Effect of gamma irradiation on pasting characteristics and resistant starch levels of starches from locally-improved cassava accessions


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The purpose of this study was to determine the effects of gamma irradiation on pasting characteristics and resistant starch (RS) levels of starches from some locally-improved cassava accessions. Three cassava accessions were collected from Ministry of Food and Agriculture-Root and Tuber Section at Pokuase, Accra, Ghana. Approximately, 10 kg of each accession was used for the starch extraction. Samples were irradiated at 0 (Control), 5, 10, 15 and 20 kGy. Pasting characteristics and RS levels of starch samples were evaluated. “Ankrah” recorded the highest RS levels (58.24 to 69.97%) amongst the three improved cassava starch accessions with TME 419 having the least RS content. Irradiation significantly (p < 0.05) affected RS content, with the highest RS content obtained at 10 kGy absorbed dose. “Bosome Nsia” recorded the highest levels of non-resistant starch (NRS) content (47.56 to 63.16%) with values increasing gradually with increasing irradiation dose. Gamma irradiated modified “Ankrah” starch had the lowest gelatinization temperature, lowest maximum viscosity and highest setback and breakdown viscosities implying a good substitute to be used in food preparations.

Key words: Cassava starch, modification, gamma irradiation, resistant starch, pasting characteristics.

INTRODUCTION

Cassava (Manihot esculenta) is produced throughout the tropical regions of the world and either consumed as a fresh vegetable root crop or processed into flour or fermented food products, providing mostly carbohydrate in the form of starch. In Ghana, agriculture is currently the third contributor to the Gross Domestic Product (GDP), accounting for about 22.0% (GSS, 2014) with the crop sub-sector making up about 66.2% of the total agricultural production (Statistics, Research and Information Directorate of Ghana’s Ministry of Food and Agriculture [SRID, MoFA], 2011). Cassava is rated as one of the important staples in Ghana as it ranks second...
to maize in terms of production quantities. Although cassava starch can have a lot of economic importance to the food industry, direct utilization in the food industry is limited. For instance, due to the fact that cassava starch has no expansion ability, it is not utilized as much in bakery products (bread or biscuits making) as it is with wheat starch. Generally, food starches may be classified as either glycemic or resistant for nutritional purposes. Glycemic starches are those that are degraded to glucose by enzymes in the digestive tract and can be further categorized as either rapidly digestible starch (RDS, digested within 20 min) or slowly digestible starch (SDS, digested between 20 and 120 min). Resistant starches (RS) however are the portion of starch that escapes digestion in the small intestines of healthy individuals. In resisting digestion in the small intestine, RS like dietary fiber, becomes available as substrate for fermentation by anaerobic bacteria in the colon (Muir and O'Dea, 1992). RS is also considered as the third type of dietary fibre as it can deliver some of the benefits of insoluble and soluble fibre.

In recent years, great emphasis is placed on the relationship between health, lifestyle and diet. Hence, consumers are becoming more and more aware of the importance of dietary fibre and of their own personal fibre gaps. RS has a role to play with regards to the nutritional benefits of fibre fortification. They occur naturally in many unprocessed foods. RS have similar physiological role compared to fiber, this includes the ability of RS to increase stool wet weight and the excretion of fecal short chain fatty acids (SCFAs) metabolites (Waring, 1998). There is also the lowering of fecal pH and significantly increase in the daily excretion of butyrate, the putative markers of colonic health in humans (Cummings et al., 1996; Phillips et al., 1995). As a major ingredient in foods, starch confers structure, texture, consistency and appeal to many food systems. Also, the natural occurrence of starch in large quantities in cassava roots renders it favourable for industrial use, wherein modification of its structure and physicochemical properties can be exploited for beneficial applications (Bertolini, 2010).

In the food industry, starches are physically, chemically or enzymatically modified to alter their structure to enhance and extend their applications. Radiation is a very convenient tool for polymer material modification through degradation, grafting and cross-linking. In a research to determine the effect of gamma irradiation on the physicochemical properties of cross-linked waxy maize RS, Chung et al. (2010) reported that RS contents slightly decreased as the irradiation dose increased, whereas the RS content in unmodified waxy maize starch increased with an increase in irradiation dose. In a related study, Yoon et al. (2010) documented that, enzyme-RS portions increased in gamma irradiated corn starches with increase in irradiation dose (5 to 20 kGy). Certain food processing methods, such as retorting, baking, or drying at high temperatures, are known to slightly increase RS levels (Baghurst et al., 1996).

The main aim of starch modification is to improve the functionality of the starch for industrial application. For instance starches used in the food manufacturing industries are generally modified to enhance pasting characteristics (such as paste consistency, smoothness, and clarity), as well as to impart freeze-thaw and cold storage stabilities (Wu and Seib, 1990; Perera et al., 1997; Shi and BeMiller, 2000). This study therefore sought to determine the effects of gamma irradiation on pasting characteristics and RS levels of starches from some locally-improved cassava accessions.

**MATERIALS AND METHODS**

**Source of cassava roots**

Three cassava accessions, namely "Ankrah", "Bosome Nsia" and TME 419 were collected from the root and tuber section of the Ministry of Food and Agriculture (MoFA), Pokuase, Accra-Ghana. Cassava roots were transported immediately after harvesting to the laboratory for starch extraction.

**Extraction of starch samples**

Total starch content was determined using crude water method. About 10 kg of each accession was peeled, washed and chopped into slices using knife. The chopped roots were milled using a disc attrition mill (Hormeku Engineering Company Ltd., Ghana). The milled cassava pastes were reconstituted with about 25 L of clean tap water for crude starch extraction using a laboratory sieve of 250 µm mesh (DIN 4188, Prüf-sieb) under the influence of gravity and shaking. The starch suspension was allowed to settle for approximately 45 min to enable the starch settle to the bottom of the containing plastic buckets. The supernatant water was decanted leaving the starch paste. The starch paste was scraped onto aluminum drying trays and sent into a solar dryer of the Root and Tuber Development Unit of Food Research Institute (FRI), Pokuase, Ghana. The starch samples were allowed to dry for approximately 72 h, after which they were collected and packaged in labeled zipped bags and stored at ambient temperature for further analyses.

**Gamma irradiation of cassava starches**

About 500 g of dried starches were packaged in low density polyethylene bags and irradiated at doses of 0 (Control), 5, 10, 15 and 20 kGy with a dose rate of 2.087 kGy/h, using 60Co gamma source, Gamma Irradiation Facility (GIF) of the Ghana Atomic Energy Commission (GAEC). The absorbed dose was determined by using lithium fluoride photo-fluorescent film dosimeter (SUNNA Dosimeter System, UK). Gamma irradiation treatment was done three times.

**Determination of resistant and digestible starches**

Megazyme RS assay procedure kit, K-RSTAR 05/2008 (Megazyme International Ireland Ltd., Wicklow, Ireland), standard procedures based on AOAC Method 2002.02 (AOAC, 2002), and AACC Method 32-40 (AACC, 2000) were used to determine the total RS and non-resistant starch (NRS) contents in the cassava starches.
Pasting characteristics

The pasting properties of cassava starches were measured using Brabender Viscograph-E (Brabender GmbH & Co. KG, Germany). About 40 g of the sample (dry weight basis) was mixed in 420 ml distilled water to prepare slurry in a beaker. The slurry was then poured into the measuring bowl of the Brabender Viscograph-E and heated from 50°C at 3°C min⁻¹ up to a temperature of 92°C. The temperature was held constant for 15 min and then cooled at the rate of 3°C min⁻¹ to a temperature of 55°C. The viscosity profile indices recorded 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.

Statistical analysis

All measurements were done in triplicate with significant differences between means detected by Duncan’s multiple range tests (p < 0.05). Statistical analysis was performed using Statgraphics Centurion XVI.

RESULTS AND DISCUSSION

Resistant and non-starch content

RS content in “Bosome Nsia” ranged from 24.26 to 24.60% (Figure 1). RS contents of “Ankrah” were 62.21 and 58.24% for non-irradiated and irradiated (20 kGy) starch samples, respectively. TME 419 had RS contents of 20.59 and 38.26% for non-irradiated and irradiated (20 kGy) starch, respectively. “Ankrah” recorded the highest RS levels amongst the 3 improved cassava starch accessions with TME 419 having the least RS content (Figure 1). RS contents obtained in this study were found to be considerably lower compared to that reported by Megazyme International Ireland limited (2008), where RS values obtained were compared using several in vitro analytical methods to in vivo results. RS values recorded ranged from 66.5 to 83.0% for potato starch (native) and a range of 50.3 to 71.4% for native amylomaize starch for both methods. However, lower RS values (29.6 to 42.0%) were recorded for retrograded amylomaize starch.

In considering the effect of the absorbed dose on the RS content, the levels in “Bosome Nsia” gradually increased with increasing irradiation dose up to 15 kGy and then decreased. RS content in the “Ankrah” accession increased with increasing irradiation dose up to 10 kGy, then decreased gradually from 15 to 20 kGy. However, for the TME 419 accession, there was an increasing trend in the RS content with increasing absorbed dose. The RS contents obtained at the different levels of absorbed dose was found to be statistically significant (p < 0.05) for all the three improved cassava accessions (P = 0.020). In investigating the digestibility of gamma-irradiated corn starches, Yoon et al. (2010) reported that, gamma-irradiation (5 to 20 kGy) increased the proportion of both rapidly digestible (RDS) corn starch and enzyme-resistant corn starch (RS). Chung et al. (2010) also recorded an increase in RS content as irradiation dose increased up to 40 kGy, but a reduction with further increase in irradiation dose. Chung and Liu (2009) reported that the RS content of maize starch steadily increased up to an irradiation dose of 50 kGy. In both cases, the increase was attributed to possible formation of carboxyl groups during irradiation, resulting in the inhibition of enzyme attack. The increase in RS content of some accessions of irradiated cassava starches in the present study could be due to the formation of amylose-like molecules (short-chain
polymers) after gamma-irradiation of the starches, thus enhancing the RS contents of these starches (Lee et al., 2013).

The NRS contents obtained for “Bosome Nsia” were 47.56% for non-irradiated samples and 63.16% for irradiated (20 kGy) (Figure 2). “Ankrah” samples had NRS contents of 23.93% for non-irradiated (control) samples and 45.87% for 20 kGy irradiated samples. There was a gradual increase from the non-irradiated samples through to samples irradiated at 10 kGy. The levels then decreased in the case of both samples irradiated at 15 and 20 kGy. NRS levels in TME 419 were 28.61% for non-irradiated samples and 30.12% for 20 kGy samples. For TME 419, there was a gradual increase with increasing irradiation dose. The increase observed in the samples was all statistically significant (p < 0.05) for all the three cassava varieties. NRS levels in “Bosome Nsia” were the highest compared to the other two cassava starches.

**Pasting characteristics**

From the statistical analysis conducted, irradiation dose had a significant effect (p < 0.05) on the gelatinisation temperature of the various starch samples from the three cassava accessions. Gelatinization temperature ranged from 65.2 to 66.1°C (Table 1). Taggart (2004) reported a similar range for potato and tapioca starches (that is, 59 to 68°C and 62 to 73°C, respectively). These temperature ranges obtained could possibly make the starches from these accessions cook much faster and consume less energy as compared to varieties with much higher gelatinization temperatures. It was also noticed that varietal differences significantly affected the gelatinization temperature. The difference in the gelatinization temperatures among the varieties could be related to variations in the starch intermolecular bonds. High temperature of gelatinization can be an indication of the higher stability of the starch crystallites in the starch molecules, which means that more heating is required to swell the granules. Gelatinization temperature is the temperature at which the starch granules begin to swell to imbibe more water.

Maximum viscosity is measured as the highest value of viscosity attained by a paste during the heating cycle (50 to 95°C). From the results, maximum viscosity values ranged from 1,930.0±2.83 to 412.5±0.71 BU with irradiation having a significant (p < 0.05) effect on the maximum viscosity of all the three cassava accessions (Table 1). A general trend of maximum viscosity values decreasing with increasing irradiation doses was recorded. Graham et al. (2002) reported a similar trend in a similar study. “Bosome Nsia” recorded the highest maximum viscosity with “Ankrah” recording the lowest values for the various irradiation doses. In terms of the different accessions, a significant difference was recorded mainly between Ankrah and TME 419 as compared to Bosome Nsia. This difference could be probably due to differences in the amylose contents present in each of the starch sample. During the irradiation process, there was a breakdown of the starch intermolecular bonds causing the release of the amylose into the solution and affecting the viscosity. Oguntunde (1987) reported that the associative bonding of the amylose fraction is responsible for the structure and pasting behaviour of starch granules. MacArthur and D’Appolonia (1984) recorded a decrease in maximum viscosity when the effect of low dose gamma irradiation on the starch properties of wheat cultivars was examined.
and this decrease in maximum viscosity was attributed to the molecular degradation of the starch granules. The breakdown viscosity values ranged from 1.358±4.24 to 340.5±0.71 BU, with samples irradiated at 0 kGy having the higher values, whilst those irradiated at 20 kGy had lower values (Table 1). Breakdown viscosity was significantly (p < 0.05) affected by both irradiation doses given and the various accessions. Although “Ankrah” recorded the highest breakdown viscosity before irradiation, it had the least breakdown viscosity value when irradiated at 20 kGy. Generally, breakdown viscosity values decreased with increased radiation dose. El Saadany et al. (1974) also reported a sharp decrease in breakdown viscosity with increasing irradiation dose when the effect of gamma irradiation on rice starch was evaluated. Breakdown viscosity is regarded as a measure of the degree of disintegration of the swollen granules or paste stability. The decrease in breakdown viscosity values of the irradiated starch samples implies that the paste is more resistant to shear thinning during cooking, that is, higher hot paste stability (Qian and Khun, 1999). Adebobale et al. (2005) reported that the higher the breakdown viscosity, the lower the ability of the sample to withstand heating and shear stress during cooking. This implies that, the irradiated starch samples might be able to withstand heating and shear stress as compared to the un-irradiated or native starch samples.

Irradiation significantly (p<0.05) affected the setback viscosity of the various starches. There was a general decrease of the setback viscosity values as radiation dose increased. “Control samples of Ankrah” had the highest setback viscosity (292±7.07 BU) decreasing to 44.0±0.00BU for those samples irradiated at 20Gy (Table 1). TME 419 had the least setback viscosity at the various doses (Table 1). Varietal differences did not significantly (p>0.05) affect the setback viscosity of the irradiated samples, but significantly (p<0.05) affected the setback viscosity of the control samples. Setback viscosity is an important factor for starches used as food ingredient in processing and preservation, because the quality of the food texture and physical properties deteriorate with time due to retro-gradation (Nunoo, 2009). When starch is heated in water, certain characteristic changes occur. During cooling of the hot paste, there is initial sharp decrease which is followed by an increase in viscosity, viscosity increases again to a more or less constant value known as setback. Shelton and Lee (2000) described setback viscosity as a measure of gelling ability or the retrogradation tendency of starches after heating in water. That is, the lower the setback viscosity, the higher the resistance to retrogradation. Results obtained from this study is

Table 1. Pasting characteristics of three cassava accessions at different irradiation doses.

<table>
<thead>
<tr>
<th>Dose (kGy)</th>
<th>Accessions</th>
<th>Gelatinization temperature (°C)</th>
<th>Maximum viscosity (BU)</th>
<th>Breakdown viscosity (BU)</th>
<th>Setback viscosity (BU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Ankrah</td>
<td>66.1±0.14^a</td>
<td>1930.0±2.83^e</td>
<td>1358.0±4.24^e</td>
<td>292.0±7.07^b</td>
</tr>
<tr>
<td></td>
<td>Bosome Nsia</td>
<td>65.9±0.07^ab</td>
<td>1885.0±8.49^d</td>
<td>1325.5±10.61^cE</td>
<td>265.0±4.14^b</td>
</tr>
<tr>
<td></td>
<td>TME 419</td>
<td>65.2±0.07^ac</td>
<td>1652.0±16.97^e</td>
<td>1122.0±11.31^cE</td>
<td>262.5±4.95^d</td>
</tr>
<tr>
<td>5</td>
<td>Ankrah</td>
<td>66.1±0.07^a</td>
<td>998.0±5.66^d</td>
<td>719.5±4.95^d</td>
<td>105.0±22.63^b</td>
</tr>
<tr>
<td></td>
<td>Bosome Nsia</td>
<td>65.8±0.07^ac</td>
<td>1179.0±86.27^c</td>
<td>840.0±8.49^cD</td>
<td>67.5±31.82^A</td>
</tr>
<tr>
<td></td>
<td>TME 419</td>
<td>65.2±0.14^a</td>
<td>1046.0±5.66^vd</td>
<td>777.0±2.83^d</td>
<td>105.0±4.24^c</td>
</tr>
<tr>
<td>10</td>
<td>Ankrah</td>
<td>66.0±0.00^a</td>
<td>632.0±5.66^c</td>
<td>488.0±2.83^c</td>
<td>67.5±4.95^a</td>
</tr>
<tr>
<td></td>
<td>Bosome Nsia</td>
<td>65.8±0.00^AB</td>
<td>719.5±14.85^R</td>
<td>552.0±14.44^c</td>
<td>60.5±3.54^A</td>
</tr>
<tr>
<td></td>
<td>TME 419</td>
<td>65.6±0.07^BC</td>
<td>763.5±0.71^ZC</td>
<td>595.5±0.71^Xc</td>
<td>60.0±1.41^B</td>
</tr>
<tr>
<td>15</td>
<td>Ankrah</td>
<td>66.1±0.07^a</td>
<td>528.0±4.24^GB</td>
<td>420.0±1.41^B</td>
<td>57.5±7.78^A</td>
</tr>
<tr>
<td></td>
<td>Bosome Nsia</td>
<td>66.1±0.00^C</td>
<td>634.0±11.31^R</td>
<td>496.5±12.02^B</td>
<td>55.5±2.12^A</td>
</tr>
<tr>
<td></td>
<td>TME 419</td>
<td>65.6±0.00^C</td>
<td>658.5±0.71^R</td>
<td>520.0±2.83^B</td>
<td>48.5±2.12^AB</td>
</tr>
<tr>
<td>20</td>
<td>Ankrah</td>
<td>66.1±0.00^A</td>
<td>412.5±0.71^A</td>
<td>340.5±0.71^A</td>
<td>44.0±0.00^A</td>
</tr>
<tr>
<td></td>
<td>Bosome Nsia</td>
<td>65.4±0.07^BC</td>
<td>457.5±12.02^A</td>
<td>380.5±7.78^A</td>
<td>43.0±2.83^A</td>
</tr>
<tr>
<td></td>
<td>TME 419</td>
<td>65.9±0.00^AB</td>
<td>581.0±9.90^A</td>
<td>471.5±7.78^A</td>
<td>41.0±8.49^A</td>
</tr>
</tbody>
</table>

Values are means of triplicate readings with a standard deviation. Mean values in a column among the various accessions within a particular dose with the same superscript (x, y, z) were not significantly different (p>0.05) from one another. Mean values of accessions in a column across the various doses with the same superscript (A, B, C, D, E) were not significant p>0.05 from one another.
comparable to that reported by Yu et al. (1999), where lower setback viscosities were reported for irradiated starches as compared to the native starches. Sanni et al. (2001) also reported that lower setback viscosities recorded during cooling indicated higher resistance to retrogradation. It was also established by Pomeranz (1991) that higher setback viscosities would cause undesirable gel texture or high syneresis (the leakage of water) and low freeze-thaw stability.

Conclusions

Starches from the local cassava accessions have varied content of RS, with “Ankrah” having the highest RS content when compared with the other two accessions worked on. Gamma irradiation caused significant reductions in pasting viscosities of the starches. The considerable amount of RS in the starches from the cassava accessions used in this study suggests their potential in low glycemic index (GI) foods. The low viscosities recorded by the gamma-irradiated starches indicate their suitability in complementary or composite foods for children.

Conflict of Interests

The authors have not declared any conflict of interests.

REFERENCES