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Research Article

# Relationship between the physicochemical properties of starches and the glycemic indices of some Jamaican yams (*Dioscorea* spp.)

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Starch granules from round leaf yellow yam (RY), Lucea yam (LY), white yam (WY), and Chinese yam (CY) grown in Jamaica were isolated and the relationship between starch amylose content, crystallinity, microscopic properties, *in vitro* digestibility, and the glycemic index (GI) of the tubers was investigated. The results indicate that RY had the highest amylose content (265.30 ± 0.09 g/kg starch) while CY the lowest (111.44 ± 0.03 g/kg starch). A corresponding variation in starch digestibility and GI was also observed, as CY which had the highest *in vitro* digestibility had the highest GI (21.27 ± 0.01 and 97.42 ± 0.62%, respectively), while RY, LY, and WY starches with low digestibility had lowest GI. Differences in the crystalline pattern of the different starches were observed, where RY, LY, and WY displayed the type B crystalline pattern while CY had the intermediate crystallite (type C).

**Keywords:** Amylose / *Dioscorea* spp. / Glycemic index / Starch / Yam

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## 1 Introduction

Yams form a prestigious component in the diet of millions of the world's population in Africa, Southeast Asia, the Pacific, and the Caribbean as a primary source of digestible carbohydrates [1]. There are over 20 cultivars of edible yams grown in Jamaica, belonging to five cultivated species, namely: *Dioscorea rotundata*, *D. alata*, *D. cayenensis*, *D. trifida*, and *D. esculenta*.

Starch is the major carbohydrate reserve in yam tubers, accounting for up to 85% of the dry weight matter [2], where it is normally found as granules, typically consisting of amylose (10–30%) and amylopectin (70–90%) molecules. Starches extracted from Jamaican yams have shown significant variations in their physical and chemical properties [3]. These differences in the starches physicochemical properties often tend to illicit variations in functional characteristics such as digestibility and crystallinity [3]. The variations in starch properties and botanical origin have also been shown to impact on the metabolic effects and the susceptibility of starch to α-amylase digestion [4]. The degradability of starch when consumed is of importance especially to diabetic and hyperlipidemic individuals [5]. Starches which are easily degraded tend to have a higher insulin demand than the slower degrading starches [5]. Bornet *et al*. [4] reported that the co-ingestion of other carbohydrates, protein, fat, and dietary fiber in mixed meals as well as digestibility of food may influence blood glucose and insulin responses. On the other hand, the effect of starchy foods on blood glucose and insulin responses may vary significantly due to the materials intrinsic properties [4].

Glycemic index (GI) is a classification of the blood glucose-raising potential of foods relative to glucose [6]. Earlier work of Bornet *et al*. [7] on starch rich foods consumed as part of an isoglucosidic, isolipidic, or isoproteinic mixed meal showed differences in the glycemic and insulinemic responses. The differences observed were attributed not only to the fiber content of the food but also to the botanical origin of the different starches. The digestibility of starches and their effect on the GI of the corresponding food have been shown to depend on a number of factors such as the amylose and amylopectin content [8] and particle size [9].

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**Abbreviations: CY,** Chinese yam; **GI,** glycemic index; **LY,** Lucea yam; **RY,** round leaf yellow yam; **WY,** white yam

Significant differences in physicochemical properties of yam starches [3] as well as in the GIs of different West Indian foods [10] have been reported. However, the relationship between the starch properties and GI in the tubers studied remain to be explored. This study was designed to investigate such relationship.

## 2 Materials and methods

### 2.1 Yam samples

Mature tubers of *D. cayenensis*, cultivar (cv), round leaf yellow yam (RY), *D. alata* cv. white yam (WY), *D. rotundata* cv. Lucea yam (LY), and *D. esculenta* cv. Chinese yam (CY) were collected from a local farm in St. Ann, Jamaica. Samples of tubers and aerial parts of the plants were submitted for identification by botanist at the University of the West Indies (Mona Campus, Kingston, Jamaica) and confirmed with herbarium specimens.

### 2.2 Starch isolation

Starch was extracted by the method of Moorthy and Nair [11] with modifications. Freshly harvested yam tubers (100.0 g) were peeled and homogenized with 1 M NaCl (900.0 mL) solution using a Waring commercial blender (Waring Products Inc, USA). The mixture was filtered through triple layered cheesecloth and starch washed through with water. The granules were allowed to settle, water was decanted followed by centrifugation at 5000 rpm for 10 min. The starch was allowed to air-dry overnight.

### 2.3 Determination of apparent amylose content

The apparent amylose content was determined by the method of Farhat *et al.* [12] with modifications. Starch (500.0 mg) was defatted by standard AOAC (2000) methods using hexane. Defatted starch (100.0 mg) was dispersed in ethanol (1.0 mL) and 1 M NaOH (9.0 mL). The volume was made up to 100.0 mL with distilled water and a 5.0 mL aliquot transferred to a volumetric flask containing water (25.0 mL). Acetic acid (0.5 mL) and iodine solution (1.0 mL) were added, the volume made up to 50.0 mL with water and absorbance recorded at 620 nm.

### 2.4 Determination of percentage digestibility

Percentage digestion was determined by the method of Hassan and West [13] with modifications. Starch (10 mg) was suspended in porcine pancreatic α-amylase solution (5 mL enzyme, approximately 30 unit/mg starch), buffered with 0.05 M citric acid/sodium acetate buffer pH 5.5, and 0.02% $CaCl_2$. Samples were incubated for 24 h at 40°C and reaction stopped by addition of 1 mL of a 1 M NaOH solution, followed by centrifugation at 500 × *g* for 10 min. The extent of hydrolysis was calculated from the amount of reducing sugar liberated, which was determined as outlined by Nelson [14].

### 2.5 Determination of starch crystalline properties

Starches were stored over saturated $CuSO_4$ solution (50–55% RH) at ambient temperature for 2 wk. X-ray spectra were recorded with 2θ angles, 4–38° with step size of 0.005° at 25°C using a Bruker D5005 X-ray diffractometer. Potato, corn, and pea starches were used as standards.

### 2.6 Microscopic studies of starch granules

Starch for scanning electron microscopic studies were sieved using a number 60 Fisher sieve, mounted, and coated with gold (1 nm) using a Polaron sputter coater and analyzed using a Bruker scanning electron microscope at a magnification of $3.26 \times 10^2$ for RY, LY, and WY. CY starch was viewed at a magnification of $1.32 \times 10^3$ due to the small size of the granules. Sieved starch granules were suspended in water and 500 granules measured with a Nikon SMZ-10 light microscope equipped with a graticulated eyepiece. Projected mean granule diameter was calculated by averaging the diameter of 500 starch granules [15].

The specific surface area of starch granules was calculated by using the equation for a spherical particle [15].

### 2.7 Determination of tuber proximate composition

The proximate composition of the yam tubers were determined by the standard AOAC [16] methods and the available carbohydrate content calculated by difference [17–19]. Crude fat, fiber, ash, protein, and moisture contents were determined as outlined in methods 920.39, 962.09, 942.05, 976.05, and 930.15, respectively.

### 2.8 Determination of GI

The GI of the foods was determined in the boiled state. Firstly, the inedible portions of the tuber crops were removed and discarded. The edible portions were washed and allowed to air-dry at room temperature for 10 min. They were then cut into chunks of approximately 25 mm and were gently boiled with the lid of the cooking vessel on for 20 min, followed by simmering heat and the lid off for a further 10 min. After the boiling process, the available carbohydrate content was established, to assess the loss of carbohydrate that may have occurred by leaching. The foods were then cut into 50 g available carbohydrate portions, which were required for GI analysis.

The 50 g available carbohydrate portions of the different yam tubers were then fed to ten healthy nondiabetic subjects with BMI ranging from 21.63 to 27.26 $kg/m^2$ and ages from 18 to 40 years after a 10–12 h overnight fast. The yam tubers were consumed over a 7 min time period and capillary blood samples taken (3–4 drops) at 0 min (baseline) followed by 15, 30, 45, 60, 90, and 120 min after consumption of the test food [19]. Blood samples were collected into heparin tubes and stored at –20°C before glucose analysis by glucose oxidase method using an UV/Vis Ultraspec spectrophotometer (Model 1100 pro). GI was calculated by expressing the glycemic response area for the test foods as a percent of the mean response area of the reference food taken by the same subjects [19, 20]. Pure glucose was used as the reference food with a GI assumed to be 100 and was tested in all the subjects, at the beginning, middle, and end of the study [18]. All subjects were appraised verbally and in writing of the study protocol and all gave written informed consent. Ethical Committee approval was obtained prior to start of study.

### 2.9 Statistical analysis

Experimental data obtained were evaluated using the one-way ANOVA Duncan's *t*-test ($p < 0.05$).

## 3 Results and discussion

The amylose content of the starches differed significantly among the yam varieties studied ($p < 0.05$). Starch from RY was found to have the highest apparent amylose content, while CY had the lowest (Table 1).

The difference in amylose content observed may be attributed to genetic variations among the cultivars. It has been postulated that the amylose content of starches may be affected by the expression of the amylose extender gene which is believed to be responsible for the synthesis of amylose in cereals [21].

RY, LY, and WY were found to exhibit the open hydrated hexagonal crystalline pattern (type B), while CY had an intermediate crystalline form (type C) which is believed to be a composite of the type A and type B forms (Table 2, Fig. 1). Padmanabhan and Lonsane [22] and Parker and Ring [23] have shown that starches with high amylose/low amylopectin content tend to possess the type B structure, while those with low amylose/high amylopectin contents are of either the type A or the intermediate type C form. This is further supported by the results from this study as the type C crystalline pattern found in CY corresponded to a low amylose content, while the type B structure found in RY, LY, and WY corresponded to high amylose contents.

**Table 1.** Percentage *in vitro* digestibility and amylose content of yam starches and the corresponding GI of the tubers

| Yam cultivar | *Amylose content (g/kg) | *Hydrolysis (%) | **GI |
|---|---|---|---|
| RY | $265.31 \pm 0.09^d$ | $13.74 \pm 0.03^d$ | $68 \pm 3^b$ |
| LY | $216.01 \pm 0.02^c$ | $14.75 \pm 0.08^c$ | $74 \pm 7^c$ |
| WY | $203.44 \pm 0.03^b$ | $15.55 \pm 0.01^b$ | $75 \pm 6^c$ |
| CY | $111.41 \pm 0.03^a$ | $21.27 \pm 0.01^a$ | $97 \pm 10^a$ |

Mean ± SEM (*$n$=6, **$n$=10). Figures in columns sharing the same superscript are not significantly different ($p < 0.05$).

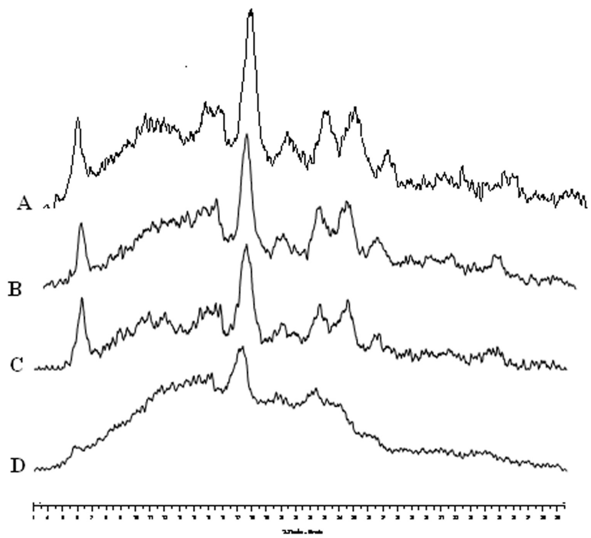


**Figure 1.** X-ray diffraction patterns of (A) RY, (B) LY, (C) WY, and (D) CY.

**Table 2.** Granule size, granule shape, and crystalline form of different yam starches

| Yam cultivar | Granule diameter (μm) | | Granule shape | Crystalline form |
|---|---|---|---|---|
| | Diameter range | Mean Diameter | | |
| RY | $24.51–48.50^d$ | $34.50^d$ | Ellipsoid | B |
| LY | $16.51–42.10^c$ | $30.60^c$ | Ellipsoid | B |
| WY | $18.10–40.50^b$ | $27.33^b$ | Polyhedral | B |
| CY | $1.11–11.21^a$ | $5.41^a$ | Round | C |

Figures in columns sharing the same superscript are not significantly different ($p < 0.05$).

Microscopic analyses of the starch granules showed differences in granular size and shape among the yam varieties studied (Table 2, Fig. 2). Those of RY and LY were ellipsoid in shape with mean granular diameters of 35.5 and 30.6 μm, respectively while CY displayed rounded starch granules with a mean diameter of 5.4 μm. The specific surface area of the different yam starches was found to be directly proportional to the mean diameter of the starch granules. CY starch was found to have the largest specific surface area while RY had the least (Table 3). Variations were also observed in the granule mass and number of granules *per* gram starch. CY starch was found to have the lowest granule mass and the largest number of granules *per* gram starch while RY starch had the largest granule mass and lowest number of granules *per* unit mass. The results

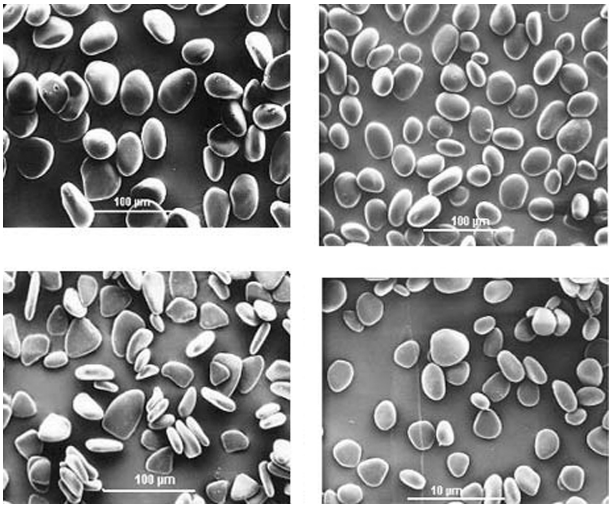


**Figure 2.** Scanning electron micrographs of (A) RY, (B) LY, (C) WY, and (D) CY.

**Table 3.** Specific surface area, granule mass, and number of granules *per* unit mass

| Yam cultivar | Specific surface area ($m^2$/kg) | Granule mass ($g \times 10^{-10}$) | Number of granules/g starch ($10^7$) |
|---|---|---|---|
| RY | 117.401$^d$ | 340.012$^d$ | 2.899$^d$ |
| LY | 130.611$^c$ | 230.001$^c$ | 4.317$^c$ |
| WY | 140.853$^b$ | 170.003$^b$ | 5.714$^b$ |
| CY | 626.911$^a$ | 1.612$^a$ | 621.301$^a$ |

Figures in columns sharing the same superscript are not significantly different ($p < 0.05$).

also indicate some level of correlation between granule size and the amylose content, as starches with smaller granules tend to have low amylose content.

CY starch was found to be the most easily digested under *in vitro* conditions while RY, LY, and WY starches were the least susceptible to α-amylase digestion (Table 1). The results showed that the percentage digestibility of the starches increased with decrease in granular size and amylose content. Starch with small granules tends to have a higher specific surface area and a larger number of granules *per* unit weight thereby increasing the area of contact thus making them more easily accessible to enzymatic degradation than those with larger granules.

The crystalline patterns observed may have contributed to the digestibility of the starches, as it was found that the type C starch was more digestible than the type B. This could be due to the amylose content of the starches as it has been reported that starches with low amylose contents are more crystalline and thus more digestible, while starches with high amylose contents are more amorphous and are less susceptible to enzymatic degradation [24]. It was also reported that the metabolic effects and the *in vitro* susceptibility of starch to α-amylase depend on the botanical origin and the properties of the starch [4].

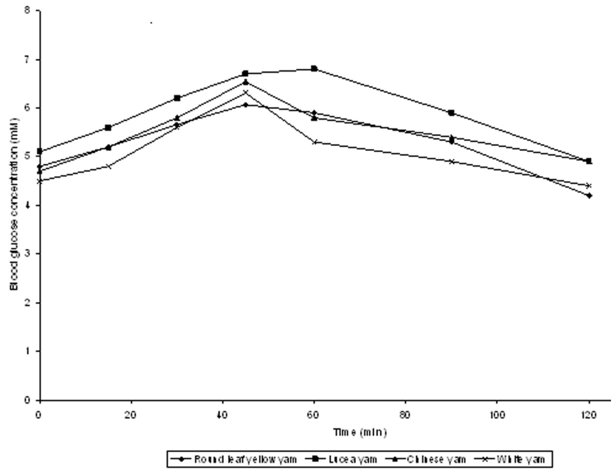


**Figure 3.** Incremental plasma glucose responses of the different yam tubers within 120 min.

The GI of the yam tubers differed significantly (Table 1). A direct relationship between the starch digestibility and GI was observed. CY was found to have the highest GI (97 ± 10), while RY had the lowest (68 ± 3). A corresponding variation in starch digestibility and GI was also observed where, CY starch with the lowest amylose content and digestibility had the highest GI, while RY, LY, and WY starches with higher amylose contents and lower digestibility had lower GIs relative to CY. Similar correlations between amylose content and GI have been reported for rice [17]. In practice, very few starches are consumed raw, however a relationship between raw and processed starches and glycemic response have been reported [4]. In this study, a similar relationship was observed between the properties of the raw starches and the GI and response of the corresponding yam tubers. Figure 3 shows the incremental postprandial plasma glucose concentration. RY tuber elicited the lowest increase in blood glucose, while CY exhibited the highest. LY was also observed to elicit the slowest glycemic response, with peak glucose concentration at 60 min of consumption as opposed to 45 min observed for the other tubers.

The results from this study implies that yam starches with high amylose content and low *in vitro* digestibility may be digested and absorbed at a slow rate, thereby releasing their product of digestion slowly as they pass through the digestive tract. Starches that are digested and absorbed at a slower rate could result in lower blood glucose responses, while those which are digested and absorbed at a faster rate could produce large increases in the blood glucose, which may necessitate greater insulin and other endocrine responses when ingested [20, 5]. The results from this study are in correlation to this theory as starches from CY, which had a high *in vitro* digestibility had a greater blood glucose response than those of RY, LY, and WY which had lower digestibility. The results from this study also suggest that CY is a high glycemic food, RY is ranked as low, and WY and LY are ranked as intermediate glycemic foods and as such, one should be careful when recommending diets consisting of yams for diabetic individuals.

## 4 Concluding remarks

The *in vitro* digestibility of the raw yam starches is significantly affected by the amylose content, granular size, and the crystallinity of the starch granules. Yam starches with small mean diameters, high specific surface area, low amylose contents, and of the type C crystalline form were the most digestible *in vitro*. The GIs of the different yam tubers is affected by the physiochemical properties of the native starches and were found to be related to the *in vitro* digestibility of the starch.

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*The authors have declared no conflict of interest.*

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