QUALITY EVALUATION OF FERMENTED PRE-GELATINIZED UNRIPE PLANTAIN AND SOYBEAN-BASED COMPLEMENTARY FOODS 1: PHYSICOCHEMICAL, SENSORY AND RHEOLOGICAL PROPERTIES

ABSTRACT

Aims: This study aimed at evaluating the effect of the degree (%) of starch gelatinization (G) and fermentation (F) on the physicochemical characteristics of the flours and also the sensory and flow properties of the gruels of unripe plantain fruits and soybean seeds based complementary foods.

Study design: Completely randomized design

Place and duration of the study: This study was carried out in Makurdi, Benue State, Nigeria, between January and November 2023.

Methodology: Plantain slices heated to obtain 10% to 100% starch gelatinization were subjected to accelerated natural fermentation followed by drying and milling to yield fermented (F) flours. Non-gelatinized (NG) and nonfermented (NF) lots served as controls. The flours were each combined with soybean flour to obtain 16 g protein/100 g of each mixture based on the proximate compositions of the inputs using material balancing technique. The flours' oil absorption capacities (OAC), water absorption capacities (WAC), packed bulk densities (PBD), sensory attributes (taste, mouth feel, appearance, overall acceptability) and flow properties of their gruels were evaluated using standard methods. Significant differences and separation of the data means were achieved by Duncan multiple range and Turkey's tests using an SPSS package, respectively.

Results: Gelatinization and fermentation increased WAC and OAC, but decreased packed bulk density (PBD) of the flours with concomitant reduction in pH, viscosities and improved sensory attributes of the gruels. Generally, viscosities increased with increase in slurry concentration and decreased with increase in temperature and shear rates. The flow behavior indices ranged from 0.27 to 0.64, with lower values in gelatinized and fermented samples, showing more pseudoplastic behavior in pretreated samples.

Conclusion: Gelatinization and natural fermentation are therefore adaptable technologies, especially at rural levels, to improve acceptability and bulk reduction of resistant starch-based complementary foods.

Keywords; Gelatinization, Fermentation, Sensory, Rheological, Plantain, Soybean.

INTRODUCTION

Plantain (*Musa paradisiaca*) is an important staple starch and commercial crop in West and Central Africa where 50 % of the world's plantain crop is produced (Makanjuola and Ajayi 2017). It is high in carbohydrate and some essential minerals, but low in protein and fat. An average plantain fruit provides approximately 220 calories per 100 g and is a good source of potassium and dietary fibre (Bolarinwa et al. 2016). Plantain can be used in many ways such as cooking, boiling, steaming, frying, roasting, or can be dried and milled into flour (Bolarinwa et al. 2016). Due to its versatility and good nutritional value, the crop is used as a popular dietary staple. It is a less sweet variety of banana that can be consumed ripe or unripe. Its use as an inexpensive source of calories in many African countries has enabled plantain to gradually find applications in weaning food formulations and composite flour preparations (Folorunso and Ayodele 2018). The plant is a source of food, beverages, fermentable sugars, medicines, flavoring, cooked foods, silage, fragrance, rope, cordage, garlands, shelter, clothing, smoking material, and numerous ceremonial and religious uses (Adamu, Ojo, and Oyetunde 2017). Much attention has been put on cereals in the production of complementary foods, leading to scarcity and increase in the price of these raw materials. Despite its high nutritional value, the use of unripe plantains in complementary foods is limited due to its high concentration of resistant starch that is not easily digested in infants.

Soya bean or soybean (*Glycine max*) is a legume of major dietary and economic importance in Africa. The seeds are an excellent source of protein (35-40%), calcium, iron, phosphorus and vitamins. Soybean contains all 20 natural amino acids. In addition to being an excellent source of cheap proteins, it also contains all essential fatty acids, magnesium, lecithin (about 3%, which are important for brain development, especially in infants), riboflavin, thiamine, fiber and folic acid. Thus, soybeans are ranked as the richest in food value of all plant foods consumed in the world (Bolarinwa et al. 2016). The crop contains a high amount of Lysine (Makanjuola and Ajayi 2017) and a reasonable amount of methionine lacking in plantain, making it a good supplement for plantain.

Complementary foods are solid, semisolid or liquid foods that are introduced to infants in addition to breast milk, usually after the sixth month of age. In rare cases, some infants may need complementary feeding earlier, but not before the fourth month of age (Fewtrell 2008). Adequate complementary foods generally consist of foods that are rich in protein, energy and micronutrients (especially iron, zinc, calcium, vitamin A, vitamin C and folates) and free from contaminants (pathogens, toxins and harmful chemicals) (Ogbo et al. 2017).

Rheology is the study of deformation and flow of matter. In other words, it is the study of how materials deform, flow, or fail when force is applied. Rheology involves the flow behavior of liquids and the deformation behavior of solids. In the food industry, rheological measurements are important for: obtaining a quantitative description of the mechanical properties of the material, gaining information related to the molecular structure and composition of the material, characterizing and deducing the performance of the material during processing and for quality control. Rheological measurements are an important tool to aid in process control and process design (Amjid et al. 2013).

Earlier studies on pre-gelatinization and fermentation revealed that each of these processes has positive effects on the physicochemical characteristics of flours and sensory attributes of foods. However, the degree of gelatinization and the optimization effect of gelatinization and fermentation have not been exploited so far. This piece of work is thus aimed at accessing the effect of varying degrees of gelatinization and fermentation on the physicochemical characteristics of flour and the sensory and rheological properties of gruels from unripe plantain and soybean-based complementary foods.

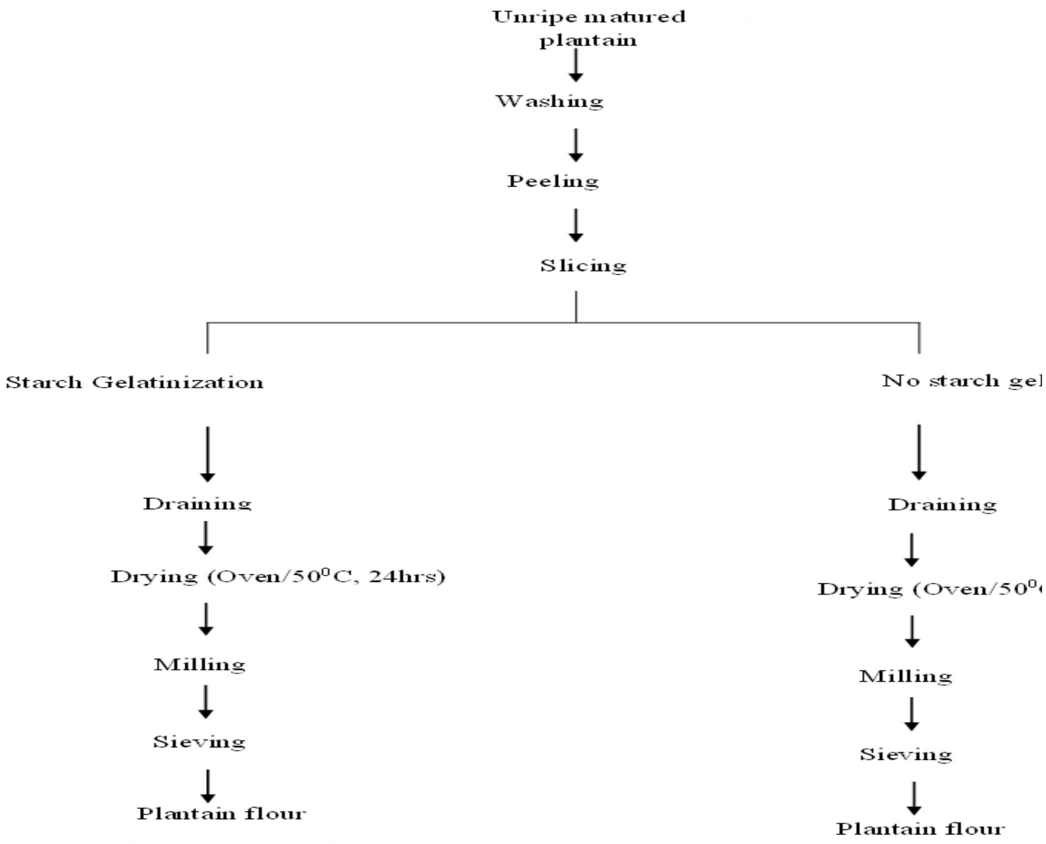
- **MATERIAL AND METHODS**

2.1. Sourcing of Raw Materials and Preliminary Handling

Five big bunches (approximately 10 kg) of unripe mature plantain fruits, the *Big Ebanga cultivar* (False 'Horn'), and 4 kg of dry soybean seeds were purchased from the Wurukum market in Makurdi, Benue State- Nigeria. The raw materials were sorted and cleaned prior to use for experiments.

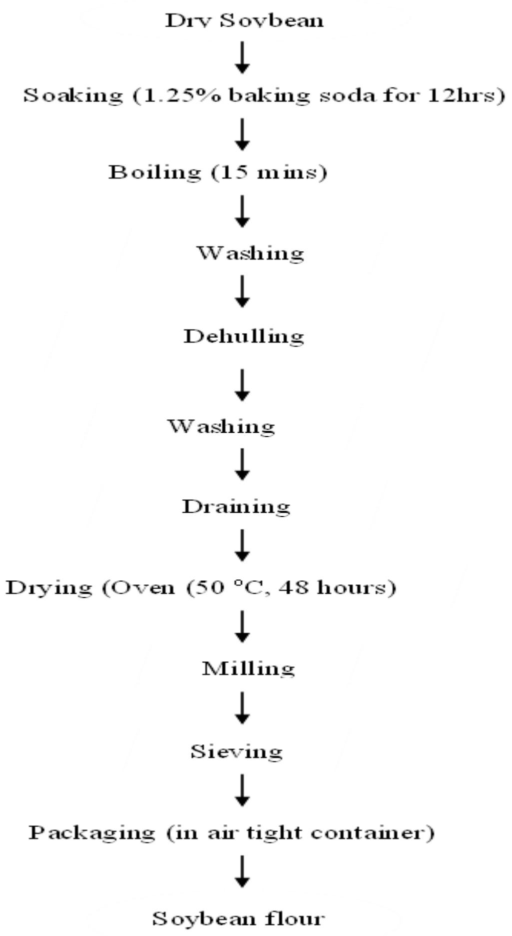
- **Preparation of complementary foods**

The unripe plantain was processed into flour by a modification of the method described by Folorunso & Ayodele, (2018) (figure 1). Following this method, mature unripe plantain fruits were washed, peeled with a knife, and the pulp cut into small round slices of about 2mm thick using a portable plantain slicer. A portion of the plantain was heated to obtain 10%, 18%, 23%, 33%, 74% and 100% starch gelatinization at 80 ° C for 45 seconds, 20, 40, 60, 120 and 150 minutes respectively. The non-gelatinized-nonfermented and non-gelatinized fermented samples were used as control. The flour obtained was subjected to accelerated natural fermentation by backslopping as described by Ariahu et al. (1999) through four cycles to a final pH of 4.5 and a total titratable acidity (TTA) of 0.05 % when the products remained fairly stable with no changes in pH. Dry soybean seeds were processed into soybean flour by a modification of the methods used by Kohli et al. (2017) and Aduke, (2017). Following this method, the soybean seeds were sorted and soaked in water containing 1.25% baking soda for 12 hours (1 kg soybean per 2 liters of water). The seeds were then boiled for 30 minutes to remove antinutrients, oligosaccharides, and beany flavor, and to reduce the viscosity of the resulting porridge (Agume et al., 2017). The seeds were then dehulled (to further reduce the antinutrient content) by rubbing them between the palms and dried in a hot air fan driven oven at 50 ° C for 48 hours. When dry, the seeds were milled and sieved using a 100-um particle size sieve (Figure 2). Following material balance calculations, the proportions of plantain flour were mixed with soyabean flour to obtain a 16 g/100 g protein food, as recommended by the Protein Advisory Group (PAG). The fourteen (14) complementary foods produced were preserved in zip-lock cellophane bags prior to


Unripe matured plantain
Washing
Peeling
Slicing
Starch Gelatinization
Draining
Drying (Oven/50^0C, 24hrs)
Milling
Sieving
Plantain flour
No starch gel
Draining
Drying (Oven/50^0
Milling
Sieving
Plantain flour

analysis.

Figure 1: Flow chart for plantain flour production
Source: (Folorunso& Ayodele 2018).



Source: (Kohli et al., 2017) and (Aduke 2017) with modifications.

Figure 3.3: Flow chart for soybean flour production.

Figure 2: Flow chart for soybean production

Source: (Kohli et al., 2017) and (Aduke, 2017) with modifications

- **Physicochemical characteristics of flours used in the production of complementary foods**

pH and TTA were evaluated during fermentation, using the method of (Ariahu, U. Ukpabi, and Mbajunwa 1999)**.** Fermentation was stopped when the pH became constant in all samples.

The oil absorption capacities (OAC), water absorption capacities (WAC) and the packed bulk densities (PBD) of the flours were determined using standard methods as described by Makanjuola & Ajayi, 2017.

- **Organoleptic Properties of Gruels from Formulations**

Sensory evaluation was performed using descriptive analysis and affective testing (Ariahu, C. Ukpabi, and Mbajunwa 1999). All samples were coded and randomly selected.

Panelists (15) consisted of post-graduate CEF'TER students, who were maintained for three days. Each received the newly formulated samples and the super cereal. Each day, the panelists were required to indicate their preference for the samples in terms of appearance, aroma, taste, texture and overall acceptability. A seven-point unstructured descriptive scale was used to rate the sensory attributes of the samples. Panelists were asked to identify appearance as extremely dark, very dark, dark, slightly dark, slightly light, very light and extremely light. The aroma was identified as extremely beany, beany, rancid, slightly pleasant, pleasant, very pleasant and extremely pleasant. The taste was identified as extremely unpleasant, unpleasant, sour, tasteless, pleasant, very pleasant and extremely pleasant. The texture was identified as extremely watery, watery, slightly watery, slightly thick, thick, very thick and extremely thick. A 7-point structured hedonic scale ranging from (1 = extreme disapproval and 7 = extreme approval) was used to score overall acceptability of the products. The assessment was conducted under fluorescent light in a special room. The samples were presented to the panelists at random.

The same amount (20 g) of formulated products and super cereal was measured and each was cooked with the same amount (150 ml) of distilled water by boiling for the same length of time (2 minutes) while stirring with a glass rod into smooth gruels. Porridges were stored in insulated 2 L food flasks from which they were served to the panelists. The gruels were served in 100 ml coded colorless transparent plastic bowls. About 50 ml of the gruels was served hot (70-80 ^{o}C). Colorless plastic cups and spoons were provided for testing the sample. Drinkable water was provided to rinse the mouth between evaluations.

- **Determination of the rheological properties of Gruels**

Porridges were prepared from each product using 5-20% w/w concentrations of flour to water by boiling and stirring the slurries in 200 ml glass beakers for 10 minutes. The viscosities of the cooked paste of the gruels were determined using a Brookfield viscometer (LV-8, Viscometers UK). Brookfield evaluations were performed using spindle number 4 and 6, 12, 30 and 60 rpm shear rates at 40 ° C. Readings were recorded after a 2-minute rest period. The viscosity values obtained were recorded in Nsm^{-2} and converted to centipoise, while the shear rate was recorded in rpm (Ariahu, U. Ukpabi, et al. 1999).

- **Statistical analysis**

All data obtained in this study were analyzed using SPSS (Statistical Package for Social Sciences) version 26. The mean and standard deviation of the analyzes were calculated in Excel. The significant difference was made using the Duncan multiple range test, while Turkey's test was used to separate the data means. The data obtained from rheological studies were fitted into equations and subjected to least squares linear regression analysis to obtain slope indices and intercept coefficients that characterize the flow behavior of the emulsions. Significance was accepted at P=0.05.

- **RESULTS**

From analysis, results of six samples; 2 non gelatinized, 2 pregelatinized, and 2 fully gelatinized, were reported.

3.1. Physicochemical properties of flours

While values for pH decreased from 6.65 on day 1 to 4.50 on day 4, TTA increased from 0.01 on day 1 to 0.14 on day 4. The values were higher in the control than in the test samples (Table 1).

Table 1: Change in pH during plantain flour fermentation

Time (h)	Sample		
	NGPF	G18PF	G100PF
0	6.65^c±0.02	6.49^d±0.03	6.45^c±0.02
24	5.52^b±0.02	6.09^a±0.02	5.37^b±0.02
48	4.60^a±0.10	5.40^b±0.10	4.95^a±0.03
72	4.50^a±0.10	4.75^a±0.02	4.95^a±0.03
96	4.50^a±0.10	4.70^a±0.02	4.95^a±0.00

Values are means ± standard deviations of replicate measurements. The The mean values in the same row followed by different superscripts are significantly different (*P*=0.05).

Key:

NGPF = non-gelatinized plantain flour, G18PF = 18% gelatinized plantain flour, G100PF = 100% gelatinized plantain flour

Oil Absorption Capacity (OAC) decreased in fermented samples. The OAC values ranged from 0.77 ± 0.00 g / ml for sample G18FPS to 1.44 ± 0.00 g / ml for sample G100PS. The optimization effect of gelatinization and fermentation led to a significant increase *(P* =0.05) in OAC in the samples.

The water absorption capacity (WAC) was higher in test samples than in control samples. Gelatinization led to an increase in WAC, while fermentation led to a decrease. The highest

WAC (2.68 ± 0.00 g/mL) was recorded by the G100PS samples, while the lowest (1.77 ± 0.00 g/ml) was recorded by the control sample NGFPS. Changes made by gelatinization and fermentation were significant at $P = 0.05$.

The packed bulk density values ranged from 0.69 ± 0.00 g/mL in sample G100FPS to 0.94 ± 0.00 g/mL in sample NGNFPS. Both starch gelatinization and fermentation led to a decrease in bulk densities of the flour. These values were lower in test samples than in control samples. However, this decrease was not significant at $P = 0.05$ for fermentation (Table 2).

- **Appreciation of the palatability of gruels made from the various formulations.**

The SC sample recorded the highest score of 6.67 ± 0.49 for appearance. This value was significantly different from all other treatments at $P = 0.05$, *the* values recorded for all other treatments did not differ significantly.

Sample SC also recorded the highest score of 5.80 ± 0.77 for aroma, while the least score of 4.05 ± 0.12 was recorded by sample G100FPS. These values were not significantly different at P=0.05.

The Sample SC was also ranked highest in terms of taste (5.47 ± 1.46), while the sample G100FPS registered the lowest score (3.07 ± 0.24) for taste. These values were not significantly different at P=0.05.

In terms of texture, sample SC recorded the lowest score of 3.13 ± 1.64, the value being significantly different from all other samples, while sample G18PS recorded the highest score of 5.20 ± 1.15, not significantly different from the other plantain and soybean treatments.

Overall, sample G18PS was ranked best with a score of 5.13 ± 0.64, while sample G100FPS was rated least with a score of 4.00 ± 0.8. These values were not significantly different at $P = 0.05$ (Table 3).

Table 2: Functional Properties of Plantain and Soy Complementary Foods as Influenced by Gelatinization and Fermentation

Parameter (g/mL)	Sample

	NGNFPS	NGFPS	G18PS	G18FPS	G100PS
PBD	0.94^{c}±0.00	0.92^{c}±0.00	0.87^{b}±0.00	0.86^{b}±0.00	0.70^{a}±0.01
WAC	1.95^{b}±0.00	1.77^{a}±0.00	2.48^{h}±0.00	2.27^{f}±0.00	2.68^{k}±0.00
OAC	1.16^{g}±0.00	1.14^{f}±0.00	1.42^{j}±0.00	0.77^{a}±0.00	1.44^{k}±0.00

Values are means ± standard deviations of replicate measurements. Mean values in the same row followed by different superscripts are significantly different (*P*= .05).

Key:

NGNFPS = non-gelatinized, non-fermented plantain-soy blend, NGFPS = non-gelatinized, fermented plantain-soy blend, G18PS=18% gelatinized plantain-soy blend, G18FPS=18% gelatinized and fermented plantain-soy blend, G100PS= 100% gelatinized plantain-soy blend, G100FPS= 100% gelatinized and fermented plantain-soy blend

PBD=packet bulk density, WAC=water absorption capacity, OAC=oil absorption capacity,

Table 3: Mean sensory scores of complementary foods from plantain and soybean formulations, and super cereal

Attributes	Mean Score				
	NGNFPS	NGFPS	G18PS	G18FPS	G100PS
Appearance	3.93^{ab}±0.88	3.86^{ab}±0.86	3.60^{ab}±0.91	3.93^{ab}±0.96	4.07^{ab}±0.88
Aroma	5.27^{ab}±1.33	4.50^{ab}±1.61	4.87^{ab}±1.60	5.00^{ab}±1.41	4.15^{ab}±0.30
Taste	4.87^{ab}±0.64	4.86^{ab}±0.66	5.40^{bc}±1.13	5.00^{abc}±0.91	3.47^{ab}±0.12
Texture	4.47^{bc}±1.13	4.71^{bc}±0.99	5.20^{c}±1.15	4.53^{bc}±1.06	3.57^{ab}±0.11
Overall A.	4.40^{b}±0.83	4.07^{ab}±0.73	5.13^{ab}±0.64	5.00^{ab}±0.85	4.07^{a}±0.85

Key: NGNFPS = non-gelatinized, non-fermented plantain-soy blend, NGFPS = non-gelatinized, G100FPS= 100% gelatinized and fermented plantain-soy blend, SC = Super cereal from WFP

- **Rheological properties of gruels of plantain and soybean complementary foods as influenced by gelatinization and fermentation**

For all samples, the curves for viscosity versus shear rate showed that an increase in shear rate led to a decrease in viscosity. Gelatinization and fermentation led to a decrease in viscosity (Figure 3). Curves for viscosity against concentration showed an increase in viscosity with an increase in gruel concentration. This was not the same for the NGNFPS control sample, where there was a decrease in viscosity with an increase in concentration, up to a critical point (12, 700) for rpm 6, (11, 400) for rpm 12, (11, 500) for rpm 30 and (10, 10,000) for rpm 60. After the critical point, an increase in concentration led to an increase in viscosity (Figure 4).

The flow behavior index (n) decreased with increasing sample concentration. The values of n were higher in the control than in the test samples. The consistency Index (m) increased with sample concentration. These values were decreased by gelatinization and fermentation (Table 4).

Figure 3. Effect of shear rate on the viscosity of complementary food formulations

Figure 4: Effect of concentration on viscosity (at rpm 6, 12, 30 and 60) of gruels from plantain and soybean complementary food as influenced by gelatinization and fermentation

Table 4: Power-law model of plantain and soybean complementary foods as influenced by gelatinization and fermentation

Flow index	Concentration (%)	Product			
		NGNFPS	NGFPS	G18PS	G18FPS
n	5	0.71	0.64	0.57	0.51
	10	0.57	0.51	0.41	0.45
	15	0.46	0.43	0.33	0.40
	20	-	0.34	-	0.27
m	5	45.12	7.85	3.3	6.17
	10	637.78	217.02	3,51	33.45
	15	688.15	589.93	76.08	197.67
	20	-	696.93	-	596.93

Key:

n: Flow behavior index, m: Consistency index

NGNFPS = non-gelatinized, non-fermented plantain-soy blend, NGFPS = non-gelatinized, fermented plantain-soy blend, G18PS=18% gelatinized plantain-soy blend, G18FPS=18% gelatinized and fermented plantain-soy blend, G100PS= 100% gelatinized plantain-soy blend, G100FPS=100% gelatinized and fermented plantain-soy blend

- **DISCUSSION**

4.1. Physicochemical properties of complementary foods

While pH decreased, TTA increased during accelerated natural fermentation. Fermentation, an anaerobic process, involves the breakdown of starch by facultative anaerobic microorganisms such as Lactic Acid Bacteria (LAB). These LABs produce high amounts of lactic acid and very little acetic acid. This leads to a rapid drop in pH (Agbor, B. Tiku, and Hermann 2022). By lowering the pH of the medium, these lactic acid bacteria also inhibit the growth of other pathogenic organisms during solid state fermentation (Ghosh 2015). Backslopping allowed the elimination of pathogenic microorganisms and the establishment of a stable microbial community in the LAB. Decrease in pH and increase in TTA during fermentation was also reported by Agbor et al. (2022), working on cassava fermentation during water fufu production.

The functional properties of a material are parameters that determine its application and end-use. These properties indicate how the food materials under examination will interact with other food components directly or indirectly, affecting the processing applications, food quality, and ultimate acceptance (Awoyale, Oyedele, and Maziya-Dixon 2020).

Oil absorption capacity (OAC) is the ability of the flour protein to physically bind fat by capillary action (Lasekan and Shittu 2019). It is a measure of the ability of food material to absorb oil (Awoyale et al. 2020). This property is very important, as it increases mouthfeel and serves as a flavor retainer in foods (Lasekan and Shittu 2019). Fermentation led to a decrease in the OAC of the samples, while the combined effect of gelatinization and fermentation led to an increase in the OAC. Similar findings were made by Lasekan & Shittu (2019), where solid-state fermentation led to a decrease in OAC of plantain flour, and also by Igbabul et al. (2014) working on fermentation of mahogany bean. During fermentation, dissociation and denaturation of proteins may take place, and this may expose the polar amino acid of plantain proteins, thereby promoting the hydrophobicity of such proteins (Lasekan and Shittu 2019).

Starch gelatinization increased the WAC, while fermentation led to a decrease. Values were higher in test samples than in control samples. WAC represents the ability of the product to associate with water under conditions where water is limited (Awoyale et al. 2020). Similar reports of high WAC during blanching were given by Olatunde et al., (2017). High WACs were also recorded when plantain flour was blanched at 100 ° C for 5, 10 and 15 minutes (Oluwalana et al., 2011). Similarly, Lin in Osundahunsi (2006) opined that heat denaturation improved the water imbibing capacity of sunflower proteins. The WAC results obtained in this study are contrary to those reported by (Falola et al. 2015), stating that fermentation and blanching led to a decrease in the WAC of green plantain flour. The higher WAC recorded could probably be due to the presence of crude fiber, which is known for its ability to absorb water and swell. The increase in the water absorption capacity implies a high digestibility of the starch (Falola et al. 2015).

Packed bulk density values ranged from 0.69±0.00 g/mL to 0.94±0.00 g/mL and were decreased by both the degree of gelatinization and fermentation. These values were higher in control samples than in test samples. The bulk density gives an indication of the relative volume of packaging material required. The bulk density is related to the reduction in particle size, which is evidence of the milling of the product. In addition, bulk density is an indication of the porosity of a product, which influences the packaging design and could be used to determine the type of packaging material required. A low bulk density is an advantage in bulk storage and transportation of flour (Falola et al. 2015). A decrease in bulk density in test samples is in line with the work of Oluwalana et al. (2011a), who reported that bulk density of plantain flour samples reduced with blanching. Karim et al. (2020) also reported a decrease in bulk density during blanching. Ogodo et al. (2016) also reported a decrease in bulk density when maize was fermented naturally. These results were, however, contrary to those of Falola et al. (2015), who reported that bulk density of flour is not affected by factors such as blanching and temperature but is affected by factors such as particle size. (Borremans et al. 2020) reported an increase in bulk density during fermentation of mealworm powders. The decrease in bulk density in gelatinized samples may be due to changes in the porosity of starch present in plantains, which subsequently decrease the bulk density (Fadimu et al. 2018). Low bulk density in foods is advantageous in weaning food formulations, as it promotes the digestibility of the formula, especially among children with an immature digestive system (Belkacemi 2022).

- **Palatability of Gruels of Complementary Foods from Plantain and Soybean as Influenced by Gelatinization and Fermentation**

The sample SC was preferred for appearance and aroma. This sample had a bright attractive colour that was quite distinct from all other plantain-soy formulations. The brighter color of the corn flour compared to the plantain flour could be responsible for the attractive color of the sample SC.

The preference of the sample G18PS for taste could be due to its high OAC content, which improves mouthfeel.

The sample SC contains milk and vegetable oil, which could explain the preferred aroma.

Insignificant differences in all sensory parameters above suggest that all the food formulations could be consumed with little difference in preference, with none of the samples recording a mark below average. Sample G18PS emerging overall accepted goes in line with works of Xu et al., (2021), who postulated that the degree of starch gelatinization plays a very important role in imparting desirable product texture. However, the overall nonsignificant difference in samples G18PS and G18FPS go in line with Aduke, (2017) who stated that fermentation led to an improvement in the colour, taste, aroma and texture of products obtained from plantain flour,

• Rheological Properties of Gruels from Plantain and Soybean Complementary Foods as Influenced by Gelatinization and Fermentation

Food systems are complex systems that will behave differently with applied stress and shear as a result of pretreatments. At comparable slurry concentrations, gelatinization and/or fermentation resulted in a significant decrease in gruel viscosities compared to the non-gelatinized-nonfermented samples. Similar results were obtained by Ariahu et al. (1999b) , recording a decrease in viscosity as a result of germination and fermentation with an increase in the shear rate. The reduction in viscosity in the gelatinized and fermented samples could be due to the breakdown of macromolecules into smaller units. This reduction in viscosity is nutritionally advantageous, as the food could be easily swallowed by babies, as well as increase digestibility. This decrease in viscosity due to gelatinization and fermentation is also advantageous because, at comparable consistencies, more nutrients could easily be added to the gelatinized fermented samples compared to the non-gelatinized-nonfermented ones.

The decrease in viscosity with increasing concentration for the NGNFPS control sample shows that the fluid undergoes shear thinning to a critical point, showing pseudoplastic behavior. Thus, the viscosity versus concentration plot was biphasic with a critical point. This biphasic behavior could be the result of interaction between food molecules. At given concentrations, especially for non-gelatinized products, there will be an association, while at other concentrations, there will be dissociations. This association and dissociation could be responsible for alignment of the molecules, hence the biphasic behavior. In degraded molecules, the J curves are as a result of the interaction forces, such as collision and cohesion, and external friction between solid particles which are mainly determined by the particle shape. In terms of pumping requirements, the NGNFPS sample will require a higher energy input to move the products from one point to another in the factory.

Decrease in viscosity with increasing shear rate shows that the formulations are non-Newtonian fluids, exhibiting pseudoplastic behavior. While viscosity of Newtonian fluids is constant with increased shear rate, the viscosity of pseudoplastic fluids decreases with increase in shear rate. Power law is the simplest model that approximates the behavior of a non- Newtonian fluid. Polymers have a power law coefficient (n) and a consistency index (m) (equation 1) that describe their general viscosity with respect to changing temperatures and shear rate.

According to the power law model,

(1)

Where;

μ= viscosity, =shear rate, m= consistency index and n= flow behavior index

For Newtonian fluids, n=1. If $0 < n < 1$, then the fluid shows pseudoplastic or shear thinning behavior. The further n is from one, the greater the degree of thinning. Lower n values in test samples than in the control samples is advantageous in the mixing ability, pumping ability and pouring ability of industrial products. The tolerance of these products to strain guarantees a longer shelf life than in the control samples.

• CONCLUSION

The pre-gelatinization of plantain starch prior to fermentation and the combination with soybean flour in complementary foods formulations improved acceptability and reduced the bulk of gruels. At comparable slurry concentrations with non-gelatinized-nonfermented samples, gelatinization and/or fermentation resulted in significant decrease in gruel viscosities with a change in flow behavior indices (n) from pseudo-plastic (n<1) towards Newtonian (n=1) patterns. This is advantageous for improvements in the density of nutrients. Gelatinization and natural fermentation are adaptable technologies, especially at rural levels, for improving acceptability and bulk reduction of resistant starch-based complementary foods.

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Abbreviations

NGNFPS= non-gelatinized non-fermented plantains and soybeans

G18PS= 18% gelatinized plantain and soybean

G100FPS= 100% gelatinized and fermented plantain and soybean

cP= Centipoise