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*Original Article*

# Physicochemical and Functional Properties of Cassava Starch from Different Varieties as Affected by Gamma Irradiation

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## Abstract

**Introduction:** The most commonly consumed essential edible crop in many tropical countries in Africa, South America, and Asia is Cassava (*Manihot esculenta Crantz*). There are limitations on the utilization of cassava roots by processors, and they are also highly perishable and bulky. Raw cassava starches are excessively weak in terms of their structure and functionality, hence, limiting the diversity of industrial applications. The objective was to estimate the outcome of gamma irradiation as an amending agent on raw cassava starch from three cassava types (Ankra, Bosome nsia and TME419).

**Materials and methods:** Ankra, Bosome nsia and TME419 were the cassava varieties used for the study. The cassava starch was extracted, and then modified using cobalt-60 source. The administered doses were 5, 10, 15 and 20 kGy at a dose rate of 2.087 kGy/hr, and using zero as the control. The physicochemical and functional properties of the raw and modified cassava starches were evaluated using standard procedures.

**Results:** Gamma irradiation significantly reduced the amylose and carbohydrate contents as well as the colour of cassava starch. Amylose content of Ankra, Bosome nsia and TME 419 were 14.45, 16.39 and 18.21%, respectively. Also, the irradiation reduced the amylose content from 20.21% (control) to 17.47, 15.98, 14.99 and 13.27% at 5-20 kGy, respectively. The carbohydrate content of 44.44, 44.09 and 27.28% were recorded for Ankra, Bosome nsia and TME 419, respectively. Further, the irradiation decreased the carbohydrate content from 48.08% (control) to 45.63, 36.81, 34.94 and 27.54% at 5-20 kGy, respectively. The irradiation doses did not significantly affect the emulsion capacity and stability, and bulk density. The swelling power decreased as the radiation dose increased while solubility index, water and fat absorption capacities and least gelation significantly increased with the radiation dose.

**Conclusion:** Therefore, gamma irradiation could be exploited to alter cassava starch for industrial applications likewise a chemical modification.

**Keywords:** Gamma irradiation, Physicochemical, Functional, Cassava starch.

## Introduction

Cassava (*Manihot esculenta* Crantz) is a staple starchy crop with an excessive commercial reputation [1]. After rice and maize, cassava is acknowledged as the 3rd crucial food basis in the tropics [2]. A complex polymer found in large amounts in many plant cereals, tubers, and roots is

called starch. The amylose chain, which has alpha 1-4 links, and the amylopectin chain, which has together α-(1-4) links and α-(1-6) links, are two polymer chains that combine to form starch. According to Nwokocha *et al.* [3], cassava starch possesses exceptional qualities that are useful for commercial applications, comprising extreme paste viscosity and clearness as well as good freeze-thaw stability.

The concentric structure (hilum) of the starch granule order is composed of stellate levels with alternating crystalline and amorphous regions. The main components of the amorphous regions are amylose chains and amylopectin-branched sites. According to Copeland *et al.* [4] and Varatharajan *et al.* [5], the duplicate helices of the amylopectin side chains are primarily what make up the crystalline portions of the lamellae. Amylose makes up 10 to 30% of starch, and amylopectin makes up 70 to 90%, depending on the variety and the botanical source.

Cassava starches can be modified for industrial use since native forms of cassava starch are unsuitable for such purposes. Altered cassava starches are now used in several food businesses to advance their technological standards. Different physical and chemical procedures are being used to alter most natural starches. Such alteration supports molecular disorder, polymer breakdown, molecular rearrangement, and chemical group and polymer crosslinking [6]. Due to the changes observed, problems including solubility, retrogradation and syneresis, shear stress resistance, and thermal fragmentation are also improved.

To change the raw starch, safe and environmentally friendly technologies are needed. Incorporating new functional groups into the starch polymer, including carboxyl, acetyl, hydroxypropyl, amine, or any other, is one way that starch is chemically modified. This process has the potential to leave products with hazardous residues, rendering them unfavourable to the environment [7].

Thermal technologies may also be employed, but they have many disadvantages, such as a higher rate of starch degradation, and the products they produce are more oxidized (have a high concentration of -CHO and -COOH groups) despite the wider range of potential applications [8]. Diverse physical approaches, including extrusion, hydrothermal treatment, microwave, and irradiation have been utilized to change starch due to the aforementioned difficulties through chemical and thermal modification approaches [9].

It is acknowledged that radiation technology has the potential to change raw starches to improve their solubility and enzymatic digestion, and increase their suitability for use in the food sector. The application of gamma radiation plays an important role in the starch alteration procedure. According to Abu *et al.* [2] and Bao *et al.* [10], breaking down of starch polymers by gamma irradiation causes a continuous decrease in the molecular weight of amylose and amylopectin as well as decreased viscosity, increased solubility, and increased acidity with increasing radiation dose. Bao *et al.* [10] reported that higher radiation doses increase the crystallinity of wheat and rice starches and decrease potato starch. According to Lee *et al.* [11], and Bao *et al.* [10], gamma irradiation upsurges the gelatinization enthalpy of bean starch while reducing that of rice, corn, wheat, and potato starches. A decreased or no contrast in starch digestibility was detected at lower doses, but the advanced doses of gamma irradiation limited starch digestibility [12]. Radiation processing is known to result in radiolytic product formation or radiation-degraded products (RDPs).

Furthermore, MacArthur and D'Appolonia [13] investigated how three

hard red spring wheat cultivars' starch characteristics were affected by low-dose gamma irradiation. Additionally, isolated starches were reported to have been damaged, as evidenced by changes to highest viscosity, core viscosity values, and water binding capacity. Reduced starch solubility was observed along with a reduction in swelling power, which was linked to the molecular breakdown of starch granules. The decline in swelling power with diminished solubility of starch was documented and ascribed to the molecular breakdown of starch granules. Abu *et al.* [14] reported that black-eyed pea flour and paste at 2, 10, and 15 kGy had starch-associated useful properties like swelling power, gel strength, and viscosity significantly decreased. These reductions were dose-dependent and attributable to radiation-induced degradation of starch. The radiation-induced decrease in swelling and gel strength was attributable to a reduction in viscosity owing to starch degradation. Tran *et al.* [15] also indicated that the microstructure of irradiated cassava starch remained unchanged despite the deformed starch granules. Cassava varieties bred and released purposely for industrial utilization are limited due to the quality of starch. However, cassava starch with its increasingly diverse industrial application in Ghana and globally demands the modification of the starch of cassava. In overcoming some challenges associated with the chemical modification of starches, it is imperative to apply gamma irradiation in the modification of cassava starch. The goal of this study was, therefore, to evaluate the qualitative characteristics of cassava starch after gamma irradiation.

## Materials and Methods

### *Sample and sample preparation*

Cassava varieties used for the study were Ankra, Bosome nsia, and TME419. They were obtained from the Municipal Agriculture Development Unit of the Ministry of Food and Agriculture (MoFA) at Pokuase in the Greater Accra Region. All three cassava varieties were cleaned and peeled. The flesh cassava was sliced into 1 mm thickness, and then dipped in water (water: slices; 3: 1 w/w) at 30 °C for 24 h, as described by Bradbury [16]. The cassava slices were then washed twice with potable water and dehydrated using an air oven (Gallenkamp, United Kingdom) at 50 °C for 24 h. The dehydrated cassava slices were ground in a household blender (Binatone-BLG-605SS, China) and screened using a sieve of size 0.425 mm. The flour was vacuum-packed, and stored at room temperature (30±4 °C) for further analysis. The gamma irradiation of cassava starch was done at the Radiation Technology Centre, Ghana, and a Cobalt-60 source was used. The administered doses were 5, 10, 15 and 20 kGy at a dose rate of 2.087 kGy/hr. Non-irradiated cassava starch was used as the control.

### *Determination of moisture content*

AOAC [17] was used to analyze the moisture content. Two grams (M0) of cassava starch sample (done in triplicates) were weighed into pre-dried moisture tins that had been cooled. The samples were then dried for 1 h in an air oven (Gallenkamp, United Kingdom) at 130 $^{o}$C. The dried samples were then cooled in a desiccator and weighed (M1). The average mass of the three masses was used to calculate the moisture content of the cassava starch. The moisture content expressed as a percentage was calculated as follows:

$$\text{Moisture content} = \frac{M0-M1}{M0} \times 100 \quad (1)$$

*Determination of fat content*

The Soxhlet extraction method was used to estimate the fat content of cassava starch based on AOAC [17]. About 5 g of cassava starch was placed in the thimble and accurately weighed. A small dried cotton wool was plugged into each thimble. The pre-dried boiling flask was weighed, and the cassava starch was placed in the Soxhlet extractor. The boiling flask, Soxhlet flask, and condenser were assembled. About 350 ml of petroleum ether was put in the flask. Several glass boiling beads were added, and extraction was done for about 4 h at a rate of 5 or 6 drops (condensation) per second by heating the solvent in a boiling flask. The boiling flask containing the extracted fat was dried in an air oven (Gallenkamp, United Kingdom) for 30 min at 100 ˚C. After, it was cooled in a desiccator, and then weighed. Percent fat was calculated as:

$$\%\ Fat\ \left(\frac{wt}{wt}\right) = \frac{(wt\ of\ boiling\ flask+extract)-(wt\ of\ boiling\ flask)}{(\ sample\ wt\ )} \times 100 \quad (2)$$

*Determination of protein content*

The Micro-Kjeldahl method based on AOAC [17] was used, and the crude protein content of cassava starch was calculated. One gram of the cassava starch sample was weighed into a digestion flask. Ten grams of catalyst mixture ($K_2SO_4$+GSe) and 20 ml of $H_2SO_4$ were added, and the mixture was boiled briskly for about 2 h until the solution became clear. The solution was allowed to cool and the volume made up to 100 ml by adding distilled water in a volumetric flask. A solution of 10 ml was taken into a flat bottom flask and about 15 ml of 40% NaOH was added to make the content strongly alkaline. The content was collected with 10 ml of 2% boric acid solution containing 2-3 drops of mixed indicator (methyl red and bromo-cresol green) in a flask. About 50 ml distillate was collected and 0.01 NHCl was titrated against the 50 ml distillate (the obtained purple colour indicated the endpoint). Blank determination was also done on the reagents. The following formula was used to calculate the per cent nitrogen (%N) and the protein content:

$$\%N = \frac{\text{(Vol. of Acid – Vol. of Blank) x 0.01 x 14 x 100 x 100}}{\text{1 g x 100 x 10}}\ x\ 100 \quad (3)$$

$$\text{Protein (\%) = \%N x 6.25} \quad (4)$$

*Determination of ash content and pH*

Ash and pH were determined using AOAC [17]. In determining the total ash content, 5 g of cassava starch (triplicate) was weighed into porcelain crucibles. The crucibles containing the cassava starch were placed in a high-temperature muffle furnace (Carbolite, England), and heated for 6 h at 600 ºC. The ash content (dry basis) was calculated as:

$$\text{Ash (\%)} = \frac{\text{Mass of ash}}{\text{Mass of dry cassava starch}}\ x\ 100 \quad (5)$$

The pH was determined by weighing a triplicate of cassava starch (5 g dry basis) into a beaker. It was then mixed with 20 ml of distilled water, and the resulting suspension was stirred for 5 min and left to settle for 10 min. The pH of the water phase was measured using a calibrated pH meter (edge HI2002, Hanna Instruments).

*Analyzing the amylose content*

The spectrophotometric standard procedure (ISO 6647) was used to calculate the amylose content (percentage weight/weight) of cassava starch [18]. About 100 mg of cassava starch and 9 ml of 1 M NaOH and 1 ml of 95% ethanol were mixed. The mixture was heated in a boiling water bath for 10 min to gelatinize. It was then put in a volumetric flask after chilling, and 100 mL of distilled water was added. A 5 mL portion was then added to 1 mL of 1 M acetic acid and 2 mL of iodine solution (0.2 % I2, 2 % KI). The solution was diluted with distilled water to 100 ml, and allowed to remain for 10 min. Spectrophotometric quantification was carried out at 620 nm with a Shimadzu UV-Vis Spectrophotometer (Model UV-1601), utilizing quartz cells with a 10 mm path length and two iterations of the multipoint working curve technique. For each replicate, two decisions were made on different test parts derived from the same sample. Using purified amylose as the standard, a formula derived from the standard curve was used to establish the apparent amylose content. The acquired amylose values should coincide with the dependent relative variables used later to build and validate the developed calibration.

*Determination of total carbohydrate*

The total carbohydrate content of cassava starch was estimated using the method of Hedge and Hofreiter [19]. One hundred milligrams of cassava starch was homogenized in hot ethanol (80%) to remove sugars. The obtained residue was retained after centrifugation using MedGroup Multipurpose High-speed Centrifuge (MSLZL19). Hot ethanol (20%) was used to wash the residue until the washing did not produce colour with the Anthrone reagent. The residue was then well-dried over a water bath. To the residue, 5 ml of water and 6.5 ml of 52% perchloric acid were added. Starch was extracted at 0 °C for 20 min, and the supernatant was retained after centrifugation. The extraction was repeated with fresh perchloric acid. The supernatants were pooled after the centrifugations to make up to 100 ml. To 0.2 ml of the supernatant, 0.8 ml of distilled water was added. Standards were prepared by taking 0.2, 0.4, 0.6, 0.8, and 1 mL of the working standard, after which the volume was made up to 1 mL in each tube with water. About 4 ml of the Anthrone reagent was added to each tube. The reaction mixture was heated for 8 min in a boiling water bath. The mixture was cooled rapidly, and the green colour intensity was read at 630 nm using a Shimadzu UV-Vis Spectrophotometer (Model UV-1601). Glucose content in the cassava starch was determined using the standard graph. The total carbohydrate content was expressed as a percentage by multiplying the value by a factor of 0.9.

*Determination of colour*

The colour meter (Color Tec PCMTM Color Tec Associates, Inc., 28 Center Street, Clinton, NJ 08809) was used to assess the colour of cassava starch. The colour was measured as lightness (L∗), redness/greenness (a∗), and yellowness/blueness (b∗). The tool was initially standardized (L*=97.95, a*= -0.14, b*=1.64) with a Business Xerox 80 g/m$^2$ white paper with 136 CIE whiteness D 65 [20].

*Determination of emulsification properties*

The emulsification property of the cassava starch was analyzed using the technique of Beuchat [21].

$$\text{Emulsion capacity (\%)} = \frac{\text{Vol. of water after homogenization} - \text{Vol. of water before homogenization}}{\text{Vol. of water before homogenization}} \text{ X } 100$$

$$\text{Emulsion stability (\%)} = \frac{\text{The volume of water after the time}}{\text{The initial volume of water}} \text{ X } 100 \quad (6)$$

*Determination of water absorption capacity (WAC)*

The approach of Sathe and Salunkhe [22], as restructured by Adebowale *et al.* [23] was used to estimate WAC. The proportion of the volume of the supernatant to the original volume of water injected into the cassava starch, expressed as a percentage was used to determine the WAC (%).

*Determination of least gelation concentration (LGC)*

LGC was investigated using the method described by Abbey and Ibeh [24]. The LGC was analyzed as the concentration at which cassava starch in the inverted test tubes did not slip or fall.

*Determination of fat absorption capacity (FAC)*

FAC was calculated with the procedure outlined by Beuchat [21]. FAC was defined as the amount of fat that was absorbed by cassava starch as a proportion of the initial fat volume.

$$\text{Fat Absorption Capacity (FAC) (\%)} = \frac{\text{The volume of supernatant}}{\text{The initial volume of oil added.}} \text{ X } 100 \quad (7)$$

*Determination of bulk density*

Bulk density was analyzed using the procedure described by Narayana and Narasinga [25].

$$\text{Bulk density} = \frac{\text{Weight of tcahe cassava starch in a test tube}}{\text{Volume of the measured cassava starch in a test tube}} \quad (8)$$

*Determination of swelling power (SP) and solubility index (SI)*

Swelling power and solubility index were calculated using the modified method of Leach *et al.* [26]. About 1 g of cassava starch was weighed into a previously weighed 50 mL centrifuge tube, and 40 mL of distilled water was added. The suspension was stirred uniformly and gently to prevent the rapture of cassava starch granules. The suspension was heated in a thermostatically controlled water bath (OLS200 Grant, England) at 85 °C for 30 min, with constant stirring. Upon removing the tube from the water bath it was wiped and allowed to dry and cool to ambient temperature. The supernatant was then poured into a weighed crucible and dried in an air oven (Gallenkamp, United Kingdom) at 105 °C. The weight of the dried supernatant after cooling and the weight of the sediment paste were used to calculate the solubility and swelling power, respectively.

$$\text{Solubility index} = \frac{\text{Weight of dried supernatant}}{\text{Weight of cassava starch sample}} x\ 100 \quad (9)$$

$$\text{Swelling power} = \frac{\text{Weight of sedimented cassava starch paste}}{\text{Weight of dry cassava starch sample}} \quad (10)$$

*Data analysis*

Three separate experiments were performed with a factorial design. The major variations in radiation dose and cassava varieties were identified using MANOVA. Separate analyses were performed on the radiation dose and cassava variety data. Significant means were separated using Fischer's LSD Test at P ≤ 5%. Also, principal component analysis (PCA) was performed.

## Results and Discussion

*Effects of radiation dose and variety on physicochemical properties of cassava starch*

Radiation dose and varietal effects on the nutritional composition of cassava are presented in Tables 1 (a and b). The ash and protein contents showed no significant difference ($P \geq 0.05$) concerning the radiation dose applied, but for the used varieties there were significant differences. Oluwole *et al.* [27] reported that cassava had a protein content of between 2 and 3% which corroborates the results in Table 1. Ash is the inorganic residue left after heating a biological material in the presence of oxidizing agents. As a result, "ash content" refers to a measurement of all the minerals in a food. The obtained results of ash content were comparable to the 0.12 reported by Perez *et al*. [28] for cassava starch.

Moisture content and pH depicted significant differences concerning the radiation dose as well as varietal differences (Table 1). However, fat content was not significantly different with regards to the radiation dose unlike the varietal differences (Tables 1 (a and b)). Generally, the moisture and pH were reduced with increasing radiation dose. Moisture is a vital requirement in stored food items, moisture levels greater than 13% promote microbial growth and subsequent deterioration of food quality [29]. Thus, small levels of moisture are promising and give a relatively long shelf life. The difference in moisture content could be due to the varietal differences and the degree of drying. These moisture levels were consistent with those stated for root and tuber starches [3, 28-29], suggesting the possibility of a greater shelf life for all the samples. Cassava starches from Nigeria had a pH value of 6.56, according to Nwokocha *et al.* [3]. This was similar to TME 419 acquired from IITA Nigeria. Three cassava cultivars growing in Cameroon were found to have pH values ranging from 5.43 to 6.56 [30]. Work done by other researchers proved that tuber starches have significantly lower fat composition [29].

The dose effects and variety on the amylose content of cassava starch were highly significant, and a significant interaction concerning dose and variety was also observed. Amylose content declined with increasing radiation dose. Similar trends were also observed by Abu *et al.* [2] and Bao *et al.* [10]. Those researchers reported that the breakdown of starch polymers by gamma irradiation resulted in a continuous decrease in the molecular weight of the amylose. Yu and Wang [31] reported that irradiation plays an enormous role in the apparent decrease of the amylose content in starch with increasing doses, attributable to the

breakdown of starch granules by gamma irradiation. The aforementioned reports and the results obtained in this study confirmed that the amylose concentration of cassava is dependent on the variety. The amylose concentration of cassava is believed to be genetically influenced, but not influenced by plant age or environmental factors [32].

The results obtained from Tables 1 (a and b) showed that radiation dose had a substantial effect ($p < 0.05$) on the carbohydrate content of the cassava starch samples from the 3 varieties. The carbohydrate content of cassava starch decreased with increased radiation dose. With regards to the varietal effect, TME 419 had the lowest carbohydrate content of 27%, suggesting a relatively more susceptibility to radiation degradation than cassava starches from Ankra and Bosome nsia. This implies that the degree of radiation-induced degradation of the carbohydrate was dependent on the cassava variety. The decrease in carbohydrate content of irradiated cassava starch could be due to the radiation-induced splitting of glycosidic bonds accompanied by the degradation of carbohydrate molecules into smaller units of carbohydrate dextrins. Carbohydrate molecules may undergo oxidative and hydrolytic breakdown when exposed to radiation [10, 13].

The L* value indicated the whiteness level; zero represented black while hundred represented white colour. The a* value indicated the degree of redness while the b* value indicated the degree of yellow colouration. The L* value of the non-irradiated cassava starch was 96.7, the a* value was -0.17, and the b* value was 1.39 (Tables 1 (a and b)). These values indicated that the cassava starch samples were almost white with no red colouration but had a slight yellow colouration. The L*, a*, and b* values changed when the cassava starch was irradiated. The L* value decreased as the radiation dose increased (Table 1a), but the opposite happened with the a* and b* values. Thus, radiation affected the colour of the samples due to the high energy discharged from the radiation source. The visual quality of colour is determined by the light that objects emit, transmit, or reflect. The monosaccharides from the cassava starch polysaccharide degradation caused by the gamma irradiation's caramelization reaction might be the cause of the colour change. Greenwood and Mackenzie [33] indicated that this can hydrolyze chemical bonds, severing up large molecules of starch into little pieces of dextrins, sugars, and sugar acids that may or may not be electrically charged as free radicals. This alteration in colour might also be attributed to the degradation of colour-inducing compounds due to irradiation. The variations observed in the varieties (Table 1b) indicated that the cassava variety had a substantial effect on the colour of the cassava starch. These variances could result from variations in the genetic makeup and the environment the plant thrived [34].

*Effects of radiation dose and variety on functional properties of cassava starch*

The obtained data from the functional properties are presented in Tables 2 (a and b). Radiation effect on emulsion capacity, emulsion stability at both 30 mins and 1 hr as well as bulk density showed no significant differences ($P \geq 0.05$) between them. Regarding the varietal differences, Ankra and Bosom nsia showed significant differences ($P \leq 0.05$) in the emulsion capacity. Stability at 30 mins also showed a significant difference between Bosom nsia and TME 419, but emulsion stability for 1 hr did not show any significance (Table 2b).

**Table 1a** Effects of radiation dose on the nutritional properties of cassava starch

| Dose kGy | pH | Ash content (%) | Moisture Content (%) | Amylose content (%) | Fat content (%) | Protein (%) | Carbohydrate (%) | L* value | a* value | b* value |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 7.68±0.01e | 0.14±0.01a | 12.28±0.09c | 20.21±0.12e | 0.68±0.00a | 1.90±0.08a | 48.08±0.05e | 96.70±0.05a | -0.17±0.01e | 1.39±0.02a |
| 5 | 7.39±0.01d | 0.12±0.01a | 11.91±0.09b | 17.47±0.12d | 0.68±0.00a | 2.10±0.08a | 45.63±0.05d | 95.28±0.05b | -0.24±0.01d | 2.14±0.02b |
| 10 | 7.19±0.01c | 0.14±0.01a | 11.47±0.09a | 15.98±0.12c | 0.68±0.00a | 1.95±0.08a | 36.81±0.05c | 93.62±0.05c | -0.29±0.01c | 2.61±0.02c |
| 15 | 7.13±0.01b | 0.12±0.01a | 11.35±0.09a | 14.99±0.12b | 0.67±0.00a | 2.14±0.08a | 34.94±0.05b | 92.63±0.05d | -0.33±0.01b | 2.75±0.02d |
| 20 | 7.03±0.01a | 0.13±0.01a | 12.20±0.09c | 13.27±0.12a | 0.68±0.00a | 2.06±0.08a | 27.54±0.05a | 90.60±0.05e | -0.38±0.01a | 2.98±0.02e |

*Means ± S.D. within each column with dissimilar letters were significantly different (P ≤ 0.05)*

**Table 1b** Effects of cassava variety on the physicochemical properties of cassava starch

| Variety | pH | Ash content (%) | Moisture Content (%) | Amylose content (%) | Fat content (%) | Protein (%) | Carbo-hydrate (%) | L* value | a* value | b* value |
|---|---|---|---|---|---|---|---|---|---|---|
| Ankra | 7.62± 0.01z | 0.09± 0.01x | 11.47± 0.07x | 14.55± 0.1x | 0.68± 0.002y | 2.25± 0.06y | 44.44± 0.04z | 94.52± 0.04x | 0.24± 0.01y | 2.33± 0.02z |
| Bosomensia | 7.39± 0.01y | 0.21± 0.01y | 11.94± 0.07y | 16.39± 0.1y | 0.66± 0.002x | 1.96± 0.06x | 44.09± 0.04y | 93.76± 0.04y | 0.19± 0.01z | 2.58± 0.02x |
| TME419 | 6.82± 0.01x | 0.08± 0.01x | 12.12± 0.07y | 18.21± 0.1z | 0.69± 0.002z | 1.88± 0.06x | 27.28± 0.04x | 93.01± 0.04z | 0.42± 0.01x | 2.21± 0.02y |

*Means ± S.D. within each column with dissimilar letters were significantly different (P ≤ 0.05).*

A mixture of two or more wholly or partially immiscible liquids, such as oil and water, where the dispersed phase is the liquid that is present as droplets suspended in the continuous phase is known as an emulsion [35]. Smaller

starch granules could stabilize smaller droplets since native starches are clean-label ingredients. Bulk density depends on the samples' particle sizes, and it measures the heaviness of the starch sample. Tiger nut flours have been found to have a density of 0.55 to 0.62 g/cm$^3$ by Oladele and Aina [36], which was less than that of cassava starch.

Solubility index and swelling power significantly showed differences ($P \leq 0.05$) concerning radiation dose (Table 2a). The solubility index increased as the radiation dose rose whereas the swelling power declined with increased radiation dose (Table 2a). This means that solubility was inversely proportional to the swelling power regarding the applied dose. The solubility index measures the dextrinisation of starch whilst swelling power measures the capability of starch to gulp water and expand. These characteristics show that the amorphous and crystalline regions interacted [37]. Furthermore, the solubility index can be swayed by amylose and amylopectin characteristics [37]. As mentioned by Duarte and Rupnow [38], the molecular breakdown of the starch caused by irradiation was the cause of the rise in solubility of the irradiated cassava starch. Irradiation causes fragmentation of the outside amylopectin chain leading to the reduction in molecular weight. This further crosslinks with the amylose chains; hence, the decrease in swelling power and increased solubility of the irradiated cassava starch. The solubility index and swelling power values of cassava varieties differed significantly from each other. TME 419 and Ankra showed no significant difference ($p \geq 0.05$) in solubility index whilst Bosom nsia and TME 419 also showed no significant difference in swelling power (Table 2b). Moorthy [29] mentioned that, the swelling power of cassava starch differed among varieties. The swelling properties of cassava flour and cassava starch vary [29]. Starches' solubility and swelling power may be influenced by their kinds, inter-associative pressures between the amorphous and crystalline domains, and the presence of other components [39].

Fat absorption capacities (FAC) and water absorption capacities (WAC) showed significant differences in terms of the radiation dose applied (Table 2b). As indicated by Lawal *et al.* [40], FAC is helpful in the formation and interaction of foods, specifically in flavour preservation, palatability improvement, and shelf-life extension, especially in baked goods. There was a general increase in FAC as the radiation dose increased. Abu *et al.* [2] evaluated the physicochemical properties of starch and reported that fat absorption was dose-dependent. They reported that the proliferation in fat content in starch was accredited to an improved capability of damaged or cross-linked starch to physically entangle fat as radiation dose advances. Hence, corroborates the findings of this study. Generally, the WAC of the cassava starch significantly increased with increasing irradiation dose. Morante et al. [41] examined the functional properties of starch modified with gamma irradiation. And reported a substantial increase in WAC of starch with increased radiation dose, attributable to irradiation damage or disruption of starch into smaller molecules such as dextrins that have a higher attraction for water than native starch. The FAC and WAC significantly differed among the varieties, except Bosom nsia and TME419 which showed no significant difference between them. WAC of cassava starch is based on the source of material used in preparing the cassava starch. The observed differences in the cassava varieties may be due to the nature of the cassava starch [22]. The least gelation capacity results are represented in Tables 2 (a and b). Significant differences existed between the radiation dose and variety. The least

gelation values increased as the radiation dose increased. The least gelation is the least percentage of concentration needed to form a gel in a starch. Bosom nsia had the least gelation whereas TME 49 had the highest value (Table 2b). Gel formation is dependent on various cassava used for the cassava starch. Amylose creates a three-dimensional network with swelling granules embedded in the matrix as the starch paste cools. Starch gelation is the term used to describe this occurrence [42]. Retrogradation, which involves the crystallization of amylose and amylopectin, causes structural changes in the starch gel.

**Table 2a** Effects of radiation dose on the functional properties of cassava starch

| Doses (kGy) | Emulsion Capacity | Emulsion Stability (30 mins) | Emulsion Stability (1 hr) | Bulk Density ($gcm^{-3}$) | Solubility Index (%) | Swelling Power(g) | Fat Absorption Capacity (%) | Water Absorption Capacity (%) | Least Gelation Capacity |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 6.42±0.60a | 95.67±0.77a | 98.33±4.83a | 0.84±0.01a | 11.33±2.15a | 10.08±0.31d | 4.67±0.51a | 11.78±0.31a | 6.22±0.24b |
| 5 | 5.88±0.60a | 94.22±0.77a | 84.88±4.83a | 0.81±0.01a | 24.44±2.15b | 5.84±0.31c | 6.67±0.51b | 13.0±0.31b | 4.0±0.24a |
| 10 | 6.72±0.60a | 95.11±0.77a | 95.89±4.83a | 0.81±0.01a | 33.89±2.15c | 5.1±0.31bc | 9.0±0.51c | 14.11±0.31c | 6.33±0,24b |
| 15 | 6.05±0.60a | 97.56±0.77a | 96.67±4.83a | 0.80±0,01a | 35.11±2.15c | 4.33±0.31ab | 11.11±0.51d | 15.67±0.31d | 7.89±0.24c |
| 20 | 7.30±0.60a | 95.89±0.77a | 95.56±4.83a | 0.84±0.01a | 42.44±2.15d | 3.84±0.31a | 11.11±0.51d | 17.78±0.31e | 9.56±0.24d |

*Means ± S.D. within each column with different alphabetical letters were significantly different (P≤0.05).*

**Table 2b** Effects of cassava variety on the functional properties of cassava starch

| Variety | Emulsion Capacity | Emulsion Stability (30mins) | Emulsion Stability (1hr) | Bulk Density ($gcm^{-3}$) | Solubility Index (%) | Swelling Power (g) | Fat Absorption Capacity (%) | Water Absorption Capacity (%) | Least Gelation Capacity |
|---|---|---|---|---|---|---|---|---|---|
| Ankra | 7.16±0.46y | 95.60±0.59xy | 96.87±3.74x | 0.83±0.01y | 34.27±1.67y | 6.49±0.24y | 10.47±0.39y | 14.47±0.24y | 7.0±0.19y |
| Bosome nsia | 5.68±0.46x | 94.27±0.59x | 89.06±3.7x | 0.79±0.01y | 22.47±1.67x | 5.29±0.24x | 7.80±0.39x | 15.67±0.24z | 5.27±0.19x |
| TME419 | 6.58±0.46xy | 97.20±0.59y | 96.87±3.74x | 0.84±0.01y | 31.60±1.67y | 5.74±0.24x | 7.27±0.39x | 13.27±0.24x | 8.13±0.19z |

*Means ± S.D. within each column with different alphabets were significantly different (P≤0.05).*

*Principal component analysis (PCA)*

The physicochemical and functional properties of cassava starch were further evaluated with PCA regarding the different varieties and radiation doses (Figures 1 (A and B)). The PCA observed in Figure 1A was slightly different from that of Figure 1B. The initial 2 principal components summed up to about 98.91% of the variations observed in terms of radiation dose (Figure 1A). However, in Figure 1B the first 2 principal components summed up to 100% of the observed variations in reference to varieties of cassava.

In Figure 1A, LGC and WAC were associated with 20 kGy whereas FAC, S.I and 'b' were linked to 15 kGy and 10 kGy. Carbohydrate and L were associated with 5 kGy while 'a', amylose and S.P related closely to 0 kGy. According to the results of the biplot, the amylose content recorded a strong correlation with L, a, carbohydrate and S.P, but a weak correlation with WAC, FAC, S. I, b and LGC. From the biplot, amylose, 'a', L, carbohydrate and S.P were clustered together. Likewise, WAC, FAC, b, and S.I were clustered together. The amylose content correlated positively with S.P, 'a', L, and carbohydrate but correlated negatively with the other parameters. The radiation doses significantly altered amylose content in cassava starch, however, at 0 kGy amylose content remained high. The PCA indicated that amylose content is a critical property of cassava starch. Thus, amylose influences starch's functional properties [43], and hence, determines the kind of food product to be formulated.

The LGC, 'a' and amylose were associated with TME419 (Figure 1B).

Carbohydrate, L, FAC, S.P and S.I were related to Ankra, whereas 'b' and WAC were linked to Bosom nsia. The biplot showed that amylose had a strong positive correlation with 'a' and LGC, and a negative correlation with other parameters. The obtained results support the assertion that amylose content differs with the variety of cassava [44].

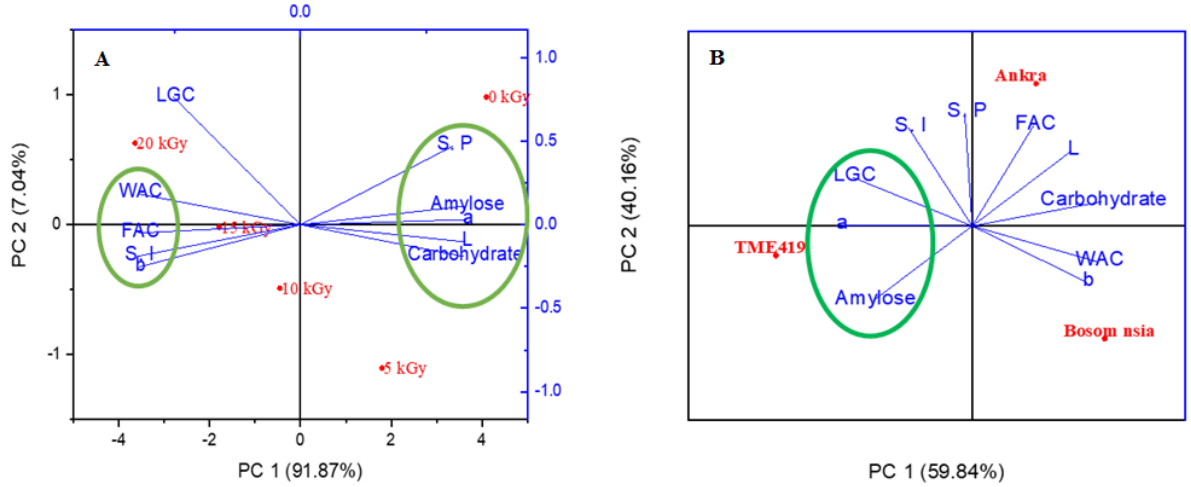


**Figure 1** PCA: (A) is a biplot (score and loading plots) showing the radiation effect on cassava starch properties; (B) is a biplot (score and loading plots) showing the varietal effect on cassava starch properties; LGC = Least gelation capacity, S.P = Swelling Power, WAC = Water absorption capacity, FAC = Fat absorption capacity, S.I = Solubility Index, L = lightness/whiteness, a = redness/green, b = blue/ yellowness

## Conclusion

The amylose content differed between the cassava varieties as follows 14.45% (Ankra), 16.39% (Bosome nsia) and 18.21% (TME 419). Similarly, the different varieties exhibited differences in the carbohydrate content. Thus, 44.44, 44.09, and 27.28%, respectively, for Ankra, Bosome nsia, and TME 419. Although the fat, ash, and protein contents of cassava starch were unaffected by the irradiation, the irradiation reduced the amylose, carbohydrate, pH, moisture and colour values. The irradiation decreased the amylose content from 20.21% (control) to 17.47, 15.98, 14.99, and 13.27% at 5-20 kGy, respectively. The irradiated cassava starch recorded a decrease in carbohydrate content from 48.08% (control) to 45.63, 36.81, 34.94, and 27.54% at 5-20 kGy, respectively. The emulsion capacity and stability, and bulk density were not significantly altered by the irradiation doses. However, swelling power decreased with increasing irradiation dose while solubility index, water, and fat absorption capacities and least gelation significantly increased with increasing irradiation dose. Significant alterations in some properties of cassava starch were attributable to the applied gamma radiation. Therefore, cassava starch properties can be altered with gamma radiation for industrial purposes instead of chemical applications. The gamma irradiated cassava starch can be used in food processing, textile making, pharmaceuticals, and polymer processing, among others.

## Conflict of Interest

The authors declare that they have no conflict of interest in this article.

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