±0.02^{b}

Keys: C+I: Cooking Irradiated @ 10Kgry, 10kgry: irradiated @ 10 kgry, 5Kgry: Irradiated @5kgry

Table 8: Summary of amino acid profile of *Irvingia gabonensis* seed

Amino Acid (mg/100mg)	Raw	Cooked	C+I	5 kGy
Total Amino Acid (TAA)	81.17	75.45	89.03	84.34
Total Essential Amino Acid (TEAA)	42.37	32.96	48.56	41.29
TEAA/TAA (%)	52.19	43.68	54.54	48.95
Total Non-Essential Amino Acid (TNEAA)	34.28	29.54	35.58	38.99
Total Sulfur Amino Acid (TSAA)	3.00	2.40	2.54	2.60
% Cystine in TSAA	48.66	49.58	51.96	50.76
Total aromatic Essential Amino Acid (ArEAA)	6.69	6.39	6.63	6.63
Total Acidic Amino Acid %	33.57	20.70	24.66	22.87
Total basic Amino Acid (TBAA) %	15.01	17.47	21.22	8.54
Total Neutral Amino Acid (TNAA) %	8.09	3.43	12.98	2.30
Ratio of TEAA: TNEA	1.24	1.12	1.36	1.06
Predicted Protein Efficiency Ratio (PER)	2.77	3.04	2.96	3.19

Keys: C+I: Cooking Irradiated @ 10Kgry, 10kgry: irradiated @ 10 kgry, 5Kgry: Irradiated @5kgry

4. Discussion

This study showed that processing with gamma irradiation at low doses and cooking, both as single treatments and combined hurdle treatments did not significantly ($p>0.05$) affect the *Irvingia gabonensis* seed moisture content. Rady *et al*. (2002) observed similar trends and reported that gamma irradiation had no significant effect on moisture content of oil seeds. However, combining irradiation with cooking increased the moisture content of the seeds, compared to single irradiation or cooking treatments, indicating a synergistic action of the hurdle effect. Fat was reduced with increase in irradiation doses up to 10 kGy, probably due to liquefaction of fat in cooking. Protein is reportedly lower with high irradiation due to denaturation of protein as also previously reported by Enujiugha and Akanbi (2005).

The reduced concentrations of antinutritional factors in the seeds with the different processing steps was also in agreement with what was observed in a previous study with ground nut (Enujiugha *et al.*, 2023b). This trend was also reported by Enujiugha *et al.* (2012) in the processing of African oil bean seeds (*Pentaclethra macrophylla* Benth) and by Oyinloye *et al.* (2023) in the processing of melon seeds (*Citrullus vulgaris*). Many oilseeds are known to contain several anti-

nutritional factors such as protease inhibitors (especially trypsin inhibitors), lectins or haemagglutinins, phytates, oxalates and polyphenols, among others (Enujiugha *et al.*, 2023a; Enujiugha, 2005). Numerous studies have indicated that these anti-nutrients can be eliminated or reduced significantly by processing techniques such as thermal heating (e.g. infrared heating, extrusion cooking, irradiation, steam treatment and pelleting), milling, soaking, germination, fermentation, cooking and protein extraction (Enujiugha *et al.*, 2003). The findings in this study are in agreement with the report of Asunni et al. (2024) who employed the hurdle treatment in the processing of African locust bean seeds (*Parkia biglobosa*).

The decrease in iodine value with increased irradiation dose observed in this study is consistent with the results reported by Enujiugha et al. (2012), who also observed a decrease in the iodine value upon application of the same range of low dose irradiation (1 -10 kGy). Irradiation probably broke some double bonds and induced oxidation processes in the fatty acids resulting in saturation (Anjum *et al.*, 2006). These results also agree with reports by Arici *et al.* (2007) and Al-Bachir (2004) that unirradiated samples have highest iodine values, suggesting saturation of oils as a result of irradiation. The observed increase in the peroxide value with increased irradiation dose might be due to oxidation and preferential cleavage of bonds in the oils. In an earlier research, increase in the peroxide value was attributed to interaction of gamma radiation with fat molecules, which triggered oxidation, dehydration and polymerization reactions (Evren and Gulden, 2008). The increase of free fatty acids (FFAs) with increased irradiation dose indicates that large original molecules of oils, which contain long-chain fatty acids, degrade to smaller molecules as a result of synergistic hydrolysis/oxidation and cleavage of bonds (Agatemor, 2006).

Considering the functional properties of the seeds, the findings in this study are in agreement with the report of Zayas (1997) who found that the water holding capacity was not affected by gamma irradiation. According to Asunni *et al.* (2004), water absorption capacity (WAC) is an important functional property of proteins and is a measure of the quality (juiciness, texture, binding of structure, appearance and mouth feel) of flour. In this study, there was a slight decrease in the water absorption capacity of the cooked (as a single treatment) sample compared to the raw seed. From the results of oil absorption capacity (OAC), it is clear that, no significant difference was observed in oil absorption capacity of *Irvingia gabonensis* seeds at both low dose irradiation of 5 kGy and the control raw sample. These results are in agreement with previous finding of Abu *et al.* (2005); however, cooking as a single treatment led to reduction in oil absorption compared to the raw seed and this is consistent with the results obtained by Enujiugha (2003) in the cooking of *Tetracarpidium conophorum* nuts. The changes in emulsion properties may be attributed to protein aggregation as well as surface hydrophobicity and changes in the seed characteristics, which affect emulsifying properties in different ways (Enujiugha and Akanbi, 2005).

Low dose irradiation did not bring about any significant change in mineral composition. According to Asunni *et al.* (2024), minerals act as stabilizers of the structures of membranes and cellular components. Zinc, for example, is an important component of several enzymes and their biochemical functions, especially in the synthesis and degradation of macromolecules such as carbohydrates, proteins, lipids and nucleic acids. It plays an important part in the development of sound cognitive capacity in children.

The results of the present study have shown that while some amino acids increased with higher irradiation doses, others decreased and this could be related to the structure of amino acids. Simple amino acids due to irradiation undergo reductive deamination and decarboxylation. In aliphatic amino acids with increasing chain length, providing additional C-H bond for interaction with OH radical reduces the amounts of oxidative deamination (Olotu *et al.*, 2014b). The results are comparable to those reported for melon seeds (Oyinloye *et al.*, 2023), African locust bean (*Asunni et al.*, 2024) and groundnut (Enujiugha *et al.*, 2023b). The findings in this study compare favourably with results obtained with other oilseeds and legumes (Olotu *et al.*, 2014; Oyinloye *et al.*, 2023). However, comparing the amino acid changes due to irradiation of *Irvingia gabonensis* seed with some cereal such as wheat (Srinivas *et al.*, 1972) shows no significant difference between the results.

Total amino acids (TAA), total essential amino acids (TEAA), total non-essential amino acids (TNEAA) and total neutral amino acids (TNAA), respectively decreased in all cooked samples due to denaturation of the protein structure by cooking according to (Kingsley, 1995) as indicated in Table 8. The different processing treatments raised the protein efficiency ratio in the seeds, and according to Enujiugha *et al.* (2023), these results could be related to the structure of amino acids, as simple (or common) amino acids due to irradiation undergo reductive deamination and decarboxylation. The high content of essential amino acids in the African bush mango seeds make them a potential source of dietary protein. The seed also has potential for increased utilization as an important vegetable protein source in diets of rural populations in less-developed tropical areas where the growth of the plant is encouraged.

5. Conclusion

It could be concluded from the findings of this study that combined effect of gamma irradiation and cooking increased nutrient bio-availability, but only had slight positive effect on the nutritional value. It has also shown from this study that irradiation dose up to 10 kGy is an effective tool in preservation of *Irvingia gabonensis* seed and maintenance of its oil quality.

Ethical approval

This work is part of a wider study approved by the Ethics Committee of the School of Agriculture and Agricultural Technology, Federal University of Technology, Akure, with assigned number FUTA/SAAT/ETH/2011/14

Conflict of Interest
The authors declare that there are no conflicts of interest.

Authors' contributions
S.A. Fagbemi and V.N. Enujiugha: conceptualization; methodology; writing original draft and providing resources; editing and final review
J.O. Olorunnusi: formal analysis; initial review and editing;
M.A. Okeji and A.O. Asunni: methodology; references; editing and final review
All authors have read and approved the final manuscript.

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References

Abu , J. O., M. Klaus., G. D. Kwaku, G. Duodu and M. Amanda (2005) Functional properties of cowpea (*Vigna unguiculata* L. Walp) flours and pastes as affected by ã-irradiation. *Food Chemistry*, **93**, 103-111.

Adejobi, T. H., Olorunnusi, J. O., Adegbanke, O. R., Oguntoyinbo, O. O., and Enujiugha, V. N. (2024). Effect of ginger and garlic inclusion on the performance of *Lactobacillus plantarum* in maize (*Zea mays* L.) fermentation into *Ogi*. *IPS Journal of Applied Microbiology and Biotechnology*, **3**(1), 46–56. https://doi.org/10.54117/ijamb.v3i1.18

Al-Bachir, M. (2004) Effect of gamma irradiation on fungal load, chemical and sensory characteristics of walnut. *Stored Products Research*, **40**, 355-362.

Anjum, F., Anwar, F., Jamil, A., Iqbal, M. (2006) Microwave roasting effects on the physico-chemical composition and oxidative stability of sunflower seed oil. *Journal of the American Oil Chemists Society*, **83**,777–784.

AOAC (2012). *Official Methods of Analysis*, 19th Edition (George W. Latimer, Jr., ed.). Association of Official Analytical Chemists (AOAC) International, Gaithersburg, Maryland, USA.

Arici, M., Colak, F. A., Gecgel, U. (2007) Effect of gamma radiation on microbiological and oil properties of blackcumin (*Nigella sativa* L.). *Grasas Aceites*, **58**(4), 339–343

Asunni A. O., Fagbemi S. A., Oyinloye A. M., Gowon C. B. and Enujiugha V. N. (2024). Amino Acid Profile and Physicochemical Properties of African Locust Bean (*Parkia biglobosa*) Seeds as affected by Combined Irradiation and Cooking. *International Journal of Environment, Agriculture and Biotechnology*, 9(1), 153-164. Doi:10.22161/ijeab.91.16

Burns, R. (1971) Method for estimation of tannin in grain sorghum. *Agronomy Journal*, **63**, 511- 512.

Campbell-Platt, G., and Grandson, A. S. (1990). Food irradiation and combination processes. *International Journal of Radiation Applications and Instrumentation*, **35**, 237.

Enujiugha, V.N. (2000). Development of a new food paste from seeds of *Pentaclethra* species. *Applied Tropical Agriculture*, **5**(2), 89-94.

Enujiugha, V.N. (2003) Chemical and functional characteristics of conophor nut. *Pakistan Journal of Nutrition*, **2**(6), 335-338

Enujiugha, V.N. (2005). Quality dynamics in the processing of underutilized legumes and oilseeds. In: *Crops: Growth, Quality and Biotechnology* (R. Dris, Ed.), WFL Publisher, Helsinki, Finland, pp 732-746.

Enujiugha V. N. (2020). Biotechnology for healthy nutrition and productive lifestyle. Inaugural lecture series 120. Federal University of Technology, Akure, Nigeria, 90p.

Enujiugha, V.N., and Akanbi, C.T. (2005). Compositional changes in African oil bean (*Pentaclethra macrophylla* Benth) seeds during thermal processing. *Pakistan Journal of Nutrition*, **4**(1), 27-31

Enujiugha, V.N., and Olagundoye, T.V. (2001). Comparative nutritional characteristics of raw, fermented and roasted African oil bean (*Pentaclethra macrophylla* Benth) seeds. *La Rivista Italiana delle Sostanze Grasse*, **78**(4), 247-250

Enujiugha, V.N., Akanbi, C.T., and Adeniran, H.A. (2008). Evaluation of starters for the fermentation of African oil bean (*Pentaclethra macrophylla* Benth) seeds. *Nutrition and Food Science*, **38**(5), 451-457

Enujiugha, V.N. and Ayodele-Oni, O. (2003). Evaluation of nutrients and some anti-nutrients in lesser-known under-utilised oilseeds. *International Journal of Food Science and Technology*, 38, 525-528.

Enujiugha V. N., Adeyemo M. B. and Adisa A. M. (2023a) Nutritional and safety implications of consuming melon seeds and impacts on international trade: A review. *Food and Humanity*, 1, 241–249. https://doi.org/10.1016/j.foohum.2023.05.020

Enujiugha, V.N., Badejo, A.A., Iyiola, S.O., and Oluwamukomi, M.O. (2003) Effect of germination on the nutritional and functional properties of African oil bean (*Pentaclethra macrophylla* Benth) seed flour. *Journal of Food, Agriculture and Environment*, **1**(3/4), 72-75.

Enujiugha V. N., Oguntoyinbo O. O., Oyinloye A. M., Adesina O. A., Olowolafe M. O. and Adekanmbi F. S. (2023b). Variations in Chemical Composition, Functional Properties and Oil Quality of Groundnut (*Arachis hypogaea*) as Influenced by Medium Dose Gamma Irradiation using Cobalt-60 Source. *IPS Journal of Nutrition and Food Science*, 2(2), 63-72. https://doi.org/10.54117/ijnfs.v2i2.30

Enujiugha, V. N., Olotu, I. O., Malomo, S. A., and Sanni, T. A. (2012). **T**he effect of γ-irradiation and cooking on the physicochemical properties of African oil bean seed (*Pentaclethra macrophylla* Benth) and its oil extract. *Journal of Food Research*, **1**(2), 189-201.

Evren, G., and Gulden, O. (2008) The effect of food irradiation on quality of pine nut kernels. *Radiation Physics and Chemistry*, **77**, 365–369

Ige M. M., Ogunsua A. O. and Oke O. L. (1984) Functional Properties of the Proteins of Some Nigerian Oilseeds, Conophor Seeds and Three Varieties of Melon Seeds. *Journal of Agricultural and Food Chemistry*, **32**, 822-828.

Kingsley, M. O. (1995). Effect of processing some antinutritive and toxic component on the nutritional composition of African oil bean seed (*Penthaclethra macrophylla* Benth). *Journal of the Science of Food and Agriculture*, **68**, 153-158. http://dx.doi.org/10.1002/jsfa.2740680204

Olagunju, A. I., Omoba, O. S., Enujiugha, V. N. and Aluko, R. E. (2018a) Development of value-added nutritious crackers with high antidiabetic properties from blends of Acha (*Digitaria exilis*) and blanched Pigeon pea (*Cajanus cajan*). *Food Science and Nutrition*, **6**(7), 1791-1802.

Olagunju, A. I., Omoba, O. S., Enujiugha, V. N., Alashi, A. M. and Aluko, R. E. (2018b) Pigeon pea enzymatic protein hydrolysates and ultrafiltration peptide fractions as potential sources of antioxidant peptides: An in vitro study. *LWT - Food Science and Technology*, **97**, 269-278.

Olotu, I.O., Enujiugha, V.N., Obadina, A.O., and Owolabi, K. (2014a). Fatty acid profile of gamma-irradiated and cooked African oil bean seed (*Pentaclethra macrophylla* Benth). *Food Science and Nutrition*, 2(6), 786-791.

Olotu, I.O., Enujiugha, V.N., and Obadina, A.O. (2014b). The Effect of γ-Irradiation and Cooking on the Amino Acid Profile of African Oil Bean Seed (*Pentaclethra macrophylla* Benth). *Journal of Food Processing and Preservation*, 38, 2020-2026.

Oyedokun, J., Badejo, A.A., and Enujiugha, V.N. (2016). Biochemical changes associated with poly- γ –glutamic acid synthesis during spontaneous and *Bacillus subtilis* fermentation of *Parkia biglobosa* seed into iru. *Advances in Food Sciences*, **38**(3), 117-124.

Oyedokun, J., Badejo, A. A., Oluwayomi, S. F., and Enujiugha, V. N. (2020). Synthesis of poly-γ-glutamic acid during fermentation of African locust bean (*Parkia biglobosa*). *Applied Tropical Agriculture*, **25**(2), 74-78.

Oyinloye, A.M., and Enujiugha, V.N. (2017). Evaluation of the suitability of *Tetracarpidium conophorum*, *Pentaclethra macrophylla* and *Citrullus vulgaris* seed oils for some fried products. *La Rivista Italiana delle Sostanze Grasse*, **94**, 117-124.

Oyinloye A. M., Enujiugha V. N. and Owolabi O. M. (2023). Effect of gamma irradiation and cooking on the physico-chemical properties, nutrients, and anti-nutrients compositions of egusi melon (*Citrullus vulgaris*) seeds. *La Rivista Italiana delle Sostanze Grasse*, 100(4), 263-269.

Price M. L., Scoyoc S. V. and Butler L. G. (1978) A critical evaluation of the vanillin reaction as an assay for tannin in sorghum grain. *Journal of Agricultural and Food Chemistry*, **26**, 1214-1218.

Prinyawiwatkul W., Beuchat L. R., McWatters K. H. and Phillips R. D. (1997) Functional properties of cowpea (*Vigna unguiculata*) flour as affected by soaking, boiling, and fungal fermentation. *Journal of Agricultural and Food Chemistry*, 45(2), 480-486.

Rady, A.H., S.M. Abdel Hady, F.M. Elnashabi, E.A Afifi and E.M. Salam (2002) Influence of Gamma rays and Microwave h e a t in g on the Quality of Olive fruits and their virgin oil. *Isotope and Radiation Research*, 34, 369-380.

Reddy, N. R., Sathe, S. K. and Salunkhe, D. K. (1982) Phytates in legumes and cereals. *Advances in Food Research*, **28**, 1-9.

Sanusi, R. A, Akinyele, I. O., Ene-Obong, H. N. and Enujiugha, V. N. (2017). (Editors). Nigerian Food Composition Table (Harmonized edition). Nigeria Foods Database Network, University of Ibadan, Nigeria, 85p.

Srinivas, H., Ananthswamy, H.V., Vakil, U.K., Sreeniasan, A. (1972). Effect of gamma irradiation on wheat proteins. *Journal of Food Science*, 37, 715

Stadlmayr, B., Charrondierre, U.R., Addy, P., Samb, B., Enujiugha, V.N., Bayili, R.G., Fagbohoun, E.G., Smith, I.F., Thiam, I. and Burlingame, B. (2010) (Editors). Composition of selected foods from West Africa. FAO Publications, Rome, Italy, 43p.

Steel, R.G.D. and Torrie, J.H. (1980) *Principles and Procedures of Statistics: A Biometrical Approach*, 2nd Ed., McGraw Hill Inter. Book Co., Tokyo, Japan.

Talabi, J.Y., and Enujiugha, V.N. (2014). Physical and chemical evaluation of oils from selected underutilized oilseeds. *Der Chemica Sinica*, **5**(6), 9-12.

Talabi, J.Y., Oguntoyinbo, O.O. and Enujiugha, V.N. (2023). Serum lipid profile and organ histology of albino rats fed on conophor (*Tetracarpidium conophorum*) nut oil-based diets. *IPS Journal of Nutrition and Food Science*, **2**(1), 9-12. DOI: https://doi.org/10.54117/ijnfs.v2i1.18

Zayas, J.F., (1997). Functionality of proteins in food. (p.81) New York: Springer.

Zeb, A. and T. Ahmad, (2004) High Dose Irradiation affect the Quality Parameters of Edible Oils. *Pakistan Journal of Biological Sciences*, 7: 943-946.