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Research Article

Evaluation of the physico-chemical properties of cassava, cocoyam, sweet potato starches and glucose syrups produced from the hydrolysis of the starches with sorghum malt enzyme extract

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Abstract
Some physicochemical properties of starches from cocoyam, cassava and sweet potato were compared for suitability in glucose syrup production. Glucose syrups were produced from the starch slurry using 30 g of sorghum malt per 250 g starch weight. Malts were produced from Nigerian sorghum varieties; SFF-Sorghum 'Farafara' and SFD-Sorghum 'Farindawa' (*Sorghumbicolor* L. Moench). The grains were steeped for 24 h with 8 h air rest and germinated for 96 h. Results showed that malted SFD and SFF-sorghum grains recorded diastatic powers (61.45 and 52.32 DU.g^{-1}), α-amylase (38.19 and 43.3 DU.g^{-1}) and β-amylase (14.13 and 18.15 DU.g^{-1}) activities, respectively. Cocoyam starch contained highest amylose (28.20%) when compared with sweet potato starch (22.50%) and cassava starch (20.40%). Solubility and swelling power of cassava, sweet potato and cocoyam starches were 17.2, 16.5 and 15.3 g.g^{-1} and 9.6, 6.2 and 7.6% at 90℃, respectively. Cocoyam starch showed the highest transition temperatures (69.5, 73.6, 82.3℃) and gelatinization enthalpy (17.3 J.g^{-1}) than sweet potato (67.4, 71.3, 78.4℃, 12.3 J.g^{-1}) and cassava (61.3, 65.5, 75.6℃, 13.4 J.g^{-1}) starches. Dextrose equivalent for cassava, sweet potato and cocoyam glucose syrups were 40, 36, 30. Cassava starch glucose syrup obtained from SFD-malt hydrolysis met most of the Standard Organization of Nigeria set specifications.

Keywords
root crops, diastatic power, alpha-amylases, dextrose equivalent, starch

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Introduction

Glucose syrup consists of aqueous solution of concentrated sugars; maltose, glucose and varying amounts of larger saccharides with different degrees of polymerization (Ojewumi et al. 2018). Higher levels of mono- and disaccharides content in the syrup impact more sweetness and higher Dextrose Equivalent (DE) value. DE is the amount of reducing sugars contained in the glucose and a measure in percentage of glycosidic bonds that have been hydrolyzed in starch (AIB 2012). The production of glucose syrup from starch through the action of enzymes involves basically four processes: liquefaction, saccharification, purification and concentration (Eshra et al. 2014). The proportion of different sugars in the syrup determines whether the sugar is maltodextrin, high maltose syrup, or high dextrose syrup. Various DE glucose syrups could be produced by manufacturers when enzyme technology and acid hydrolysis are combined.

Corn starch is traditionally used in glucose syrup production. In Nigeria, the level of glucose syrup manufacture is grossly insufficient, but its use in most industries is indispensable. It is used in pharmaceutical, brewery, bakery products, yogurt, fruit juice and confectionary (Harni et al. 2021). In cream fillings and chewy cookies, the lower 36-62 DE glucose syrups are used to add body and texture. Also, for fermentability and sweetness, the higher 62-95 DE are added (AIB 2012). Hydrolysis of edible starches with exclusively sorghum malt extracts produces high maltose syrups. As at 2016, Nigerian Sugar Development Council (NSDC) showed in the last decade's data that $5.1 million was the average yearly cost of glucose importation (Brandspur 2018). However, according to the forcasts made by the United States Department of Agriculture (USDA), the consumption of glucose in Nigeria increased from 70,000 tonnes/year in 2016/17 to about 80,000 tonnes/year in 2017/18 (Brandspur 2018).

The most important Nigerian food crops produce are tuber and root crops after cereals. Most important tropical roots and tubers remain underutilized sources of starch for the industry in various countries despite its richness in starch. Cocoyam (*Colocasia esculenta*), sweet potato (*Ipomoea batatas*), and cassava (*Manihot esculenta*) are important representatives (Oladipo 2017; Tunde 2020). Starch is a very useful and widely used raw material in industries. In the food industry, it is used as substitutes for more expensive ingredients as thickeners, stabilizers and gelling purposes (Omoreje 2020). The use of starch is favoured because of its availability, unique properties and is comparatively cheap (Watershoot 2015). Production of glucose syrup from starches of these root and tuber crops becomes economically expedient in an attempt to expand an existing market for the crops and in addition to reduce the importation of glucose syrups.

Barley grain is preferred for malting because of its outstanding malting qualities. However, in Nigeria and many other tropical countries, barley is not cultivated in adequate amount and is imported at high cost. Therefore, the need to look inward for a local substitute becomes imperative (Iwouno and Odibo 2015). Africa contributes largest sorghum production worldwide with approximately 29.7 million tons out of a total of 57 million tons (Adebo 2020; FAOATAT 2021). Two species of sorghum are widely known; *Sorghum vulgare* and *Sorghum bicolor* L. Moench. Nigeria in 2017 became second in sorghum production behind United States of America with the total output of 6.4 m metric tonnes while USA produced 8.4m metric tonnes (USDA 2018).

The aim of this study was therefore to determine the physicochemical properties of starches of local sweet potato, cocoyam, cassava and glucose syrups produced from the starches. Some properties of the starches were studied and compared with a view to determining the most appropriate functional applications in food systems suitable for sugar syrup industry. The properties of starches dictate their food applications. The paper also compared the malting and amylolytic potentials of two indigenous cultivars of sorghum during starch hydrolysis. Foreign exchange is consequently conserved by substituting locally available roots and tuber starches and sorghum malt extract enzyme for imported microbial enzymes in the sugar syrups production.

Materials and Methods

Source of materials. Freshly harvested Cassava (*Manihot esculenta* Crantz), Cocoyam (*Colocasia esculenta*), Sweet potato (*Ipomoea batatas*) and

Sorghum bicolor (SFF- Sorghum 'Farafara' and SFD-Sorghum 'Farindawa') were sourced from the Root and Tuber Crops Research Institute, Umudike and Cereals Research Institute, Umuahia, Abia State, Nigeria. The reagents were bought from Sigma Chemicals, USA and were of analytical grade.

Extraction of starch from root and tuber crops. The modified method of Yadav and Majumder (2017) was used for starch isolation from the fresh root and tuber crops. In the laboratory, the freshly harvested root and tuber crops were washed, peeled manually and chopped up. The cut pieces were homogenized in water with a blender (Model NO: HFB-3489). The resultant slurry was transferred into a beaker and potable water was sufficiently added. The particles were later filtered out by passing through a muslin cloth. Filtrate was separated after settling. The upper starch free supernatant was carefully decanted while the starch sediments at the bottom were collected and dried for 48 h in an air-dryer (UNISCOPE SM 9053, England) (UNISCOPE SM 9053, England). The dried starch samples were made to pass through 20 to 23 µm size sieve (Mastersizer 2000, UK) after which, were packaged in polyethylene bags prior to analyses.

Determination of amylose content. Amylose content of starch was determined as described by Akarsha et al. (2022). Sodium hydroxide (1N) was added to 100 mg of powdered starch sample and was incubated overnight. The volume was made up to 100 ml using distilled water and a dilution of 2.5 ml of the extract was made after adding 20 ml of distilled water. Three drops of phenolphthalein indicator were added to the mixture and a drop-wise addition of 0.1N HCl was made until the disappearance of pink color. Distilled water was added to the resulting mixture to make it up to 50 ml volume after addition of 1.0 ml of iodine solution (0.2%). Absorbance was measured at 590 nm wavelength using spectrophotometer (Ultrospec 2000, Pharmacia Biotech, Cambridge, England). Potato amylose standard curve was used to calculate amylose content as described by Sadashivam and Manickam (2008). Amylopectin was calculated by difference using Eq. 1 (Tortoe et al. 2017).

$$Amylopectin = 100\% - \%Amylose \qquad (1)$$

Determination of starch swelling power and solubility. The method used was as described by Akarsha et al. (2022). The solubility and swelling power of the starch were observed at temperatures of 70°C and 90°C. Starch slurry was obtained after it was dispersed in distilled water (1% w/v) and thereafter heated at two temperatures, 70°C and 90°C with continuous stirring in a water bath for 1 min. The slurries were cooled to room temperature and thereafter centrifuged. Centrifugation was carried out at 3000 rpm for 15 min. Residue of the wet starch was weighed (Ws) and the supernatants later decanted to a pre - weighed Petri dish and evaporated until dry at 110°C. The residue (*s*) weight was determined after drying. The percentage of solubility and swelling of the starch was calculated using Eqs. 2 and 3 given by Zhang et al. (2017) and Chel-Guerrero et al. (2016) respectively.

$$SP = \frac{Ws}{100 - (\%\, solubility) x\ 100}\ x\ 100 \qquad (2)$$

$$\%\, solubility = \frac{W2}{S}\ x\ 100 \qquad (3)$$

Here, SP = swelling power, Ws = weight of wet starch (g) and S = weight of starch on a dry weight basis (g), W_2 = Weight of soluble starch

Determination of starch thermal properties. The starch samples thermal properties were determined by a differential scanning calorimeter (DSC 200F3, NETZSCH, Selb, Germany) as previously described by Lin et al. (2017). Five milligrams of starch with excess water (1:2) were heated at 10°C.min^{-1} from 20 to 120°C. Thermal transitions of samples for gelatinization were characterized by the temperature at which gelatinization begins, To (onset temperature), the temperature at which maximum gelatinization occurred, Tp (peak temperature), and the temperature at which termination of the gelatinization process took place, Tc (conclusion temperature). The enthalpy change of gelatinization (ΔH) was recorded. Calculations of enthalpy were based on dry starch weight. Calculation of data was done with the software package (DSC 200F3, NETZSCH Company, Germany) after sample analysis.

Malting of sorghum grains. Modified method of Makeri et al. (2013) was used. The sorghum grains were steeped at 32°C (± 2) as follows: 8 h steeping, 4 h air-rest; 8 h steeping, 4 h air-rest; for 24 h. Air-rests were done by draining off the steep water

completely. After the last 4 h air-rest, the grains were placed on a cotton cloth sterilized with sodium hypochlorite (3.5% in 175 ml distilled water), covered with jute bag and germinated at room temperature (32±2℃) with water sprinkled at intervals. The green malts were harvested after 96 h of continuous germination and dried in air-oven (UNISCOPE SM 9053, England) at 50℃ for 48 h. The dried polished malts were milled into flour using attrition mill, packaged in sealed containers and stored in cupboard before use.

Determination of total malting loss. Total malting loss (vegetative loss, green malt moisture loss and respiratory loss) was calculated after the weight of the polished malts was subtracted from the weight of the original sorghum grain expressed as a percentage (Gomez et al. 1997). This is as shown in Eq. 4. Percentage malt yield was calculated from Eq. 5

$$Malting\ loss\ (\%) = \frac{initial\ grain\ dry\ weight - dry\ malt\ weight}{initial\ grain\ dry\ weight}\ x\ 100 \quad (4)$$

$$\%\ Malt\ Yield = 100 - Total\ malt\ loss \quad (5)$$

Determination of diastatic power. Diastatic power of malts was determined using the ferricyanide method of Gomez et al. (1997) as described by Dahiya et al. (2018). Malt flour sample (0.5 g) was weighed and transferred into centrifuge tube in which 10 ml of peptone solution was added. The sample tube was placed in a water bath at 30℃ for 2 h and 15 min during which diastatic enzymes were extracted. At the completion of the extraction, the suspensions were centrifuged for 2 min at 3000 rpm. The supernatant aliquot (0.5 ml) obtained from centrifuged suspensions was transferred from centrifuge tube into a 250 ml Erlenmeyer flask containing 100 ml buffered starch solution that was maintained at 30℃ in a water bath. Digested starch solution (5 ml) was thoroughly mixed for 1 h and further mixed with 4 ml of 0.05 N alkaline ferricyanide solution and was kept in boiling water bath for 20 min. Ten (10 ml) acetic acid salt and 0.4 ml potassium iodide solutions were added to the solution after it was cooled for 30 min. The solution was then titrated with 0.05 N sodium thiosulphate solution until complete disappearance of the blue color of the starch-iodine complex was observed. The unfiltered malt infusion and 2% buffered starch solution blank were prepared. The calculated diastatic power (DP) was made using Eq.6

$$DP = B - A\ (23 \times 200/250 \times 1/C) \quad (6)$$

Where:

A - sodium thiosulphate volume used for direct titration;

B - sodium thiosulphate volume used for blank determination;

C - unfiltered malt extract volume used for the digestion;

Determination of α- and β-amylase activity. Activities of the α- and β-amylase were determined as described by Dahiya et al. (2018). The supernatant aliquot that contains the extracted enzymes were taken into two separate Erlenmeyer flasks. The α-amylase activity was determined by inactivating β-amylase after adding to one of the flasks 0.316 g of calcium acetate (Novellie 1960). To the second flask, 0.284 g ammonium oxalate was added to inactivate the α-amylase flask (Taylor and Von Benecka 1990). Calculation of the α- and β-amylase activities were made as described earlier in the diastatic power determination.

Production of glucose syrup. Dziedzoave et al. (2004) method was used after some modifications. Batches A and B slurry were separately produced by mixing thoroughly 250 g each of cassava, cocoyam and sweet potato starches, 30 g sorghum malt grit, 10 g calcium carbonate and 250 ml water. Adjustment of the pH of the mixture was made to 6.5 using 0.1 NaOH. Batch A mixture was taken into a pot and about 1 L of boiled water was added to it and stirred thoroughly for 10 min. The content of the pot was boiled for 1 h on a hot plate. The resultant boiled mash was added to batch B slurry. The combined mixture was stirred for 10 min and was left to cool to 60-65℃. Thirty grams (30 g) of freshly weighed sorghum malt grit and 10 g calcium carbonate were added to the cooled mash while maintaining the pH at 6-7. The content was stirred thoroughly and left for 6 h after which it was placed on a hot plate, boiled briefly and filtered. Ten grams (10 g) of sodium metabisulphite was added and mixed thoroughly.

Concentration of glucose syrups. The glucose syrup filtrate obtained above was concentrated in a vacuum flask connected to a vacuum pump. Concentration process was carried out at 65℃

constant temperature until the solution was 50% total solids.

Analysis of Glucose Syrup

Dextrose equivalent determination. Determination of Dextrose equivalent of the syrup samples was according to the method of Okafor et al. (2019). The dry solids obtained as described above were used for this determination as follows: Eight gram (8.00 g) of syrup was weighed into a glass dish and was dissolved by stirring gradually in warm water to obtain 4% w/v solution. This was quantitatively transferred to a 200 ml graduated flask. The temperature was adjusted to 20℃ and made up to the mark, mixed well and filtered. Twenty-five (25) ml of the sample were poured into a conical flask and brought to boil over an open flame. Fehling's solution was titrated with the sample to within 0.5 ml of end-point. The flask was swirled and the content boiled for 2 min. Two drops methylene blue indicator was added and two drops of the sample solution was quickly added, again it was brought to boil and the brick-red copper oxide settled at the flask bottom. The supernatant liquid was observed. The decolorization of the methylene blue which is the end point was taken as the volume at which the reaction mixture turned red. Record of the titter was taken.

The percent reducing sugars (K) and dextrose equivalent (DE) were calculated using Eqs. 7 and 8, respectively.

$$K = \frac{200\ x\ Fehling's\ Factor\ x\ 100}{Sample\ Titre\ (mL)\ x\ Sample\ Weight} \quad (7)$$

$$DE = \frac{K\ x\ 100}{\%\ Total\ Solids} \quad (8)$$

Where Fehling's factor = 0.12

Determination of pH. Ten (10) ml of each of the glucose syrup sample was taken into a 100 ml beaker. A standardized pH meter (model PHS – 2F, Harris England) that was calibrated using pH 4.0 and 7.0 buffer was used to determine the pH of the syrup samples.

Determination of soluble solids (Sugar °Brix). A 10% v/v glucose syrup drop (diluted) was placed on a refractometer (Erma Inc Tokyo Japan). It was viewed and through the graduated mark in the refractometer, the sugar level was read in degree brix (°Brix)

Ash content determination. Into a previously ignited and weighed porcelain crucible was taken a 5 g weighed crushed sample. Organic matter was selectively charred by igniting the material on a hot plate placed in the fume cupboard. The crucibles were taken to muffle furnace and temperature maintained at 600℃. The contents were weighed immediately after cooling them in desiccators. The ash content percentage was weighed and calculated as follows using Eq. 9

$$\%\ Ash = \frac{Weight\ of\ crucible\ ash - Weight\ of\ empty\ crucible}{Sample\ Weight} \quad (9)$$

Statistical analysis. Data generated from all analyses were subjected to statistical analyses using SPSS version 17.0 through one way analysis of variance (ANOVA). Significant difference between samples was tested at $p<0.05$ using Fisher's least significant different test.

Results and Discussion

Amylose and amylopectin contents of starch. There were significant differences ($p<0.05$) between the amylose concentrations of the starches (Table 1). The amylose content of cassava, sweet potato and cocoyam were 20.40%, 22.50% and 28.20%, respectively. Depending on variety, various ranges of amylose content have been reported: 20-25% for sweet potato, 13.6-23.8% for cassava, and 30-43% for cocoyam (Tian et al. 1991; Moorthy 2002). In general, normal starches contain 17 to 28% amylose (Oyeyinka et al 2019). The applications of starch are considered to be derived from its amylose content structure (Zhong et al. 2018). The amylose content affects retrogradation and gelatinization properties of starches and also starch enzymatic and swelling power susceptibilities (Wang et al. 2020). The amylopectin content is directly related to the swelling capacity of starch because the amylose acts as a diluting and inhibiting agent of swelling (Alcarzar- alay and Meireless 2015). According to Akarsha et al. (2022) decreased amylose content corresponds to increase in hydrolysis rate for example, the cassava starch hydrolysis rate is faster than potato starch since it has less amylose content. The digestion of starch is restricted by amylose. The physicochemical property of the starch is determined by its amylose content (Zhang et al. 2017). Low amylose percentage implies high amylopectin proportions.

Also, the granule size and shape are determined by the percentage composition of amylose (Sing et al. 2016). The starch susceptibility to amylase is dependent on morphology, granule size, and porosity. Enzymes hydrolyze slowly starch with low relative surface area and a larger granule size when compared to starch with a smaller granule size (Akarsha et al. 2022).

Table 1. Amylose and amylopectin contents of starch

Botanical source	Amylose, %	Amylopectin, %
Cassava	20.4±0.0^{c}	79.6±0.01^{a}
Sweet potato	22.5±0.01^{b}	77.5± 0.02^{b}
Cocoyam	28.20±0.02^{a}	71.80±0.0^{c}

Mean ±SD of triplicate determinations. Means within each column not followed by the same superscript are significantly different ($p<0.05$)

Swelling power and solubility of starches. There were significant differences ($p<0.05$) observed in the swelling power (SP) and solubility of the starches when heated at 70℃ and 90℃, respectively (Table 2). The result of the swelling power of cassava, sweet potato and cocoyam were 13.4, 11.4, 10.6 g.g^{-1} at 70℃ and 17.2, 16.5 and 15.3 g.g^{-1} at 90°C and that of the solubility were found to be 4.0, 3.6, 2.8 % at 70℃ and 9.6, 6.2 and 7.6% at 90℃, respectively. Mweta and Kalenga-Saka (2015) reported mean values of 18.35, 13.52, 9.71 and 41.30, 22.80, 29.19 g.g^{-1} SP for cassava, sweet potato and cocoyam at 70℃ and 90℃ respectively; and mean values of 5.49, 4.35, 6.84 and 9.41, 7.26, 12.34% solubility at both temperatures respectively. Higher swelling power was reported by Gbadamosi and Oladeji (2013) for cassava starches than cocoyam starches which agrees with the present study. Sweet potato and cocoyam had the lowest solubility at both temperatures due to intra granular strong organization, since enormous energy is required to get these molecular forces relaxed (Lemos et al. 2018). The ability of the starch molecule to hold water through hydrogen bonding during gelatinization is depended on starch swelling power (SP) and solubility. The differences in SP among the crops in this study were attributed to bonding forces disparities within the starch granule (Oyeyinka et al. 2019). At both temperatures, cocoyam had lowest SP which indicates strong forces that holds the granules thereby making them resist swelling. Low swelling power of cocoyam starch could be due to its high amylose content (Table 1) which diminishes the expansion of the granules.

Table 2. Swelling power and solubility of starches

Botanical source	Swelling power, g.g^{-1}		Solubility, %	
	70℃	**90℃**	**70℃**	**90℃**
Cassava	13.4±0.5^{a}	17.2±0.6^{a}	4.0±0.5^{a}	9.6±0.2^{a}
Sweet potato	11.4±0.7^{b}	16.5±0.4^{b}	3.6±0.3^{b}	6.2±0.3^{c}
Cocoyam	10.6±0.4^{c}	15.3±0.3^{c}	2.8±0.6^{c}	7.6±0.5^{b}

Mean ±SD of triplicate determinations. Means within each column not followed by the same superscript are significantly different ($p<0.05$)

The difference in swelling power of the crops under study may be due to its starch granules size, amylose and amylopectin molecular structure and the amorphous and crystalline regions number of interactions between them (Lin et al. 2017). Cassava starch experiences during gelatinization a considerable swelling behavior due to its higher solubility ability when compared to other tuber crops (Chisenga et al. 2019). Starch solubility, swelling power and digestibility were reported by Wickramasinghe et al. (2009) to be inversely proportional to amylose content. Starch suitable for making glucose syrup should have higher enzyme digestibility, solubility, swelling power and lower particle size distribution (Chisenga et al. 2019). Cassava starch with least amylose content when compared to other tuber crops stands the most suitable for glucose syrup production.

Results show that significant ($p<0.05$) variations exist among the thermal properties of the starches. Low transition temperatures (℃) and gelatinization enthalpies ($J.g^{-1}$) were recorded for cassava (61.3, 65.5, 75.6℃, 13.4 $J.g^{-1}$) and sweet potato (67.4, 71.3, 78.4℃, 12.3 $J.g^{-1}$) starches respectively, whereas cocoyam showed the highest transition temperatures (69.5, 73.6, 82.3℃) and gelatinization enthalpy (17.3 $J.g^{-1}$) (Table 3). The results obtained are in agreement with those reported by Nkwocha et al. (2009). Higher enthalpy of gelatinization for cocoyam starches than cassava starches were reported by Pere et al. (2005).

Table 3. Thermal properties of starch

Botanical source	T_o, ℃	T_p, ℃	T_c, ℃	ΔH_G, $J.g^{-1}$
Cocoyam	69.5±4.0 [a]	73.6±2.9 [a]	82.3±1.8 [a]	17.30±0.8 [a]
Sweet potato	67.4±1.5[b]	71.3±1.1[b]	78.4±1.0 [b]	12.3±1.1 [c]
Cassava	61.3±1.4 [c]	65.5±1.3 [c]	75.6±0.6 [c]	13.4±2.1[b]

T_o – Gelatinization onset temperature; T_p – gelatinization peak temperature; T_c – gelatinization conclusion temperature; ΔH_G – enthalpy of gelatinization. Mean ± SD of triplicate determinations. Means within each column not followed by the same superscript are significantly different ($p<0.05$).

Transition temperatures and gelatinization enthalpies in the paste represented the gelatinization temperature, and are measures characteristic for each species. Gelatinization temperature is also directly related to the degree of molecules arrangement in starch granules (Abera et al. 2019). Thermal properties are functional properties used for evaluating starch applications (Li et al. 2022). High transition temperatures represent high degree of crystallinity, high stability, and granule structure resistance to gelatinization (Schirmer et al. 2015). The results of this study indicate that cassava starch with lowest transition temperature will gelatinize and hydrolyze most when subjected to malt enzymes hydrolysis.

Diastatic power, α-amylase activity, β-amylase activity and malt yield of sorghum malts. Diastatic power (61.45 and 52.32 $DU.g^{-1}$); α-amylase activity (43.30 and 38.19 $DU.g^{-1}$) and β-amylase activity (18.15 and 14.13 $DU.g^{-1}$) were obtained for SFD-Sorghum 'Farindawa' and SFF-Sorghum 'Farafara' varieties, respectively (Table 4). Significant variations ($p<0.05$) were observed among the measured parameters. Steeping temperature was 30℃ while the germination period was 96 h. Previous researchers' (Muoria and Bechtel 1998) results were in agreement with results of present study. Owuama (1999) reported 11-41 $DU.g^{-1}$ β-amylase activity in sorghum malt which represented 27-49% of total diastatic activity.

Table 4. Diastatic power, α-amylase activity, β-amylase activity and malt yield of sorghum malts

Parameter	SFF-Sorghum 'Farafara'	SFD-Sorghum 'Farindawa'
Diastatic power, $DU.g^{-1}$	52.32±5.4[a]	61.45±6.2[b]
α-amylase activity, $DU.g^{-1}$	*38.19±1.3[a]*	*43.30±0.5[b]*
β-amylase activity, $DU.g^{-1}$	14.13±0.5[a]	18.15± 1.6[b]
Malt yield, %	87.7±0.20[a]	81.7±0.20 [b]

Mean ± SD of triplicate determinations. Means within each row not followed by the same superscript are significantly different ($p<0.05$).

Ahmed et al.(2016) reported a range from 21 $DU.g^{-1}$ to 60.44 $DU.g^{-1}$ α-amylase activity of malted grains and 7.01 DUg^{-1} to 19.2 $DU.g^{-1}$ β-amylase activity. A commercial barley malt had an α-amylase activity of 89 $DU.g^{-1}$ and β-amylase activity of 52.3 $DU.g^{-1}$. It therefore followed that both the α-amylase activity (43.30 and 38.19 $DU.g^{-1}$) and β-amylase activity (18.15 and 14.13 $DU.g^{-1}$) of the sorghum malts were relatively low. Diastatic power is the combined α- and β-amylase activities and indicates the level of fermentable sugar that could be extracted from malt during starch hydrolysis (Dahiya et al. 2018). Alpha-amylase activity is the

starch-liquefying and dextrinizing power while β-amylase activity is the starch saccharifying or saccharolytic power (Komlaga et al. 2021). Metabolic or malting loss differences were shown among the cultivars of the grains. Total malting loss at 96 h of germination varied from 12.30% to 18.50% for SFF- Sorghum 'Farafara' and SFD-Sorghum 'Farindawa'. According to Owuama (1999), total malting loss includes leaching/steeping, metabolic/respiration and vegetative/sprout losses. Palmer et al (1989) reported malting losses of 15-20% or malt yield from 85 to 80% in sorghum compared to 7% in barley.

Volume and yield of glucose syrup produced. Glucose syrup samples volume after filtration were recorded in Table 5. Volume of syrup resulting from malt enzyme hydrolysis of cassava starch after filtration was 1176 ml, sweet potato starch was 1008 mL and cocoyam starch was 942 ml. Hydrolysis using cassava starch gave the highest yield of glucose syrup (78.4%) followed by sweet potato starch syrup (67.2%) and cocoyam starch syrup (62.8%). Gelatinization temperature of starch, ratio of amylose/amylose leaching and pH affect greatly the starch hydrolysis (Gerard et al. 2001). It has been reported that yield is also affected by botanical source of starch and source of amylase that inhibit amylase activity. Longer hydrolysis time, optimum temperature at liquefaction/saccharification and high concentration of enzyme dose increased glucose yield percentage (Dedin and Ricke 2021).

Physicochemical composition of glucose syrup. Table 6 shows syrup samples' physiochemical composition. Highest moisture content of 16.3% was recorded in sweet potato sample, while cassava sample had highest DE, 40. Factors that determine DE during liquefaction and saccharification are gelatinization temperature of starch, ratio of amylose/amylose leaching, pH, amylase dose added and time (h) taken for liquefaction (Dziedzoave et al. 2006). A range of ash contents from 0.02% to 0.04% were recorded. Standard Organization of Nigeria's (SON) specification on glucose syrup approves 0.03% maximum ash.

Table 5. Volume and yield of glucose syrup produced

Botanical source	Starch, g	WMG, g	VGS, ml	Glucose syrup yield, %
Cassava	500	60	1176	78.4
Sweet Potato	500	60	1008	67.2
Cocoyam	500	60	942	62.8

WMG – Weight of malt grit, VGS – Volume of glucose syrup after filtration

The samples moisture contents were between 15-16% which met the SON standard. The high 40 DE score for cassava starch could be among other factors as a result of its low amylose content and low transition temperature and gelatinization energy. The amylose content of sweet potato, cassava, and cocoyam starches were, 22.50%, 20.40% and 28.20%, respectively (Table 1). Aboubakar et al. (2008) observed that amylose content correlated negatively to the hydrolysability of starch. Hydrolysis of starches with high level of amylose occurred more slowly than the starches with low level of amylose. Cocoyam starch showed the highest transition temperature and gelatinization enthalpy (Table 2). The higher transition temperature and gelatinization enthalpy according to Cooke and Gidley (1992) reflect stronger crystalline structures or more molecular orders. The disruption of the crystalline structure of amylopectin during hydrothermal treatment resulted in the release of amylose into solution.

Table 6. Physicochemical composition of glucose syrup

Syrup source	Moisture, %	Ash, %	pH	DE	Sugar, °Brix	Color	Taste	Odor	Clarity
Cassava	15.40	0.02	5.5	40	110	Brown	Sweet	Odorless	Clear
Sweet potato	16.30	0.03	5.5	36	100	Brown	Sweet	Odorless	Clear
Cocoyam	15.70	0.04	5.5	30	105	Brown	Sweet	Odorless	Clear

DE – Dextrose equivalent

Reduction in the level of crystallinity is related closely to an increase in amorphous regions, α-amylase enzyme susceptibility to starch and starch digestibility (Dedin and Ricke 2021). Starch granules were caused to swell more easily during the gelatinization process due to decrease in crystalline area (Baks et al. 2008). The nature of starch crystalline structure determines starch properties. It follows therefore that weaker amylopectin structures in cassava starches could easily be destroyed by heating and hence release amylose easily (Menzel et al. 2015), the basis for high DE recorded for cassava starch. A sudden increase in the amount of leached amylose at 70℃ for cassava and 80℃ for sweet potato was reported by Mweta et al. (2015). The observed increase coincides partly with gelatinization temperatures of these starches, therefore at temperatures above the gelatinization temperatures, improved leaching is expected. The optimum temperature range for sorghum malt α- and β-amylase activity is 55-60℃. Consequently, amylolysis of cassava starch with least onset gelatinization temperature, 61℃ (Table 2) yielded highest reducing sugars content/DE during hydrolysis at 70-80℃.

Conclusions

The glucose syrups (Dextrose equivalent, 30-40) were manufactured from cassava, cocoyam, sweet potato and sorghum crops produced in commercial quantities by rural farmers in Nigeria. Cassava starch and SFD-Sorghum 'Farindawa' malt gave better results. Though the products have some limitations in low Dextrose Equivalent values, it remains good materials for certain industrial applications.

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