

Functional and Physicochemical Characteristics of Starch Obtained from Gamma-Irradiated Sweet Potato (*Ipomea batatas* L.)

F.C.K. Ocloo^{a*}, G. Otoo^b, R.M. Nkansah^c, T. Mahami^a, S. Odonkor^d and E.T. Quayson^b

^a Radiation Technology Centre, Biotechnology and Nuclear Agriculture Research Institute, Ghana Atomic Energy Commission, P.O. Box LG 80, Legon, Ghana

^b Department of Biochemistry, University of Cape Coast, Cape Coast, Ghana

^c School of Nuclear and Allied Sciences, University of Ghana, Atomic-campus.

^d Nutrition Research Centre, Radiological and Medical Sciences Research Institute, Ghana Atomic Energy Commission, P.O. Box LG 80, Legon, Ghana

ABSTRACT

Tubers and roots are important sources of carbohydrates as an energy source and are used as staple foods in tropical and sub tropical countries. Sweet potato (*Ipomoea batatas* L.) is one of the world's most important, versatile, but under exploited food crop. The aim of this study was to evaluate the functional and physicochemical characteristics of starch produced from gamma-irradiated sweet potato tubers for control of insects and sprouting. Sweet potato tubers were purchased, sorted, packed and irradiated at doses of 0 kGy, 0.2 kGy, 0.3 kGy and 0.4 kGy. Starch was extracted from the irradiated tubers and then evaluated for moisture, pH and pasting profile. Swelling power, solubility, water absorption capacity and bulk density were equally determined. The moisture contents of the starch produced from the irradiated sweet potatoes were between 10.02 and 11.88 %. The pH of the starch produced from the irradiated sweet potato ranged from 6.26 -7.07. The pH values were significantly different from each other ($p < 0.05$). Beginning of gelatinization temperature of the starch samples increased with increase in dose (i.e. from 75.5-79.6 °C. Maximum/peak viscosity decreased from 1008.2 – 937.0 BU as the irradiation dose increase. Generally, setback and breakdown viscosities significantly decreased with increasing irradiation doses. The swelling power of starches from irradiated sweet potato tubers decreased with increased irradiation dose. However, the decrease in swelling power was not statistically significant ($p > 0.05$). The solubility of starches from irradiated sweet potato tubers significantly ($p < 0.05$) increased with increased in irradiation dose. Gamma irradiation of sweet potato tubers to control insects and sprouting influences functionality of their resultant starches. The result obtained therefore could be useful in selecting appropriate dose treatment of sweet potato tubers for a particular industrial application of their resultant starches.

Keywords: Sweet potato, irradiation, starch, functional properties, physicochemical properties.

INTRODUCTION

Tubers and roots are important sources of carbohydrates as an energy source and are used as staple foods in tropical and sub tropical countries [1]. Sweet potato (*Ipomoea batatas* L.) is one of the world's most important, versatile, but under exploited food crops. Sweet potato is a high yielding crop with wide adaptation and high resistance to drought [2]. Storage of sweet potato tubers is usually in pits using ash or in sacks. However, pit storage has been found to be effective for at least four months and is constrained by sweet potato weevil damage, rotting and rodents [3]. In addition, the use of ash in sweet potato storage has been found to produce unattractive and low market value tubers due to shrinkage [4]. Thus, there is need for continued effort to develop sweet potato production towards improved processing technology and value added products. Commercial utilization of sweet potato for industrial raw materials like flour and starch is non-existent although it has the potential of adding value to the produce and helping create new domestic and export market niches for new products. However,

increase in utility would also depend on thorough understanding of the effect of processing on their properties and functionality.

Major problems associated with the storage of fresh tubers are sprouting and spoilage. Sprouting of tubers leads to the depletion of dry matter contents of the commodities. Sprouting, which is undesirable during storage, is promoted in tropical conditions. Several chemical treatments have been utilised to reduce sprouting in stored sweet potatoes and yams including naphthaleneacetic acid and sodium hypochlorite solution [5, 6]. Effective treatments include pre-harvest spraying with maleic hydrazide, or treating the harvested tubers with the methyl ester of naphthalene-acetic acid (MENA) in acetone.

Irradiation treatment is a viable alternative to chemical fumigation for sweet potato growers. Gamma irradiation has long been used to protect foods from insect infestation and microbial contamination during storage. As a major ingredient, starch confers structure, texture, consistency and appeal to many food systems. The effects of gamma irradiation on chemical composition of food products

*Corresponding Author: F.C.K. Ocloo, Radiation Technology Centre, Biotechnology and Nuclear Agriculture Research Institute, Ghana Atomic Energy Commission, P.O. Box LG 80, Legon, Ghana. Tel.: +233 244467195; fax: +233 302400807. E-mail: fidelis_ocloo@yahoo.com

have received wide attention because of the concern about food safety^[7].

The optimum irradiation dose for treating sweet potatoes against insects and microbial contamination without affecting quality may lie between 100 and 500 Gy^[8]. A dose of 600 Gy did not reduce the overall quality or taste of purple-fleshed and yellow-fleshed sweet potatoes^[9]. Hallman^[10] also found that orange-fleshed roots treated with a 300 Gy dose did not differ from control roots in color or organoleptic ratings. The present research is aimed at evaluating some functional and physicochemical properties of starches produced from sweet potato exposed to gamma irradiation to control insects and sprouting.

2.0 MATERIALS AND METHODS

2.1. Sample collection and preparation

2.1.1 Source of material

Sweet potatoes (*Ipomoea batatas*) of 'white' cultivar were purchased from a local market in Accra, Ghana, kept in boxes and then transported to the Radiation Technology Centre, GAEC, for irradiation.

2.1.2. Radiation

About 10 Kg of sweet potatoes tubers were packed in a basket for irradiation. The irradiation was done using a gamma irradiation facility of cobalt 60 source at the Radiation Technology Centre (RTC) of the Ghana Atomic Energy Commission (GAEC). The radiation doses used were 0.0, 0.20, 0.30 and 0.40 kGy at dose rate of 409 Gyhr⁻¹ in air and the absorbed dose confirmed by Fricke's dosimetry.

2.1.3. Starch Extraction

The irradiated sweet potatoes were washed, peeled and then sliced into pieces. The samples were macerated in a domestic blender with tap water for 2 min at maximum speed and filtered through a muslin cloth. The residue was re-suspended in tap water. Starch was allowed to settle for 3 hours and the supernatant was discarded. The starch was re-suspended in 2 litres of tap water, filtered through a sieve and left to settle in a tray for 2 hours. The starch samples were then dried at 60°C in an air-oven.

2.2 Laboratory Evaluations

2.2.1 Functional properties

2.2.1.1 Swelling power and solubility

Swelling power and solubility was determined as described by Schoch^[11]. Starch was accurately weighed (2g, dry basis) into a dry tared pre-weighed 250 ml centrifugal bottle. Distilled water was added to give a total volume of water equivalent to 180g. The starch was completely suspended by stirring at 200 rpm using magnetic stirrer. After taking out the stirrer, the bottle was

immediately placed in constant temperature shaking water bath at 85°C±0.2 with continuous shaking at 200 rpm for 30 minutes. The centrifuge bottle was then dried and placed on a balance followed by the addition of distilled water to obtain a total weight of 200 g. After capping, the bottle was centrifuged for 15 minutes at 1000xg. To measure solubility, 50 ml of the supernatant was then pipetted and transferred into an evaporating petri-dish and dried overnight in a hot air oven at 105°C. The dried residue was then cooled in a dessicator and weighed for soluble starch. To measure the swelling power, the supernatant was carefully removed and discarded. The bottle with the sediment paste was then weighed to give the weight of swollen starch granules. The result was expressed by the calculation:

$$\% \text{ solubility (on dry basis)} = \frac{\text{Weight of soluble starch}}{\text{Weight of sample on dry basis}} \times 100$$

$$\text{Swelling power} = \frac{\text{Weight of sediment paste} \times 100}{\text{Weight of sample on dry basis} \times (100 - \% \text{solubility})}$$

2.2.1.2. Water Absorption Capacity

This was determined using methods described by Beuchat^[12]. One gram sample was weighed into 25 ml graduated conical centrifuge tubes and about 10 ml of water added. The suspension was allowed to stand at room temperature (30 ± 2 °C) for 1 hr. The suspension was centrifuged at 200 x g (2000 rpm) for 30 minute. The volume of water on the sediment was measured and the water absorbed expressed as per cent water absorption based on the original sample weight.

2.2.1.3 Bulk Density

This was determined by the method of Narayana and Narasinga Rao^[13]. A graduated cylinder tubes was weighed and starch sample filled to 5 ml by constant tapping until there was no further change in volume. The content was weighed and the difference in weight determined. The bulk density was computed as grams per milliliter of the sample.

2.2.2 Physico-chemical properties

2.2.2.1 Moisture Content

AOAC^[14] was used. Triplicate starch samples, 2g were weighed into a cooled and weighed dish (provided with cover). The uncovered samples were dried in an oven at 130°C for 1 hr (1 hr drying period begins when oven temperature is actually 130°C). After the drying period the dishes were covered while still in oven, transferred to desiccators and weigh soon after reaching room temperature. The percent loss in weight of the sample was reported as moisture.

2.2.2.2 pH

Triplicate starch samples, 5g dry basis (db), were weighed into beakers and mixed with 20 mL of distilled water. The resulting suspensions were stirred for 5 min and left to settle for 10 min. The pH

of the water phase was measured using a calibrated pH meter ^[15].

2.2.2.3 Pasting Profile

The pasting properties of the samples were measured using Brabender Viscograph-E Measurement & Control Systems (Brabender GmbH & Co. KG, Germany). About 40 g moisture-free sample (db) was suspended in 420 ml distilled water to prepare slurry in a large beaker. The suspension of the starch was mixed thoroughly and poured into the measuring bowl of the Brabender Viscograph-E. The test was run at a speed of seventy-five (75) revolution per minute with a measuring range of 700 cmg. The temperature profile of the analysis was programmed to commence measurement at a temperature of 50 °C with heating at the rate of 3 °C/min up to a temperature of 92 °C. The temperature of the sample was held constant for fifteen (15) minutes and then cooled at the rate of 3 °C/min to a temperature of 55 °C. This temperature was also held constant for fifteen (15) minutes. The parameters recorded from the curve include: the time, temperature and viscosity at the beginning of gelatinization, maximum viscosity, start of holding period, start of cooling period, end of cooling period, and at the end of final holding period as well as breakdown and set back viscosities.

2.3 Data Analysis

Analysis of variance (ANOVA) was done using MINITAB 14 (Minitab Inc., USA). The level of significance used was $p < 0.05$ at 95% Confidence Intervals.

3.0 RESULTS AND DISCUSSION

3.1 Functional Properties

3.1.1 Swelling Power and solubility of starch from irradiated sweet potato

Swelling power provides evidence of non-covalent bonding between starch molecules. The swelling power of starches from irradiated sweet potato tubers decreased with increase irradiation dose (Table 1). However, the decreased in swelling power was not statistically significant ($p > 0.05$). The decrease could be due to the scission of the amylose and amylopectin chains in starch molecules ^[16]. Andréa *et al.* ^[17] reported that the reduction of pasting viscosity could result from a decrease in swelling due to partial depolymerization of amylopectin and/or amylose in amorphous regions. In general, swelling of most starch granules begins at the least organized, amorphous, intercrystallite regions of the granule. As this phase swells, it exerts a tension on neighboring crystallites and tends to distort them. Further heating leads to uncoiling or dissociation of double helical regions and breaks up

of amylopectin crystallite structure. The liberated side chains of amylopectin become hydrated and swell laterally, further disrupting crystallite structure. The starch molecules are unable to stretch longitudinally, and actually may have a tendency to contract to approach a random coil conformation ^[18]. Abu *et al.* ^[19] also reported reduction in swelling index of starch from irradiated cowpea.

The solubility of starches from irradiated sweet potato tubers is shown in Table 1. Solubility significantly ($p < 0.05$) increased with increase in irradiation dose. Other researchers reported increment in material soluble in water as evidence of molecular degradation of starch by irradiation ^[20, 21].

3.1.2 Water Absorption Capacity

The ability to absorb water is a very important property of all flours and starches used in food preparations. The water absorption capacity of resultant starches from the irradiated sweet potato tubers was 10 % for each sample (Table 1). This implied that the irradiation of sweet potato tubers had no effect on the water absorption capacity of their resultant starches. However, increase in water absorption capacity had been reported for starch irradiated with gamma rays (2, 10 & 50 kGy) ^[19]

3.1.3 Bulk density

The bulk density of the starches from the irradiated sweet potato tubers ranged from 0.69 – 0.79 (g/cm^3) (Table 1). These values decreased with increase in irradiation dose. The observed decrease in bulk density was statistically significant ($p < 0.05$). Bulk density is a function of particle size; particle size is inversely proportional to bulk density. Higher value bulk density of sweet potato starch suggests its suitability as drug binder and disintegrates in pharmaceuticals. Bulk density value of 0.76 was reported by Oladebeye *et al.* ^[22] for sweet potato starch.

3.2 Physicochemical Properties

3.2.1 Moisture content

The moisture contents of the starch produced from the irradiated sweet potatoes were between 10.02 and 11.88 % (Table 2). There were no significant differences ($p > 0.05$) between the moisture contents of the starch samples. This implies that, the irradiation doses given to the sweet potato had no effect on the moisture content of its resultant starch. However, the starch produced from non-irradiated sweet potatoes had higher value compared with those produced from irradiated sweet potatoes. Moisture content of dry starch varies from 6-16%, depending on the process used for drying the starch ^[23]. Higher levels of moisture can lead to microbial damage and subsequent deterioration in quality. Moisture content of 11 – 17 % had been reported for sweet potato starch ^[24, 25, 26, 27].

Table 1: Some functional properties of starches from gamma irradiated sweet potato

Dose (kGy)	Swelling Power (g/g)	Solubility (%)	Water absorption capacity (%)	Bulk density (g/cm ³)
0	4.31 ^a ± 0.72	24.65 ^a ± 0.00	10.00 ^a ± 0.00	0.79 ^a ± 0.02
0.2	3.91 ^b ± 0.75	27.58 ^b ± 2.08	10.00 ^a ± 0.00	0.77 ^b ± 0.01
0.3	3.87 ^b ± 0.74	34.06 ^c ± 4.29	10.00 ^a ± 0.00	0.73 ^c ± 0.01
0.4	3.98 ^c ± 0.70	35.34 ^d ± 0.00	10.00 ^a ± 0.00	0.69 ^d ± 0.01

a-d: Means in a column with different letters are significantly different ($P < 0.05$) from each other. Values are mean ± SD of three replicates

Table 2: Moisture content and pH of starches from gamma irradiated sweet potato

Dose (kGy)	Moisture content (%)	pH
0	11.9 ^a ± 0.2	7.03 ^a ± 0.02
0.2	11.4 ^a ± 0.4	7.07 ^b ± 0.04
0.3	10.0 ^a ± 0.3	6.26 ^c ± 0.10
0.4	11.7 ^a ± 0.7	6.76 ^d ± 0.09

a-d: Means in a column with different letters are significantly different ($P < 0.05$) from each other. Values are mean ± SD of three replicates

3.2.2 pH

The pH of the starch produced from the irradiated sweet potato ranged from 6.26 -7.07 (Table 2). The pH values were significantly different from each other ($p < 0.05$). Though, there were reductions in the pH of the starches as the dose increases, the trend observed was not dose dependent. Generally, as the dose given to the sweet potato increases, the pH of its resultant starch decreases. The reduction in pH could be attributed to breakdown in glycosidic linkages by the action of free radical generated by irradiation in the starch. pH values between 4.43 – 5.57 were reported by Tsakama *et al.* [28] for sweet potato starches. High pH starches have been found to have increased solubility. This is due to increased hydrophilic characters of the starch at these pH values [29]. On the other hand, pH values of between 5 and 7 are said to generally stimulate retrogradation. This is because salts of monovalent anions and cations, which have been found to retard retrogradation, are generally absent [30].

3.2.3 Pasting profile

The pasting characteristics of the starches produced from gamma irradiated sweet potatoes are

presented in Table 3. Generally, the pasting characteristics of the starches decreased with increase irradiation dose. However, the pasting/gelatinization temperatures increased with irradiation doses. Pasting temperature increased from 75.5 °C to 79.6 °C. Pasting temperature gives the temperature at which a perceptible increase in viscosity occurs and is always higher than gelatinisation temperature [23]. Starch from non-irradiated sweet potatoes showed significantly higher peak, final, breakdown and set back viscosities than irradiated samples ($p < 0.05$). Falade *et al.* [31] (2011) reported similar findings for yam and sweet potato tuber starches. Similarly, the effects of irradiation on pasting viscosities of various starches have also been reported by Bachman *et al.* [32] (1997), Bao *et al.* [33, 7].

Peak viscosity values were 1008.2, 982.4, 848.0 and 937.0 BU for starches obtained from sweet potato irradiated at 0, 0.2, 0.3 and 0.4 kGy respectively. Peak viscosity, which shows the maximum swelling of the starch granule prior to disintegration, has also been described as the equilibrium point between swelling and breakdown of the granules [1]. Peak viscosity is often correlated with the final product quality. It also provides an indication of the viscous load likely to be encountered during mixing [34, 35]. Peak viscosity is also a measure of the water-holding capacity of the starch in terms of the resistance of swollen granules to shear and the swelling performance of granules [36]. Ezekiel *et al.* [37] have reported a decrease in the viscosities of starches extracted from irradiated potatoes. The decrease in the peak viscosity of starches from irradiated sweet potatoes could be attributed to degradation of glycosidic bonds in the amylopectin and amylose chains.

Table 3: Pasting profile of starches from gamma irradiated sweet potato

Dose (kGy)	Pasting temp. (°C)	Peak viscosity (BU)	Viscosity @ 92 °C (BU)	Viscosity @ 92 °C after 15 min	Viscosity @ 55 °C (BU)	Viscosity @ 55 °C after 15 min.	Breakdown (BU)	Setback (BU)
0	75.5 ^d ± 0.5	1008.2 ^a ± 0.2	937.0 ^a ± 1.0	661.2 ^b ± 0.2	855.0 ^a ± 0.0	872.0 ^a ± 0.0	347.0 ^a ± 0.0	193.8 ^a ± 0.2
0.2	79.2 ^c ± 0.3	982.4 ^b ± 0.4	934.1 ^b ± 0.8	644.3 ^c ± 0.2	806.3 ^c ± 0.1	807.0 ^c ± 1.0	338.0 ^b ± 0.0	162.0 ^c ± 0.0
0.3	79.6 ^a ± 0.0	848.0 ^d ± 0.0	803.9 ^d ± 0.1	627.2 ^d ± 0.1	784.5 ^d ± 0.1	796.8 ^d ± 0.2	220.8 ^d ± 0.2	157.3 ^d ± 0.3
0.4	79.4 ^b ± 0.2	937.0 ^c ± 0.0	874.1 ^c ± 0.1	674.1 ^a ± 0.1	842.0 ^b ± 0.0	859.2 ^b ± 0.1	262.9 ^c ± 0.1	167.9 ^b ± 0.1

a-d: Means in a column with different letters are significantly different ($P < 0.05$) from each other. Values are mean ± SD of three replicates

Final viscosity values for the starch samples were 872, 807, 796.8 and 859.2 BU for 0, 0.2, 0.3 and 0.4 kGy respectively. Also, setback viscosity

values were 193.8, 162, 157.3 and 167.9 BU for 0, 0.2, 0.3 and 0.4 kGy respectively. The setback and final viscosities are mainly attributed to some degree

of re-ordering of leached amylose, which is often termed short-term retrogradation [38]. The final viscosity is used to indicate the ability of starch to form various paste or gel after cooling and less stability of starch paste is commonly accompanied with high value of breakdown [39]. Setback, defined as the difference between the breakdown viscosity and the viscosity at 50 °C, determines the tendency of starch to retrogradation. Starches with high setback viscosity would tend to have stiffer pastes than low setback viscosity [40], but are susceptible to weeping when used as filling in frozen product application. Lower setback during cooling of the paste indicates greater resistance to retrogradation.

The breakdown viscosity values for the starch samples were 347, 338, 220.8 and 262.9 BU for 0, 0.2, 0.3 and 0.4 kGy respectively. Falade *et al.* [31] also reported similar reduction in breakdown of starches obtained from irradiated sweet potato and yam tubers. Breakdown viscosity is an estimation of paste resistance to disintegration in response to heat and shear, lower breakdown viscosity showed greater resistance which would be expected of starches with lower peak viscosities. However, this is not always observed as breakdown viscosity depends on the amount of materials released into the paste [41]. The rate of starch breakdown depends on the nature of the material, the temperature and the degree of mixing and shear applied to the mixture [36]. Higher breakdown viscosity showed lower the ability of the sample to withstand heating and shear stress during cooking [29].

Conclusion

Generally, the functional and physico-chemical properties of starches produced from gamma irradiated sweet potatoes decreased with increase in irradiation dose. pH values ranged from 6.26 -7.07 and were significantly different from each other ($p < 0.05$). Beginning of gelatinization temperature of the starch samples increased with increase in dose (i.e. from 75.5-79.6 °C. Maximum/peak viscosity decreased from 1008.2 – 937.0 BU as the irradiation dose increase. Setback and breakdown viscosities significantly decreased with increase irradiation dose. The swelling power of starches from irradiated sweet potato tubers decreased with increased irradiation dose. However, the decreased in swelling power was not statistically significant ($p>0.05$). The solubility of starches from irradiated sweet potato tubers significantly ($p<0.05$) increased with increase in irradiation dose. Gamma irradiation of sweet potato tubers to control insects and sprouting influences functionality of their resultant starches. The result obtained therefore could be useful in selecting appropriate dose treatment of sweet potato tubers for a particular industrial application of their resultant starches.

Acknowledgement

The authors acknowledge the help rendered by staff of Radiation Technology Centre of the Biotechnology and Nuclear Agriculture Research Institute, Ghana Atomic Energy Commission (GAEC) for helping in the irradiation of sweet potato tubers. The authors gratefully acknowledge the unknown referees for constructive suggestions, which were helpful in substantial improvement of the article.

REFERENCES

1. Liu, Q., E. Donner, Y. Yin, R.L. Huang and M. Z. Fan, 2006. The physicochemical properties and in vitro digestibility of selected cereals, tubers, and legumes grown in China. *Food Chemistry* 99: 470-477.
2. Lu G., H. Huang and D. Zhang, 2006. Prediction of sweetpotato starch physicochemical quality and pasting properties using near-infrared reflectance spectroscopy. *Food Chemistry*. 94: 632-639.
3. Moyo, C., I. Benesi, F. Chipungu, C. Mwale, V. Sandifolo and N. Mahungu, 2004. Africa: Cassava and Sweetpotato yield in Malawi. *Afr. Crop Sci. J.* 12: 295-303.
4. Mbeza, H., I. Minde and C. Mjiku, 1997. Sweetpotato storage and its economy in Malawi. Presented at the 4th African Potato Association Congress at University of Pretoria, pp24-28.
5. Paton, J.E. and F. M. Scriven, 1989. Use of NAA to inhibit sprouting in sweet potatoes (*Ipomea batatas*). *Journal of the Science of Food and Agriculture*, 48, 421–427.
6. Lewthwaite, S.L. and C. M. Triggs, 1995. Sprout suppression in sweetpotato roots following immersion in sodium hypochlorite solutions. *New Zealand Journal of Crop & Horticultural Science*, 23, 283–287.
7. Bao, J., Z. Ao, and J. I. Jane, 2005. Characterization of physical properties of flour and starch obtained from gamma- irradiated white rice. *Starch/Starke*, 57: 480–487.
8. Lu, J.Y., S. White, P. Yakubu and P. A. Loretan, 1986. Effects of gamma radiation on nutritive and sensory qualities of sweetpotato storage roots. *J. Food Qual.* 9:425-435.
9. Wall, M.M., 2004. Compositional and sensory analyses of Hawaii-grown sweetpotatoes after x-ray irradiation quarantine treatment. *HortScience* 39:574-577.
10. Hallman, G. J., 2001. Ionizing irradiation quarantine treatment against sweetpotato weevil (*Coleoptera: Curculionidae*). *Fla. Entomol.* 84:415-417.

11. Schoch, T.J., 1964. Swelling Power and Solubility of Granular Starches. In *Methods of Carbohydrate chemistry*, Vol 4. Academic Press, New York: pp. 106-108.
12. Beuchat, L.R., 1977. Functional and electrophoretic characteristics of succinylated peanut flour protein. *J. Agric. Food Chem.* 25: 258 – 261.
13. Narayana, K. and M. S. Narasinga Rao, 1984. Effect of partial proteolysis on the functional properties of winged pea (*Psophocarpus tetragonolobus*) flour. *J. Food Sci.* 49: 944 - 947.
14. A.O.A.C., 1990. Official methods of analysis. 15th edn. Washington, D. C. Association of Official Analytical Chemists.
15. American Association of Cereal Chemists, 2000. Approved methods of the AACC. Method 02-52.
16. Rosenthal, I., 1992. *Electromagnetic Radiations in Food Science*. Springer-Verlag, USA: pp 1-19.
17. Andri a, C., C. Bertolini, C. Mestres and P. Colonna, 2000. Rheological properties of acidified and UV-irradiated starch. *Starch/Starke*. 52: 340-344.
18. French, D., 1984. Organization of starch granules. In: *Starch: chemistry and technology*. London, Academic press Inc.: pp. 183-247.
19. Abu, J.O., K. G. Duodu and A. Minnaar, 2006. Effects of γ -irradiation on some physico-chemical and thermal properties of cowpea (*Vigna unguiculata* L. Walp) starch. *Food Chemistry* 95: 386–393.
20. Radley, J.A., 1960. The effect of irradiation by high energy cathode rays on starch. *Starch/Starke*. 7: 201.
21. Duarte, P. R. and J. H. Rupnow, 1994. Gamma-irradiated dry bean (*Phaseolus vulgaris*) starch: physicochemical properties. *J. Food.Sci.* 59(4): 839-843.
22. Oladebeye, A. O., A. A. Oshodi and A. A. Oladebeye, 2009. Physicochemical Properties of Starches of Sweet Potato (*Ipomea batata*) and Red Cocoyam (*Colocasia esculenta*) Cormels. *Pakistan Journal of Nutrition* 8 (4): 313-315, 2009.
23. Moorthy, S.N., 2002. Physicochemical and Functional Properties of Tropical Tuber Starches: A Review. *Starch/Starke* 54 : 559–592.
24. Tian, S. J., J. E. Rickard and J. M. V. Blanshard, 1991. Physicochemical properties of sweet potato starch. *J. Sci. Food Agric.* 57, 459-491.
25. Lii, C-Y. and S-M. Chang, 1978. Studies on the starches in Taiwan, 1. Sweet potato, cassava, yam and arrowroot starches. *Proc. Natl. Sci. Coun. Republic of China* 2, 416-423.
26. Takeda, Y., N. Tokunaga, C. Takeda and S. Hizukuri, 1986. Physicochemical properties of sweet potato starches. *Starch/Starke* . 38, 345-350.
27. Garcia, A. M. and W. M. Walter, 1998. Physico-chemical characterization of starch from Peruvian sweet potato selections. *Starch/Starke* , 50, 331-337.
28. Tsakama, M., A. M. Mwangwela, T. A. Manani and N. M. Mahungu, 2010. Physicochemical and pasting properties of starch extracted from eleven sweetpotato varieties. *African Journal of Food Science and Technology*. Vol. 1(4) pp. 090-098.
29. Adebowale, K., B. Owolabi, O. Olayinka and O. Lawal, 2005. Effect of heat-moisture treatment and annealing on physicochemical properties of red sorghum starch. *Afr. J. Biotechnol.* 4: 928-933.
30. Chen, Z., H. Schols and A. Voragen, 2003. Physicochemical properties of starches obtained from three varieties of Chinese sweetpotatoes. *J. Food Sci.* 68: 431-437.
31. Falade, K. O., E. Ighraywe and S. S. Ikoyo, 2011. Physico-chemical characteristics of non-irradiated and γ -irradiated yams cultivars (*Dioscorea rotundata*, *Dioscorea alata*) and sweet potato (*Ipomoea batatas* (L) Lam). *Int. J. Food Sci. & Tech.* 46: 1186–1193.
32. Bachman, S., A. Gambus and A. Nowotna, 1997. Effect of gamma: radiation of some physicochemical properties of triticale starch. *Polish Journal of Food Nutrition Science*, 6, 31–39.
33. Bao, J., Q. Shu, Y. Xia, C. Bergman and A. McClung, 2001. Effects of gamma irradiation on aspects on milled rice (*Oryza sativa*) end- use quality. *Journal of Food Quality*, 24, 327–336.
34. Maziya-Dixon, B., A. G. O. Dixon and A. A. Adebowale, 2004. Targeting different end uses of cassava: genotypic variations for cyanogenic potentials and pasting properties. A paper presented at ISTRC-AB Symposium, 31 October–5 November 2004, Whitesands Hotel, Mombassa, Kenya.
35. Maziya-Dixon, B., L. O. Sanni, A. A. Adebowale, O. O. Onabanjo and A. G. O. Dixon, 2005. Effect of variety and drying methods on proximate composition and pasting properties of high quality cassava flour from yellow cassava roots. In *Proceedings of the African Crop Science Society Conference, Enttebe, Uganda*, 5–9 December.
36. Newport Scientific, 1995. *Operation Manual for the Series 4 Rapid Visco Analyzer*. Pp. 93–95. Australia: Newport Scientific Pty, Ltd.
37. Ezekiel, R., G. Rana, N. Singh and S. Singh, 2007. Physicochemical, thermal, and pasting properties of starch separated from γ -irradiated and stored potatoes. *Food Chemistry*, 105, 1420–1429.

38. Chung, H.-J. and Q. Liu, 2009. Effect of gamma irradiation on molecular structure and physicochemical properties of corn starch. *Food Chem.* 74 (5): C353-361.
39. Shimelis, E., M. Meaza and S. Rakshit, 2006. Physicochemical properties, pasting behaviour and functional characteristics of flours and starches from improved bean (*Phaseolus vulgaris* L) varieties grown in East Africa. *Agricultural Engineering International. CIGR ejournals*, FP 05015. Vol III.
40. Seog, H. M., Y. K. Park, Y. J. Nam, D. H. Shin and J. P. Kim. 1987. Physicochemical properties of several sweet potato starches. *Hanguk Nanghwa Hakhoechi* 30: 179-185.
41. Aina, A.J., K. O. Falade, J. O. Akingbala and P. Titus, 2009. Physicochemical properties of twenty-one Caribbean sweet potato cultivars. *International Journal of Food Science and Technology*, 44, 1696–1704.