Assessment of the Starch Gelling Characteristics of Plantain Fufu Flour

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Abstract
Gelling is an important functional property of starch; the gelling characteristics of starch vary depending on the source of starch and the amylose and amylopectin content of the starch. Plantain fufu is a starch-based meal that is a solid and visco-elastic-like dumpling. This study was meant to establish the gelling properties of starch in plantain fufu and use that information to establish a preparation recipe for the product and other plantain product derivatives. The plantain fufu was analyzed for its moisture content, which was 9.64 and 9.73%, respectively. Using the Brabender viscograph, the sample weight of the plantain fufu flour was determined to be 32 g, and its water addition was 386 ml. 386 ml of distilled water and 32 g of flour are used to prepare the slurry, which is heated at 1.5 °C/min to 95 °C and stirred at 75 rpm using the Brabender viscograph. Plantain fufu starch started gelling at 66 °C after 11 minutes (pasting temperature). Plantain fufu reached its average maximum gelatinization at 342 ± 7.1 BU at 88 °C after about 26 minutes; further heating of the slurry to 94 °C did not further increase the viscosity of the plantain fufu slurry. Retrogradation sets in after 75 minutes after the sample was cooled from 94 to 50 °C, and at retrogradation, there was a reduction in the viscosity to about 251 ± 5.7 BU. The gelling characteristics of plantain fufu are necessary to outline its preparation recipe by the manufacturer and also to understand the product's stability and behavior after preparation

Keywords: *Starch; Plantain; Gelatinization; Retrogradation; Fufu.*

INTRODUCTION

Foods possess certain characteristics other than nutritional and metabolic, which makes them preferred and selected by manufacturers for food processing. These are the structural and functional properties of the food components; these properties show the behaviours of the component when it is used as an ingredient along with other ingredients to produce the desired sensory attributes of the food product(Cheung & Bhavbhuti, 2015).

Interactions between food components usually depend on hydrophobicity, hydrogen bonds, and ionic and covalent forces. How water interacts with food components is important because most food matrices and preparation processes either require the addition or removal of water. These functional properties of food components are the reason why other applications of food components other than nutritional applications exist; examples include the application of starches in adhesive production, the application of milk caseins in the paint and plastic industries, and the use of lipids in soap manufacturing(Cheung & Bhavbhuti, 2015; Fennema, 1996).

Starch is the most abundant carbohydrate reserve in plants; it serves as a food and energy store for the plant. Starches are polysaccharides whose monomer units, glucose, are linked by glycosidic bonds either in a straight or branched chain fashion. Glucose units linked in a straight chain are called amylose. The glucose molecules in amylose are held together by α-1-6 glycosidic linkages. Amylopectins, the branched-chain part of starch, are held together at the point of branching by α-1-6 glycosidic bonds and then elongated like the amylose linearly (Peace Oladele, 2013; Tako et al., 2014a)

Starches in commercial applications are obtained mainly from cereal and tubers, starches and their modified versions are used industrially as adhesives, binding agents, clouding agents, gelling agents, stabilizers, anti-staling agents, foam strengthens, thickeners etc. (Cheung & Bhavbhuti, 2015; Fennema, 1996).

The majority of food crops contain a lot of starches, but cereals, roots, tubers, legumes, and some young fruits have a lot of them as well. All sources of starch, however, differ in terms of the amount and composition of amylose and amylopectins. Each plant tissue has a unique accumulation pattern of starch granules that varies in size, shape, structure, and composition. This would explain the different functional characteristics of the starches from various sources(Effah-Manu et al., 2022; Ezekiel et al., 2010; Zhuang et al., 2022)

Traditionally, cereals and tubers have been the primary sources of starch. However, the desire to boost regional economies has spurred the investigation of alternative botanical sources for starch. Moreover, as industries seek to develop new products, there is a growing need for starches that possess improved functional properties, including better water and oil absorption capabilities, viscosity, solubility, and resistance to retrogradation and syneresis. Consequently, significant advancements have been made in the extraction of starch from non-traditional botanical sources like bananas and plantains, as well as the characterization of their functional properties (Effah-Manu et al., 2022; Ezekiel et al., 2010; Olatunde et al., 2017)

Gelatinization is a functional property of starch where the starch granules absorb water and swell at high temperatures, eventually disrupting its crystalline structure and causing gelling. Starch granules are water-insoluble but can absorb water at high temperatures. The hydrogen bonds holding the molecules break and are replaced with water, which causes swelling of the starch molecules, creating a paste or thickened gel. The capacity of starch to swell resides in the amylose content, lateral chains of amylopectin, the presence of phospholipids, granule size, and the presence of holes and channels. (Cornejo-Ramírez et al., 2018). After gelatinization, starch undergoes retrogradation. This outlines the process of recrystallization of the amylopectin in the gelatinized starch granules, which went from an amorphous state to a more crystalline and ordered state. Retrogradation of starch causes its gelatinized state to further thicken and become stiff (Adamczyk et al., 2020; Xie et al., 2006)

Polysaccharides are used in food processing either in their natural state or modified form as thickeners or gel-setting agents like starch, stabilizers for emulsions and dispersions, film-forming substances, coating substances to protect sensitive food substances from undesired changes, and inert fillers to increase the proportion of indigestible substances in the diet. (Chakraborty et al., 2022; Tako et al., 2014b; Xie et al., 2006)

"Fufu" is a staple food for a lot of Ghanaians; it is usually prepared from cassava with or without the addition of plantains, cocoyam, or yam. As a result of innovative technology, the ingredients of fufu have since been transformed into flour for easy preparation, distribution, and sale. Fufu is locally prepared by peeling, slicing, boiling, and pounding the cassava or plantains in a mortar with a pestle. The new innovative fufu flour provides a much simpler method of preparation. (Apea-Bah et al., 2011; Otoo et al., 2018).

Plantains (*Musa paradisiaca L.*) are staple food s in Ghana and West Africa, they are a good source of carbohydrates, they are low in protein concentration. Plantains are a very good source of minerals i.e., potassium, calcium, iron, magnesium, phosphorus and copper. Plantain has found a use in saponification (soap making) because of is rich potassium content. Plantains are boiled and pounded to make a variety of fufu in Ghana, Starch is the major component of green plantains, with a total starch content of 61.3–76.8 g/100 g (DWB). Green plantains contain a total dietary fiber content of 14.5% dry weight basis (Adeniji & Tenkouano, 2008; Olatunde et al., 2017; Peace Oladele, 2013)

MATERIALS AND METHODS

Tools and Materials

a. Plantain fufu flour purchased from the CSIR- Food research Institute.

b. The procedure for the use of the Brabender Viscograph was determined by the international starch institute ISI 19-6e Determination of Viscosity of Starch by Brabender.

c. The moisture content of the fufu flour was determined using an electronic moisture analyzer; the moisture determination was repeated for precision, and the average moisture content was determined. The brabender viscograph (Brabender OHG, Kulturstr. 51-55, D-47055 Duisburg, Germany) was used to determine the gelling characteristics of the fufu flour. The brabender viscograph software on the computer has been preprogrammed with a protocol to determine the required amount of fufu flour and its corresponding volume of water at a predetermined percentage solid, which is dependent on the product protocol required for the analysis based on the moisture content imputed in the software. According to the software, the plantain fufu flour with a moisture content of 9.64% requires 32 g of weight and 368 ml of distilled water to conduct the experiment at 8% solids. A slurry was prepared with the given amount of fufu flour, i.e., 32 g, and a volume of distilled water of 368 ml. The slurry was transferred into the stainless-steel canister component of the brabender viscograph, and the same sample of distilled water was used to rinse the slurry residues into the canister. The canister was placed into the reaction chamber, and the head was carefully lowered onto it with the lever. The nob was turned on to start the rotation of the canister. The sample was heated at a rate of 1.5 °C per minute by means of a thermos regulator and rotated at a speed of 75 rpm with the start temperature set at 50 °C. a first holding time of 15 minutes when the temperature reaches 95 °C as the rotation continues. After holding for 15 minutes at 95°C, a reduction in temperature is initiated at a rate of -1.5°C per minute till the temperature reaches 50°C, where another holding time of 15 minutes is done. The software tracked the gelling characteristics at the various temperatures and their corresponding times and generated the results (International Starch Institute, 1999).

RESULTS AND DISCUSSION

The results of the pasting characteristics analysis of the plantain fufu flour sample are presented for two tests on the same sample because the experiment was duplicated for precision. Each graph has a subsequent breakdown of the time-to-temperature segment of the different viscosity readings. The mean and standard deviations of the two results have also been presented.

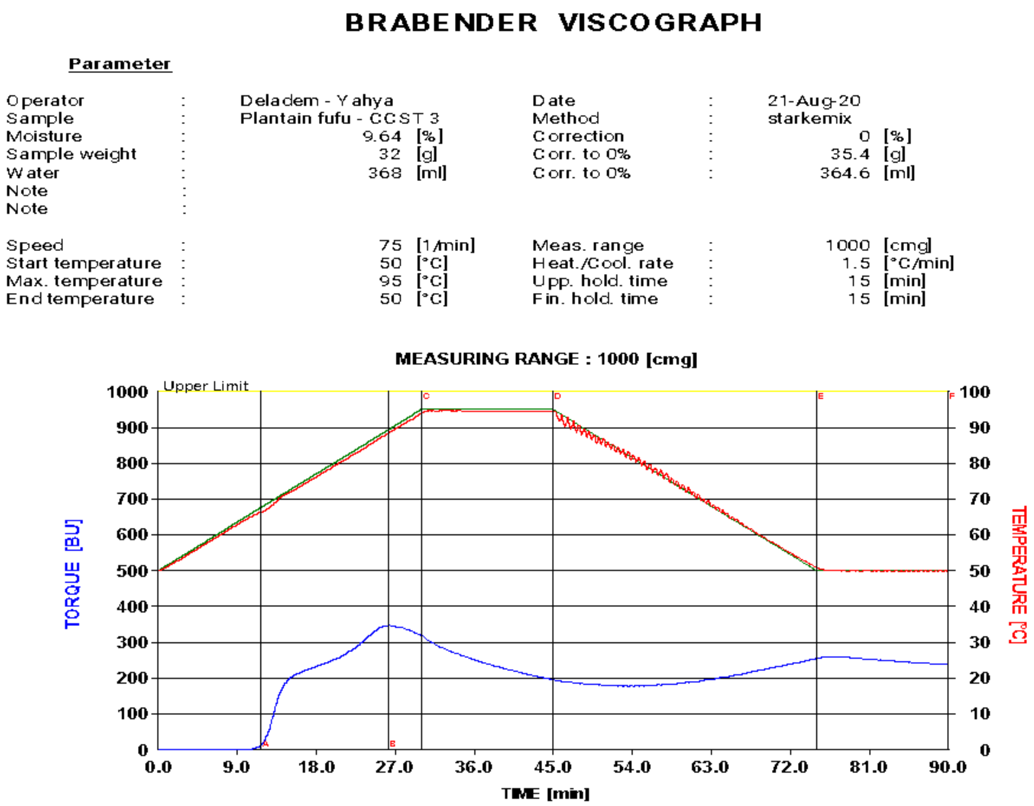

Figure 1 Graph depicting viscosity trends of the 1st run of the Plantain fufu powder sample.

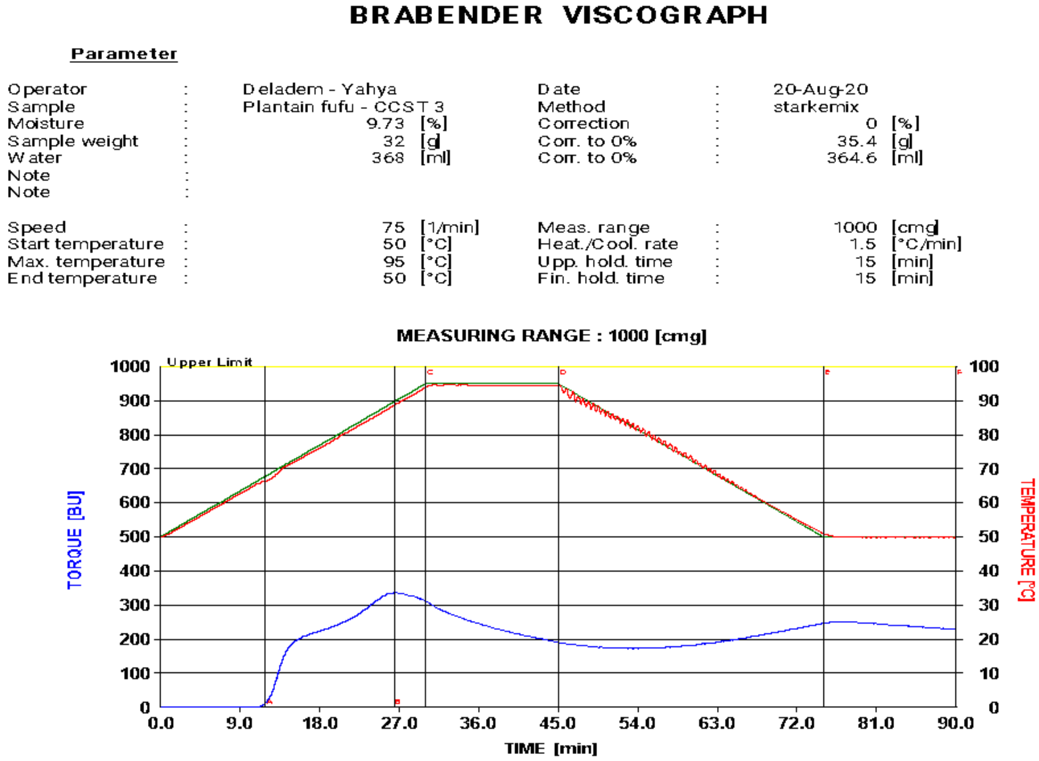

Figure 2 Graph depicting viscosity trends of the 2nd run of the Plantain fufu powder sample.

Table 1: The means of the pasting properties of Plantain fufu powder

	PARAMETER	TIME (MEAN)	TORQUE (MEAN + SD)	TEMPERATURE (MEAN +SD)
A	Beginning gelatinization	0:11:45	12 ± 0	66.45 ± 0.1
B	Maximum viscosity	0:26:20	342 ± 7.1	88.55 ± 0.1
C	start of holding period	0:30:00	315.5 ± 4.9	93.9 ± 0
D	start of cooling period	0:45:00	192.5 ± 3.5	94.5 ± 0
E	end of cooling period	1:15:00	251 ± 5.7	50.95 ± 0.1
F	end of final holding period	1:30:00	234 ± 5.7	49.85 ± 0.1
B-D	break down		148.5 ± 3.5	
E-D	set back		56.5 ± 2.1	

As indicated in the parameter section of both results, the moisture content of the fufu powder is 9.64% and 9.73%, respectively. The required fufu sample weight based on the Brabender viscograph was 32 g and 368 ml of distilled water to mix during the sample preparation, with a stirring speed of 75 rpm and a heating temperature rate of 1.5 °C per minute. The factors that influence gelatinization include the type of starch, the temperature, stirring, and the presence of any other food component like protein, lipids, salt, or sugar. The factors were considered and applied in the design of the machine(Chakraborty et al., 2022; Zhuang et al., 2022). The gelatinization of the fufu flour began at about 11:40 and 11:50, respectively, at 66.45 °C. This implies that during preparation, if the cooking temperature does not exceed 66.45 °C, the fufu's thick texture will not be achieved. The gelatinization temperature (66.45 °C) is also the minimum temperature for pasting. 26.2 minutes into gelatinization, maximum viscosity is achieved at 88.55 °C. Manufacturers would use this information to direct consumers on how to prepare the product and achieve the highest viscosity. Applicably, if a manufacturer uses starch as a thickener, then the temperature of the maximum viscosity will give the manufacturer the thickest texture for their product. The manufacturer considers other factors like salt or sugar addition, moisture, fat and lipid content in their intended product and chooses a preparation recipe to achieve the desired gelatinization. Two temperature holding points were used in the analysis. From Table 1.0, points C and D were the first holding points that saw a decline in viscosity at temperatures above 90 °C over the 15-minute span. This was done to assess the starch stability at its highest temperature. This further informs the choice of plantain starch in food processing in terms of the fact that exceeding peak gelatinization temperatures not only does not further thicken the product but also affects its stability past the peak gelatinization temperature. The second holding temperature after cooling was at about 50 °C for the same 15 minutes after the mixture had been allowed to cool further; this also tests the starch stability post-processing. The viscosity trend observed between points B and D is known as the breakdown viscosity, which is also a measure of starch stability, with a breakdown viscosity of 192 BU. High breakdown values indicate that there was less granule rupture, further inferring that the level of stability of the plantain powder's paste or gel the lower the breakdown viscosity of starch, the less stable its paste and the starch with low paste stability or breakdown exhibits weak cross-linkage among the granules(Chakraborty et al., 2022; Fennema, 1996). Points between E and D are referred to as retrogradation (set back). This is the point where the starch tries to recrystallize and gives up water.

Table 2: Pasting properties of Plantain puree – cassava starch *fufu*, and "Neat" *fufu* powder (Otoo et al., 2018)

Sample	Peak viscosity	Holding strength	Breakdown viscosity	Final viscosity	Setback	Peak time	Pasting temperature
Plantain puree and starch	350	33	89	107	-84	30:15	72.6ºC
"Neat" fufu flour	232	88	98	103	-31	29:35	70.6ºC

From Table 2, Otoo et al. (2018) conducted a similar assessment to optimize the texture of fufu with different ratios of plantain/cassava ratios of two different states of the fufu ingredients: one, a plantain puree and cassava starch and the "neat" fufu flour.

The plantain puree sample used in the study was 80g plantain and 20g cassava starch and the "neat fufu" was made up of 60% plantain, cassava 10% and 30% potatoes with E102 and E110 as colourants (Otoo et al., 2018).

The peak viscosity of the test sample and that of the "neat" fufu flour were vastly different, at 350 and 232, respectively. The "neat" fufu flour had a slightly higher pasting temperature than the test sample (70.6 °C) as compared to the 66 °C of the plantain fufu sample. From our experiment, the plantain fufu powder and the plantain puree and starch were similar; the peak viscosity of the plantain fufu powder was 342 ± 7.1 BU and that of the plantain-starch puree from Otoo et al. was 350 BU. It could be stated that the presence of 80% plantain in the plantain/cassava starch puree was the cause of the high peak gelatinization (Otoo et al., 2018). It is also important to note that the lower peak viscosity of "neat fufu" could be as a result of the different percentages used, the presence of potato also presenting its own unique gelatinization profile and the presence of food additives i.e., E102 and E110. For princples of starch gelatinization temperature, moisture, starch source, fat and lipid content, amylose/amylopectin content and sugar/salt presence all affect the gelatinization properties of starch of starch (Chakraborty et al., 2022; Tako et al., 2014a; Xie et al., 2006).

This study used a 100% plantain fufu flour, Otoo et al. used 80:20 plantain/cassava starch and "neat fufu" 60:30:10 plantain/potato/cassava ratios. These 3 varied plantain fufu samples showed different gelling properties and this can be attributed to the factors affecting starch gelatinization.

CONCLUSION

The pasting characteristics of starch in plantain fufu are unique; they differ from the characteristics of cereal starch but are similar to most tuber starch; hence, all these tubers are viable substitutes for plantain in the preparation of fufu. This explains why there are various carbohydrate sources for fufu and the variation of the meal. The starch in the plantain fufu showed a high peak viscosity of 342 BU and a minimum gelatinization temperature of 66.45°C, this in comparison with other fufu blends of high plantain content 80% and greater are consistent. However, these gelling properties are affected by properties like the starch source, additive (salt/sugar), lipid content and any other modifications. The texture and mouthfeel of the fufu can be attributed to its pasting characteristics. The pasting characteristics provide information to the manufacturer on how to produce a recipe for the plantain fufu to achieve similar characteristics to the traditionally prepared fufu and its sensory properties.

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