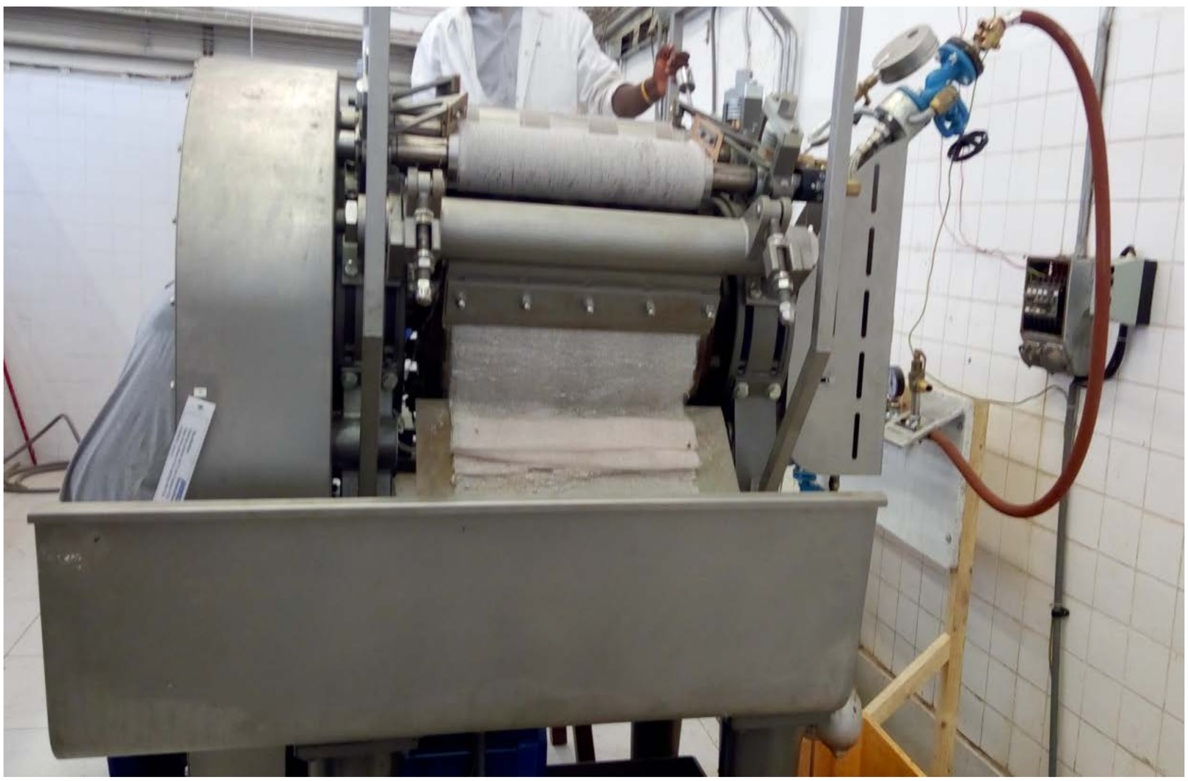
TECHNICAL REPORT SUBMITTED TO CSIR-FOOD RESEARCH INSTITUTE

PHYSIOCHEMICAL AND FUNCTIONAL PROPERTIES OF PLANTAIN, COCOYAM YAM FUFU FLOURS AND MAIZE FLOUR PRODUCTION USING A DRUM DRYER



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1.0 Background and Justification

Plantain, roots and tuber are a second source of carbohydrate in Africa and are largely produced in its regions. Africa contributes approximately 33% of the world's roots and tuber production (FAOSTAT, 2013). The continent produces 96% of the world's yams and 70% of other root crops (FAOSTAT, 2000). The Sub-Saharan region has been reported to have produced about 254 million tonnes of roots and tuber crops in 2012 (FAOSTAT, 2013). Ghana is one of the leading producers and consumers of plantain, cassava, yam and cocoyam in Sub-Saharan Africa. In 2012, it produced as much as 1,270,000 Mt of Cocoyam, 3556,000 Mt of Plantain and 6,639,000 Mt of Yam (MoFA, 2013). These major sources of carbohydrates are predominantly consumed by boiling and eating with sauces or pounded into a wet paste, commonly known as *fufu*. *Fufu* is a staple food consumed in most parts of the country and is prepared by using plantain, cassava, cocoyam and yam or a combination of these roots and tubers. Traditionally, it is prepared by pounding in a wooden mortar to produce a wet paste or dough.

Production and export of plantain, roots and tubers contribute immensely to the socio-economic growth and development of Ghana. These crops are highly perishable. Involvement of industry in post-harvest management of these crops through value addition would have best curbed this problem; unfortunately, involvement is minimal compared to production quantities of these crops. These challenges have greatly contributed to highly significant effects of post-harvest losses till date. Losses are evident in varied forms such as loss of quality, spoilage and nutritional losses (Boxall, 2001). These post-harvest deteriorations directly and indirectly contribute to economic losses (Naziri *et al*., 2014). Curbing post-harvest losses of plantains, roots and tuber will directly reduce their shortage (due to seasonality) throughout the year and improve food security.

In Ghana, poor post-harvest management systems allow factors such as mechanical damage, physiological conditions (maturity, respiration, water loss and sprouting) as well as pests and diseases to contribute largely to losses of plantains, roots and tuber. Over the years, extensive measures have been taken to educate farmers on storage of these crops. With increasing production quantities, focus has been laid on production of flours from these crops. Therefore, the concept of *fufu* flours was born. The *fufu* wet paste contains about 50% of moisture, thus, rendering it highly perishable (Oguntunde *et al.*, 1991). This conventional way of *fufu* preparation (pounding) has posed many quality and health issues for decades. Food scientists and technologists thus, aimed at introducing *fufu* flours with same or similar taste, texture and other physicochemical characteristics to those of the wet paste. Therefore, in producing *fufu* flours, a major focus is placed on the drying method which contributes vastly to the properties of the paste. According to Sanni *et al*., 2000, the optimum temperature for drying *fufu* flours in order to attain the best organoleptic characteristics is 65^0C. The drying of plantain, roots and tuber flours involving solar drying takes 2 to 3 days for optimum drying. Commercial drying of these flours involves the use of ovens, cabinet and rotary dryers. One of the most effective ways of drying is by the use of drum driers, also known as roller driers. Drum drying is one of the most energy efficient forms of drying and has been used in food industries for centuries. It is used for drying various food products in the form of slurry or puree into flakes which are later ground to powder. Drum drying is very efficient for drying highly viscous foods such as gelatinized and cooked starch. The dried products of this type of drying rehydrates better. It operates by uniformly spreading slurry of the product onto pre-heated slowly rotating steel drums. The dried product on the drum is scrapped off by a blade in contact with the surface of the drum (Fellows, 2000). Oven drying has been reported to have lesser acceptability rate compared to the wet paste (Akingbala *et al*., 1991). Solar, rotary and cabinet drying methods however, produce more acceptable products than oven drying. Rotary drying has been reported by Sanni and Akingbala, 2000, to produce more acceptable *fufu* flour with close physicochemical properties to the wet *fufu* paste. This study is therefore, aimed at elucidating the physiochemical and functional properties of plantain, yam and cocoyam flours (for *fufu* flours) and fermented maize flour using a drum dryer.

The objective of this study was to develop optimum slurry and speed of drum dryer for production of *fufu* flour. The efficacy of the drum dryer was tested by drying fermented maize, blanched and unblanched mashed plantain, cocoyam and yam.

2.0 MATERIALS AND METHODOLOGY

2.1 Materials

Figure 2.0: Picture showing plantains **Figure 2.1: Picture showing cocoyam tubers**

Figure 2.2: Picture showing Yam Tubers **Figure 2.3: Picture showing maize grain**

2.2 Methodology

2.2.1 Pretreatments: Blanching and Unblanching of plantain

2.2.1.1Blanching

Plantain (42.6kg) was used for blanching. It was peeled and cut into smaller sizes which weighed 26kg. The cut plantains were dipped into boiling water at a temperature of 97.3ºC The blanched plantains pieces were milled using 17 Liters of water to attain a weight of 40.5kg.

2.2.1.2 Unblanching

Plantain (21kg) was used; the weight after peeling was 10 kg. The peeled plantains were cut into small sizes for easy milling. Cut plantains were placed in water to prevent discoloration. Water (7litres) was used during milling. A weight of 12kg was attained.

2.2.2Preparation of Slurry for Blanched and Unblanched Plantain

2.2.2.1 Blanched Plantain

Ten **(**10) liters of water was initially added to 20 kg of blanched milled plantain to prepare slurry. The slurry was sub divided into 3 (three) portions where different liters of water was added and dried at a speed of 35rpm^{-1}. Additional 18 kg of blanched plantain was made into slurry which was divided into 2 portions and drum dried at a speed of 45rpm^{-1}. The following treatments were drum dried;

10 kg of blanched milled plantain was mixed 7.7 liters of water**,** 5 kg of blanched milled plantain was mixed with 10 liters of water**,** 12 kg of blanched milled plantain was mixed with 12 liters of water at a speed of 35rpm^{-1} and 45rpm^{-1}**,** 6 kg of blanched milled plantain was added to 5 liters of water and drum dried at a speed of 35rpm^{-1}

Figure 2.4: Picture showing sliced plantain during Blanching

2.2.2.2 Unblanched Plantain

Nine (9 kg) unblanched plantain was used for the drum dryer trials. This was further sub divided into 3 (three) portions as follows;

3kg of unblanched plantain was mixed with 2 liters of water and drum dried at a speed of 35rpm^{1}**,** 3kg of unblanched plantain was mixed with 2liters of water and drum dried at a speed of 35rpm^{-1}and 3kg of unblanched plantain was mixed with 1liter of water and drum dried at a speed of 35rpm^{-1}

2.2.3 Blanched and Unblanched Pretreatment for Yam and Cocoyam

2.2.3.1 Preparation of Slurry for Yam and Cocoyam

The preparation of slurry before drum drying of yam and cocoyam followed the same procedure as the plantain with the exception of varying proportions of slurry. Both yam and cocoyam were blanched. Yam (27 kg) and cocoyam (21 kg) were used for the study. 4 liters (blanched) and 2 liters (unblanched) of water was used for milling. Varying proportions of slurry for yam included; 3kg of blanched yam was mixed with 2 liters of water and drum dried at a speed of 25rpm^{-1},3kg of unblanched yam was mixed with 3 liters of water and drum dried at a speed of 25rpm^{-1}, 3kg of unblanched yam was mixed with 2 liters of water and drum dried at a speed of 25rpm^{-1},3kg of unblanched yam was mixed with 1 liter of water and drum dried at a speed of 25rpm^{-1}

The varying proportions of slurry for blanched cocoyam involved;

2 kg of blanched cocoyam was mixed with 3 liters of water and drum dried at a speed of 25rpm^{-1},

2 kg of blanched cocoyam was mixed with 2 liters of water and drum dried at a speed of 25rpm^{-1},

2 kg of blanched cocoyam was mixed with 1 liter of water and drum dried at a speed of 25rpm^{-1}

Figure 2.5: Picture showing sliced cocoyam during blanching

3kg of unblanched cocoyam was mixed with 2 liters of water and drum dried at a speed of 25rpm^{1},

3kg of unblanched cocoyam was mixed with 1 liter of water and drum dried at a speed of 25rpm^{1},

3kg of unblanched cocoyam was mixed with 1 liter of water and drum dried at a speed of 15rpm^{-1}

2.2.4 Preparation of Fermented Maize dough

Maize grains (62.1kg) was steeped in water for 3 days to undergo spontaneous fermentation. The steeped grains were washed and milled using the Royal grinding mill (No 2A, 500RPM). The weight of milled maize was 92 kg. An amount of water was added to the maize meal and fermented for 2 days.

2.2.4.1 Preparation of Slurry for Fermented Maize dough

Slurries were prepared using 5 kg of fermented maize which was mixed with 5; 4; 3.5; 3 liters of water. The varying proportions of slurries were dried using a Gouda drum dryer (Andritz Gouda Coenecoop 88 2741 PD Waddinxveen-Holland) at a speed of 35rpm^{-1}.

Figure 2.6: Picture showing fermented maize dough

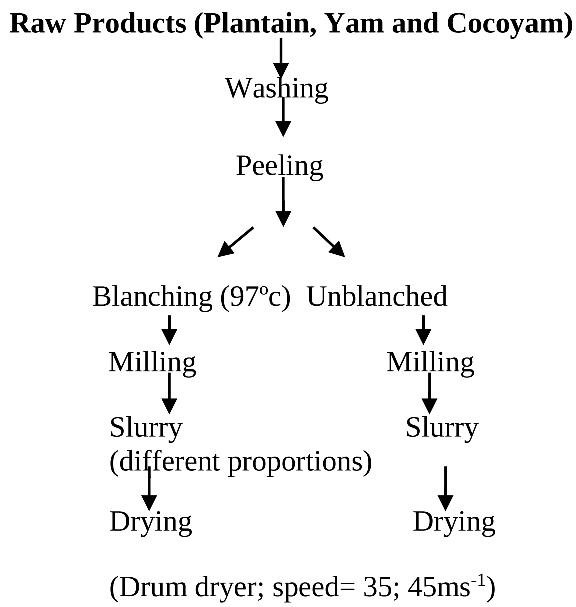

Figure 2.7: Flow charts showing the unit operations in the production of Plantain, Yam and Cocoyam flour

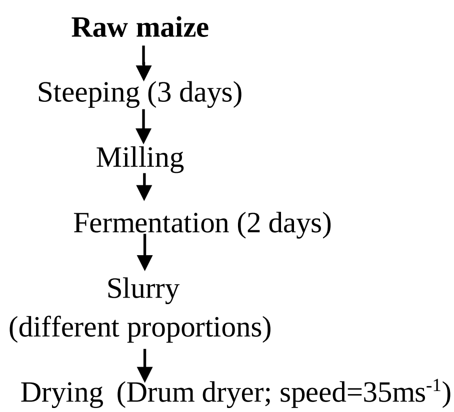

Figure 2.8: Flow charts showing the unit operations in the production of maize flour

2.2.5 Formulation of plantain flour, yam flour and cocoyam flour and fermented maize flour

The formulation of fufu flour was done using the ratio's below: 5 parts plantain to 3 parts of cassava starch; 2 parts of yam to 1 parts of cassava starch (the same ratio for cocoyam).

The formulation for banku mix flour was done using 2 parts of fermented maize flour to 1 parts of fermented cassava dough flour.

2.2.6 Physiochemical analysis

2.2.6.1 Moisture

Three grams (3g) each of the samples were weighed in triplicates and dried at 105ºC in an air oven (BS Gallenkamp, England) to a constant weight. Samples were removed, cooled in a desiccator and weighed. The procedure was repeated for each sample and the moisture content calculated and expressed as a percentage of the mass of sample taken (AOAC 1990).

2.2.6.2 pH

The pH of samples were determined using Hanna pH meter (H14222) which was previously standardized with buffers 4 and 7. One gram of the sample was weighed, dissolved in 10 ml of distilled water to form slurry and allowed to stand for 10 minutes. The pH of the slurry was measured with pH meter.

2.2.6.3 Color

The CIE tristimulus L*, a* and b* parameters were determined using chroma meter (CR-410, Konica Minolta Sensing Inc., Osaka Japan). The colorimeter operates on the CIE L, a and b color schemes, L (lightness) axis-0 is black, 100 is white, a (red-green) axis- positive values are red;

negative values are green and 0 is neutral, b (yellow-blue) axis- positive values are yellow; negative values are blue and 0 is neutral. The instrument was standardized and the samples were placed in the sample holder. Color measurement was determined in triplicates. Color intensity was calculated using the equation:

$\Delta E = \sqrt{} (\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2$

2.2.7 Determination of Functional Properties

2.2.7.1 Swelling Power and Solubility

Swelling power and Solubility determinations were carried out based on a modification of the method of Oduro *et al*., (2006). One (1g) of flour was transferred into a weighed graduated centrifuge tube (10ml). Distilled water was added to give a total volume of 10 ml. The suspension was stirred just sufficiently and uniformly avoiding excessive speed since it could cause fragmentation of the starch granules. The sample in the centrifuge tube was heated at 85ºC in a thermostatically controlled temperature water bath (Grant instruments, England LTD) for 30 minutes with constant stirring. The tube was then removed, wiped dry on the outside and cooled to room temperature. It was centrifuged (Mistral 3000i UK) for 15 minutes at 2200 rpm. The solubility was determined by evaporating the supernatant and weighing the residue. The sediment paste was weighed. The percentage solubility and swelling power were then calculated.

$$\text{Swelling power} = \frac{\text{Weight of sedimented paste}}{\text{Weight of initial sample (dry basis)- weight of sample which dissolves away}} \times 100$$

$$\%\ \text{Solubility} = \frac{\text{Weight of Soluble Sample}}{\text{Weight of sample (dry basis)}} \times 100$$

2.2.7.2 Water Binding Capacity

Water binding capacity of the flour was determined by the method Medcalf and Gilles (1965). An aqueous suspension of flour was made by dissolving 2g of flour in 40 ml of distilled water. The suspension was agitated for one hour on a Griffin flask shaker (HS501, digital, Janke 7 Kintel GMBH & CO.KG), after which it was centrifuged (Mistral 300E, UK) for 10 minutes at 2200 rpm. The free water was decanted from the wet flour, drained for 10 minutes and the wet flour weighed. The water binding capacity was then calculated. Determinations were done in triplicate

$$\text{Water binding Capacity} = \frac{\text{Bound Water}}{\text{Weight of sample}} \times 100$$

2.2.8 Cooking of fufu flour and banku mix

Fufu flour and banku mix were prepared by mixing each weighed flour with varying amount (millimeters) of water. It was cooked by continuous stirring on a moderate heat for 3 minutes and molded unto a coded plate for sensory evaluation. Preparation of fufu flour from varying proportion of blanched and unblanched plantain, cocoyam and yam flour were prepared as follows;

Table 2.0 Showing Preparation of fufu and banku from varying proportions of flour to water

BPFCS107.7	65.89g flour mixed with 199ml of water
UPFCS33	66.7g flour mixed with 175ml of water;
UPFCS32	61.1g flour mixed with 225ml of water;
UPFCS31	70.9g flour mixed with 185ml of water;
UYFCS32	55.2g flour mixed with 172ml of water;
UYFCS31	69.7g flour mixed with 215ml of water
UYFCS33:	30.6g flour mixed with 120ml of water
BYFCS32:	50.1g flour mixed with 150ml of water
BYFCS33	35.1g flour mixed with 120ml of water
BCFCS23	47.8g flour mixed with 120ml of water
BCFCS2	42g flour mixed with 135ml of water
BCFCS21	39.4g flour mixed with 115ml of water
UCFCS32	57.1g flour mixed with 92ml of water
UCFCS3115	28.2g flour mixed with 85ml of water
UCFCS3125	26.1g flour mixed with 85ml of water
FMFCF54	57.7g flour mixed with 189ml of water
FMFCF55	68.5g flour mixed with 225ml of water
FMFCF53.5	41.8g flour mixed with 150ml of water
FMFCF53	47.1g flour mixed with 150ml of water

2.2.9 Central Location test on Banku and Plantain, Yam and Cocoyam Fufu

Hedonic testing was used to assess consumer acceptability for banku produced from fermented maize flour and fermented cassava flour (*agbelima*), fufu flour prepared from plantain, yam and cocoyam (Blanched and Unblanched) and cassava starch. Consumers (10) were asked to score their preference for both fufu and banku using 9- point Hedonic scale (1= dislike extremely, 5= neither like nor dislike, 9= like extremely).

Figure 10: Picture showing Blanched Plantain Fufu

Figure 11: Picture showing Unblanched Plantain Fufu

Figure 12: Picture showing Blanched Yam Fufu

Figure 13: Picture showing Unblanched Yam Fufu

Figure 14: Picture showing Blanched Cocoyam Fufu

Figure 15: Picture showing Unblanched Cocoyam Fufu

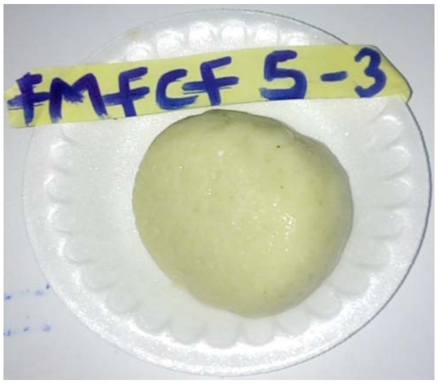

Figure 16: Picture showing Fermented Maize Banku mix

3.0 Results and Discussions

The physiochemical and functional properties of plantain, yam, cocoyam and maize (flour) produced using a drum dryer is shown in the presented tables and figures.

3.1 Physiochemical and Functional properties of Blanched and Unblanched Plantain

Table 3.0 shows the physiochemical analysis of raw plantain and Blanched mashed plantain

Table 3.0: Physiochemical analysis of raw Plantain

Sample	% Moisture	pH	Color			
			L*	a*	b*	ΔE
Raw plantain	54.82 ± 0.04	6.00±0.01	65.16±0.81	7.81±0.25	23.31±0.27	0.00±0.00
BMP	77.68 ± 0.68	5.02±0.04	58.45±0.24	3.50 ±0.09	13.24±0.14	12.85±0.20

BMP= Blanched Mashed Plantain; **L**=lightness; **a**=red(+) /green(-); **b**=yellow(+)/ blue(-); **ΔE**= Color difference

The moisture content for raw plantain is 54.82%. This value increased to 77.68% after mashing with water. Table 3.0 shows a decrease in pH from 6.0 to 5.02 after mashing. This is due to the release of hydrogen ions from the water molecules which increase the concentration of hydrogen ions, thereby decreasing the pH, and increasing the acidity. Color difference increased after mashing. The lightness (L*) value of raw plantain was 65.16, because it more yellow than white. However L* values decreased after mashing (58.45).This could also be attributed to the presence of oxygen causing the brownish discoloration of mashed plantain.

Table 3.1 shows the physiochemical analysis of blanched mashed plantain after drum drying.

Table 3.1: Physiochemical analysis of Blanched Plantain Flour (BPF)

Treatment	% Moisture	pH	Color			
			L*	a*	b*	ΔE
BP10K7.7L35	3.68 ± 0.16	5.79±0.02	66.84±0.36	-0.16±0.02	18.06±0.26	9.43±0.09
BP5K10L35	3.59 ± 0.16	5.67±0.01	70.25±0.72	-0.08±0.06	19.27±0.33	10.24±0.26
BP6K5L35	7.18 ± 0.16	5.5±0.02	75.91±0.52	-0.87±0.14	18.36±0.37	14.68±0.56
BP12K12L35	7.55 ± 0.22	5.29±0.03	73.96±0.43	-0.91±0.01	14.85±0.18	15.00±0.18
BP12K12L45	6.17 ± 0.51	5.30±0.02	73.35±0.43	-0.74±0.01	15.82±0.11	14.01±0.23

BP10K7.7L35=10kg of blanched plantain to 7.7 litres water; speed=35rpm^{-1}, BP5K10L35=5kg of blanched plantain to 10 litres water; speed=35rpm^{-1} , BP6K5L35=6kg of blanched plantain to 5 litres water; speed=35rpm^{-1}**,** BP12K12L35=12kg of blanched plantain and to 12 litres water; speed= 35rpm^{-1}, BP12K12L45= 12kg of blanched plantain to 12 litres water; speed= 45rpm^{-1}**L**=lightness; **a**=red(+) /green(-); **b**=yellow(+)/ blue(-); **ΔE**= Color difference

Table 3.1 shows physiochemical analysis of Blanched Plantain Flour (BPF). The percentage moisture after drying ranged from 3.59 to 7.55 (Table 3.1). The decreased moisture could be attributed to the temperature employed which causes distortion of cell membrane thus allowing heat to penetrate the interior of the product being dried. BP5K10L35 recorded a lower percentage moisture content of 3.59, thus the lighter the slurry, the low percentage moisture. The study also showed that speed had an effect on drying. BP12K12L45 slurry had less moisture content than that of BP12K12L35. This implies that, the higher the speed employed in drying lighter slurry, the lower percentage moisture indicating good quality of the flour.

Blanched plantain flour (BPF) showed a slight increase in pH after drying which is possibly due to less concentration of hydrogen ions. L* values increased after drying which ranged from 66.84-75.91. BPF dried at the proportion of BP6K5L35 had the highest L* value whereas BP10K7.7L35 had the lowest L* value after drying. ΔE of BPK10K7.7L35 and BP5K10L35 showed lower values of

9.42 and 10.22 respectively after drying whereas the other treatment showed higher values ranging from 14.01 to 14.68. The change in color could be attributed to the effect of drying conditions especially temperature on the color of the flour.

The physiochemical analysis of Formulated Blanched Plantain Flour and cassava starch Flour (FBPFCSF) is shown in table 3.2.

Table 3.2: Physiochemical analysis of Formulated Blanched Plantain Flour and cassava starch (BPFCSF)

Treatment	% Moisture	pH	Color			
			L*	a*	b*	ΔE
BP10K7.7L35	7.20±0.14	5.84±0.01	80.12±0.03	1.00±0.14	13.31±0.01	19.24±0.01
BP5K10L35	7.48±0.01	5.76±0.01	85.31±0.02	1.02± 0.11	13.43± 0.01	25.45±0.02
BP6K5L35	10.14±0.01	5.54±0.02	85.00±0.14	1.11±0.01	14.09± 0.01	24.63±0.01
BP12K12L35	10.28±0.04	5.40±0.35	83.79±0.01	1.09 ±0.01	11.18± 0.01	23.22±0.01
BP12K12L45	10.01±0.01	5.36±0.01	84.72±0.01	1.05± 0.01	11.47± 0.01	27.46±0.01

BP10K7.7L35=10kg of blanched plantain to 7.7 litres water; speed=35rpm^{-1}, BP5K10L35=5kg of blanched plantain to 10 litres water; speed=35rpm^{-1} , BP6K5L35=6kg of blanched plantain to 5 litres water; speed=35rpm^{-1}**,** BP12K12L35=12kg of blanched plantain and to 12 litres water; speed= 35rpm^{-1}, BP12K12L45= 12kg of blanched plantain to 12 litres water; speed= 45rpm^{-1}**L**=lightness; **a**=red(+) /green(-); **b**=yellow(+)/ blue(-); **ΔE**= Color difference

Table 3.2 shows that, BPFCSF showed increase in percentage moisture ranging from 7.20 to 10.28. Similar pH values of BPF were observed for BPFCSF which ranged from 5.36 to 5.84. L* values (BPFCSF) increased from 80.12 to 85.31 which is probably due to addition of cassava starch. The study showed increase in ΔE of BPFCSF ranging from 19.24 to 27.46 of which BP12K12L45 recorded the highest value (27.46).

The Physiochemical analysis of Unblanched Plantain Flour (UPF) is shown in table 3.3

Table 3.3: Physiochemical analysis of Unblanched Plantain Flour (UPF)

Treatment	% Moisture	Ph	Color			
			L*	a*	b*	ΔE
UP3KIL35	3.05 ± 0.40	5.79±0.01	73.75±2.02	-0.08±0.07	20.57±0.29	11.93±1.57
UP3K2L35	5.54 ± 0.32	5.77±0.01	74.95±0.92	-0.13±0.09	20.10±0.25	13.02±0.70
UP3K3L35	4.75 ± 0.07	5.80±0.02	77.85±0.32	-0.29±0.082	0.19±0.53	15.38±0.38

UP3KIL35=Unblanched plantain; speed=35rpm^{-1}, UP3K2L35=Unblanched plantain; speed=35rpm^{-1}, UP3K3L35= Unblanched plantain; speed=35rpm^{-1}**L**=lightness; **a**=red(+) /green(-); **b**=yellow(+)/ blue(-); **ΔE=** Color difference

Unblanched mashed plantain showed moisture content ranging from 3.05 to 5.54% (Table 3.3). The slurry of UP3KIL35 and UP3K2L35 recorded the lowest (3.05%) and highest (5.54%) moisture values respectively. pH value for unblanched plantain flour (UPF) increased in value from the range of 5.77 to 5.80 (Table 3.3). This could be attributed to less concentration of hydrogen ions after drying. The L* values of UP3K3L35 increased after drying. Color difference of UPF increased at the proportion of UP3K2L35 and UP3K3L35 with exception of UP3KIL35 which showed otherwise. Difference in color parameters could be attributed to non-enzymatic Maillard browning which occured under the conditions prevailing during the drying process, which would favor color change.

Table 3.4 gives the Physiochemical analysis of Formulated Unblanched Plantain flour and Cassava Starch Flour (FUPFCSF).

Table 3.4: Physiochemical analysis of Formulated Unblanched Plantain flour and Cassava Starch (UPFCSF)

Treatment	% Moisture	Ph	Color			
			L*	a*	b*	ΔE
UP3KIL35	8.81±0.02	5.49±0.01	84.57±0.10	1.02±0.00	112.22±0.10	23.36±0.01
UP3K2L35	8.96±0.10	5.52±0.01	84.63±0.29	1.09±0.02	11.45±0.04	23.77±0.01
UP3K3L35	8.95±0.12	5.65±0.03	84.94±0.27	0.90±0.03	12.15±0.26	23.48±0.01

UP3KIL35=3kg of Unblanched plantain to and cassava starch; speed=35rpm^{-1}, UPCS3K2L35=Unblanched plantain and cassava starch; speed=35rpm^{-1}, UPCS3K3L35= Unblanched plantain and cassava starch; speed=35rpm^{-1}**L**=lightness; **a**=red(+) /green(-); **b**=yellow(+)/ blue(-); **ΔE=** Color difference

Comparing unblanched plantain flour (UPF) to formulated unblanched plantain flour and cassava starch flour (UPFCSF), the study showed increase in percentage moisture from 8.81- 8.96 (Table 3.4). Similar pH values of UPF were recorded for UPFCSF ranging from 5.77 to 5.80. L* values of UPF increased from 73.75 -77.85 to 84.57-84.94 after formulating with cassava starch flour (Table 3.4). This trend is possibly due to the quantity of starch added. There was an increase in color difference at the varying proportions ranging from 23.36 to 23.77.

Figure 3.0 to 3.3 gives the functional properties of Blanched Plantain Flour and Formulated Blanched Plantain flour and Cassava Starch (BPFCS).

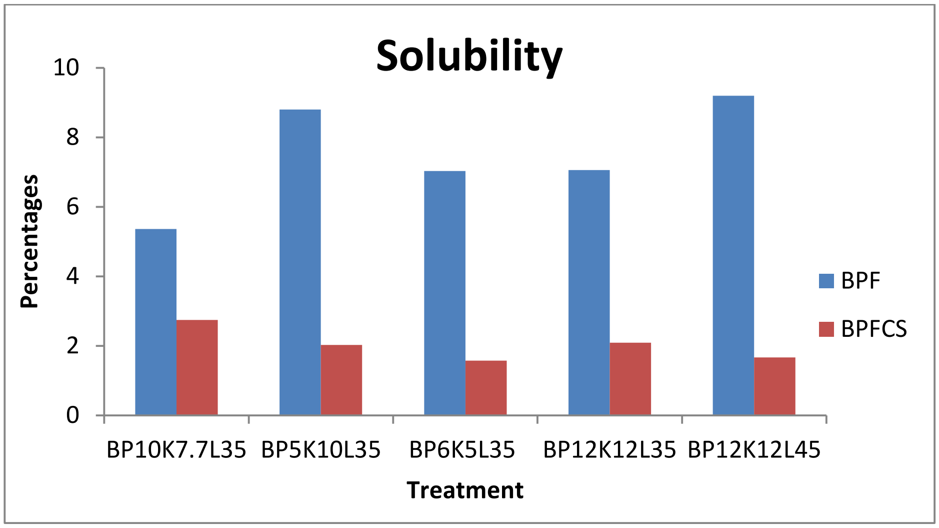

Figure 3.0: Solubility of Blanched Plantain flour **(BPF)** and Formulated Blanched Plantain Flour with Cassava Starch (**BPFCS**);**BP10K7.7L35**=10kg of blanched plantain to 7.7 litres water; speed=35rpm^{-1}, **BP5K10L35**=5kg of blanched plantain to 10 litres water; speed=35rpm^{-1} , **BP6K5L35**=6kg of blanched plantain to 5 litres water; speed=35rpm^{-1}**, BP12K12L35**=12kg of blanched plantain and to 12 litres water; speed= 35rpm^{-1}, **BP12K12L45**= 12kg of blanched plantain to 12 litres water; speed= 45rpm^{-1}

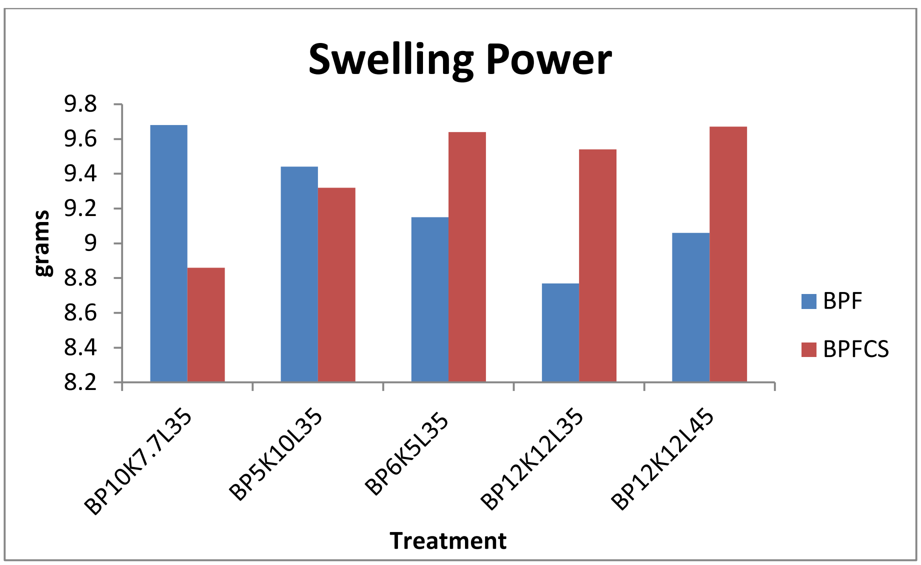

Figure 3.1: Swelling Power of Blanched Plantain flour (**BPF**) and Formulated Blanched Plantain Flour with Cassava Starch (**BPFCS**);**BP10K7.7L35**=10kg of blanched plantain to 7.7 litres water; speed=35rpm^{-1}, **BP5K10L35**=5kg of blanched plantain to 10 litres water; speed=35rpm^{-1} , **BP6K5L35**=6kg of blanched plantain to 5 litres water; speed=35rpm^{-1}**, BP12K12L35**=12kg of blanched plantain and to 12 litres water; speed= 35rpm^{-1}, **BP12K12L45**= 12kg of blanched plantain to 12 litres water; speed= 45rpm^{-1}

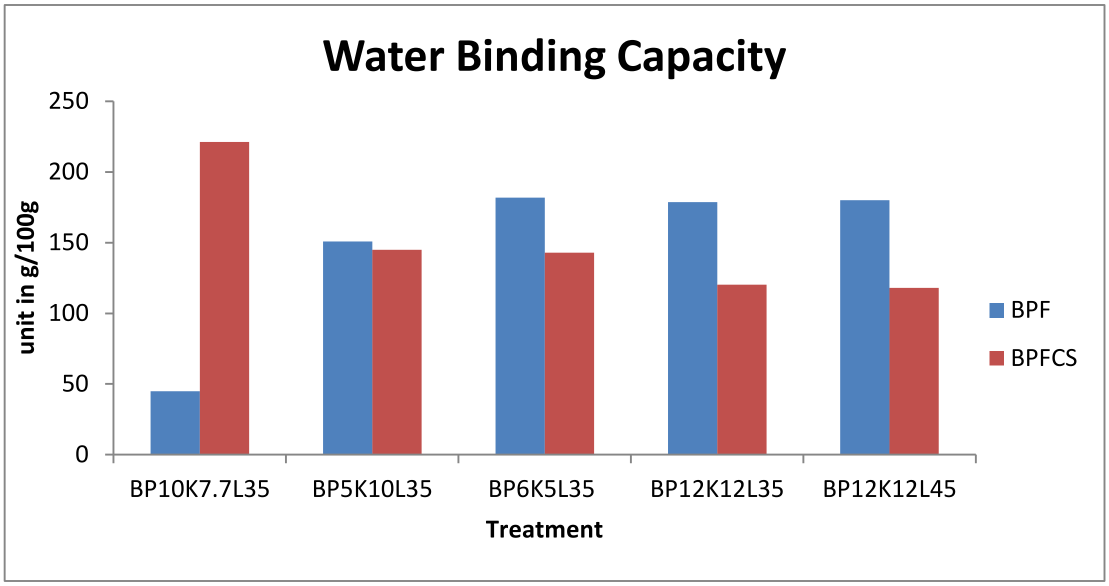

Figure 3.2: Water Binding Capacity of Blanched Plantain flour (**BPF**) and Formulated Blanched Plantain Flour with Cassava Starch (**BPFCS**)**BP10K7.7L35**=10kg of blanched plantain to 7.7 litres water; speed=35rpm^{-1}, **BP5K10L35**=5kg of blanched plantain to 10 litres water; speed=35rpm^{-1} , **BP6K5L35**=6kg of blanched plantain to 5 litres water; speed=35rpm^{-1}**, BP12K12L35**=12kg of blanched plantain and to 12 litres water; speed= 35rpm^{-1}, **BP12K12L45**= 12kg of blanched plantain to 12 litres water; speed= 45rpm^{-1}

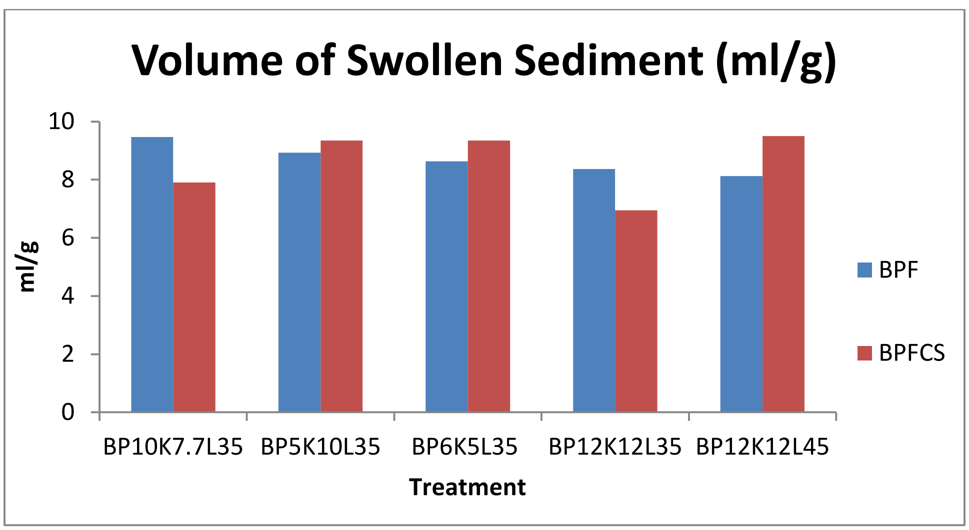

Figure 3.3: Volume of swollen sediments of Blanched Plantain flour (**BPF**) and Formulated Blanched Plantain Flour with Cassava Starch (**BPFCSF**) **BP10K7.7L35**=10kg of blanched plantain to 7.7 litres water; speed=35rpm^{-1}, **BP5K10L35**=5kg of blanched plantain to 10 litres water; speed=35rpm^{-1} , **BP6K5L35**=6kg of blanched plantain to 5 litres water; speed=35rpm^{-1}**, BP12K12L35**=12kg of blanched plantain and to 12 litres water; speed= 35rpm^{-1}, **BP12K12L45**= 12kg of blanched plantain to 12 litres water; speed= 45rpm^{-1}

The Functional Properties of Blanched Plantain Flour (BPF) and Formulated Blanched Plantain flour and Cassava Starch Flour (BPFCSF) is given in figure 3.0 to 3.3. BPFCSF had the lowest solubility value varying from 1.57 to 2.74% whereas BPF recorded the highest solubility ranging from 5.36 to 9.19% (figure 3.0). High solubility of BPF could possibly be due to texture modifying action of citric acid which enhanced flexibility of the flour in food preparation (Owuamanam, 2007). BPF and BPFCSF showed similar values for swelling power (8.77 to 9.68g) and volume of swollen sediment (7.9 to 9.5ml/g), figure 3.1, 3.3. However, water binding capacity of BPFCSF decreased with the exception of BPFCS10K7.7L35 which showed higher value (221.20g/100g) figure 3.2.

Figure 3.4 to 3.7 gives the functional properties of Unblanched Plantain Flour (UPF) and Formulated Unblanched Plantain flour and Cassava Starch (UPFCS).

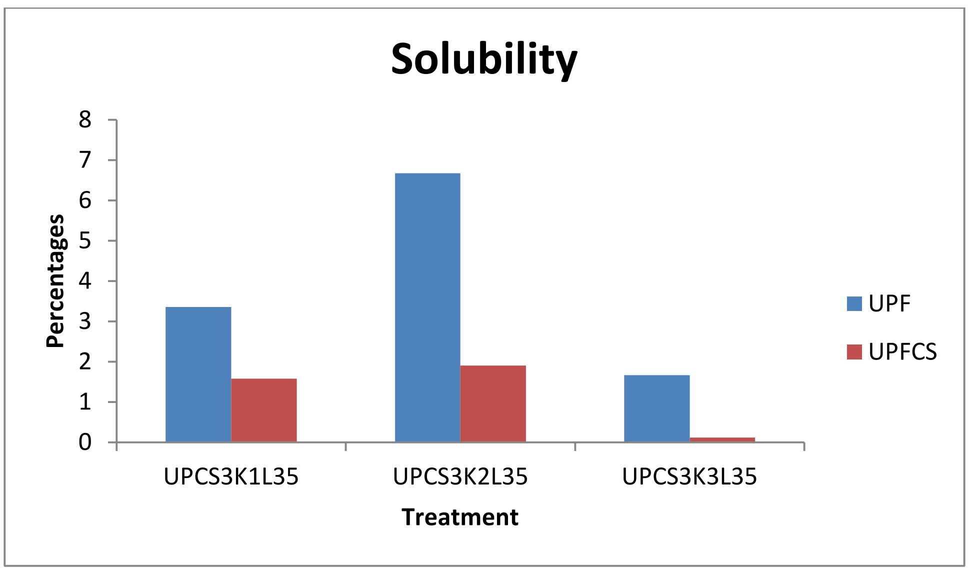

Figure 3.4: Solubility of Unblanched Plantain flour (**UPF**) and Formulated Unblanched Plantain Flour with Cassava Starch **(UPFCS)**; **UP3K1L35**=3kg of unblanched plantain to 1 litre water; speed=35rpm^{-1}, **UP3K2L35**=3kg of unblanched plantain to 2 litres water; speed=35rpm^{-1} , U**P3K3L35**=3kg of unblanched plantain to 3 litres water; speed=35rpm^{-1}**,**

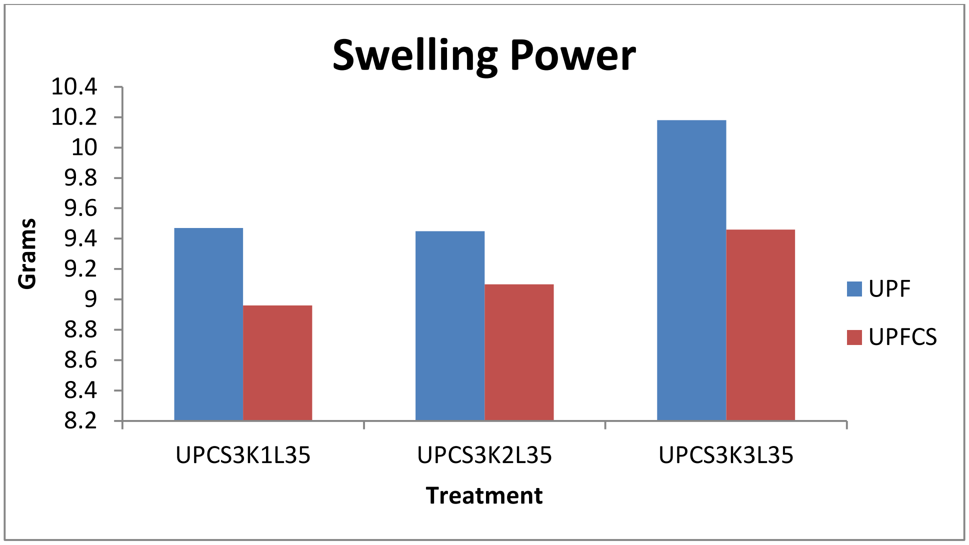

Figure 3.5: Swelling Power of Unblanched Plantain flour (**UPF**) and Formulated Unblanched Plantain Flour with Cassava Starch (**UPFCS**); **UP3K1L35**=3kg of unblanched plantain to 1 litre water; speed=35rpm^{-1}, **UP3K2L35**=3kg of unblanched plantain to 2 litres water; speed=35rpm^{-1} , U**P3K3L35**=3kg of unblanched plantain to 3 litres water; speed=35rpm^{-1}

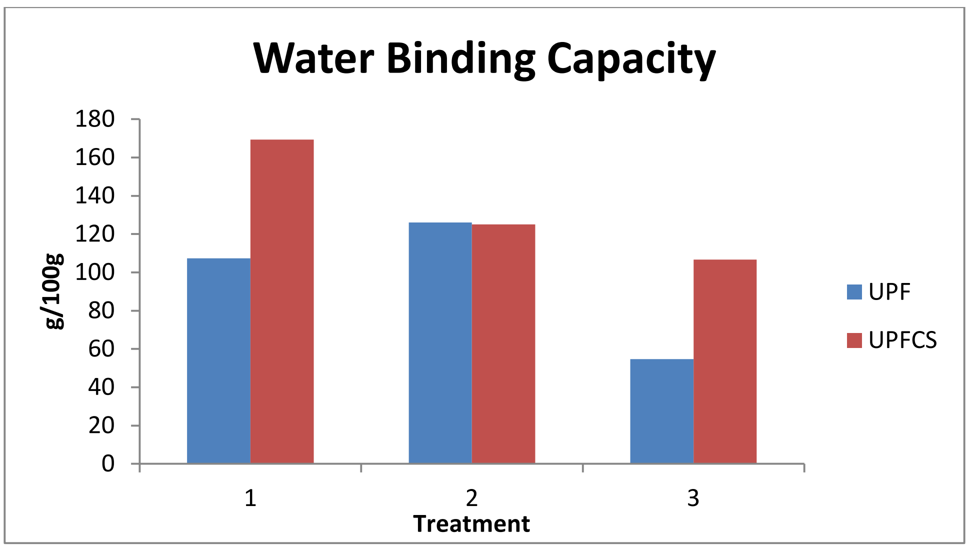

Figure 3.6: Water binding Capacity of Unblanched Plantain flour (**UPF**) and Formulated Unblanched Plantain Flour with Cassava Starch (**UPFCS**);**UP3K1L35**=3kg of unblanched plantain to 1 litre water; speed=35rpm^{-1}, **UP3K2L35**=3kg of unblanched plantain to 2 litres water; speed=35rpm^{-1} , U**P3K3L35**=3kg of unblanched plantain to 3 litres water; speed=35rpm^{-1}

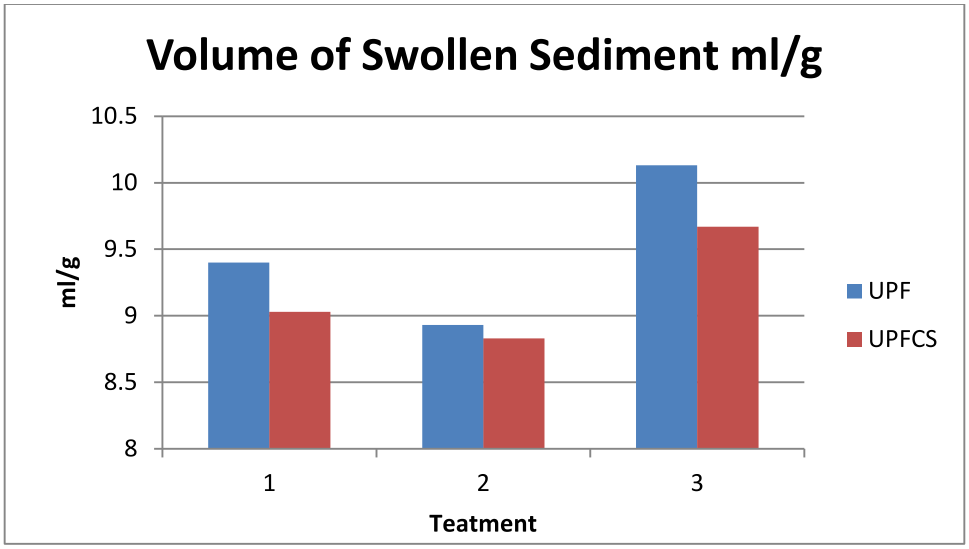

Figure 3.7: Volume of Swollen Sediments of Unblanched Plantain flour (**UPF**) and Formulated Unblanched Plantain Flour with Cassava Starch (**UPFCS**); **UP3K1L35**=3kg of unblanched plantain to 1 litre water; speed=35rpm^{-1}, **UP3K2L35**=3kg of unblanched plantain to 2 litres water; speed=35rpm^{-1} , U**P3K3L35**=3kg of unblanched plantain to 3 litres water; speed=35rpm^{-1}

The Functional Properties of Unblanched Plantain Flour (UBPF) and Formulated Unblanched Plantain flour and Cassava Starch Flour (UPFCSF) is given in figure 3.4 to 3.7. Solubility for unblanched plantain flour (UPF) and formulated unblanched plantain flour and cassava starch flour (UPFCSF) varied from 1.67 to 6.68% and 0.12 to 1.91% respectively (Figure 3.4). The solubility values of the UPF were slightly higher than that of UPFCSF. Low values for UPFCSF could be attributed to the inability of hydrogen bonds to continue to be disrupted when the aqueous suspension of flour is raised above its gelatinization range so that water molecules can become attached to the liberated hydroxyl groups (Richard *et al*., 1991). Swelling power for UPF and UPFCSF ranged from 9.45 to 10.18g and 8.96 to 9.46g respectively (figure 3.5). Results indicated that swelling power of UPF decreased after formulating with cassava starch flour and this could be attributed to the small particle size of plantain flour and its highly digestible nature (Ojinnaka *et al.*, 2009).

Water Binding Capacity of UPF ranged from 54.70 to 126.09g/100g whereas UPFCSF increased ranging from 106.71 to 169.38% (figure 3.6). High Water Binding Capacity could be attributed to lose association of the starch polymers in the native granule and low amylose content. The volume of swollen sediment showed similar results (8.83 to 10.13ml/g) for various proportions of UPF and UPFCSF (figure 3.7). This could be attributed to the bonding forces within the starch granules which influenced the swelling volume.

3.2 Physiochemical and Functional properties of Blanched and Unblanched Yam Flour

The physicochemical properties of raw and blanched yam flour are shown in Table 3.5.

Table 3.5: Physiochemical analysis of raw and Blanched Yam Flour (BYF)

Treatment	% Moisture	pH	Color			
			L*	a*	b*	ΔE
Raw yam	63.10±0.13	6.02±0.01	61.37±0.90	1.82±0.04	9.88±0.29	0.00±0.00
MBY	75.77±0.29	4.96±0.03	65.64±0.66	1.59±0.09	10.97±0.30	4.41±0.69
UMY	71.23±0.17	5.09±0.03	49.54±0.74	2.09± 0.06	9.00±0.14	11.87±0.74
Blanched yam after drying						
BY3K3L25	2.84±0.28	5.70±0.01	77.85±0.56	0.83±0.07	12.68±0.27	16.75±0.60
BY3K2L25	2.10±0.21	5.63±0.02	79.92±0.61	0.76±0.04	12.77±0.31	18.80±0.61

BY3K3L25= 3kg of blanched Yam to 3 litres water; speed=25rpm^{-1}, BY3K2L25= 3kg of blanched Yam to 2 litres water; speed=25rpm^{-1}**MBY**= Mashed Blanched Yam; **UMY**=unblanched mashed yam; L=lightness; a=red(+) /green(-); b=yellow(+)/ blue(-);**ΔE=** Color difference

Percentage moisture content of raw yam was 63.10 (Table 3.5) which reduced after drying varying proportions of slurry. Blanched yam (BY3K3L25; BY3K2L25) showed a moisture value of 2.10 and 2.84% after drying. The percentage moisture for blanched yam flour could be attributed to the permeability of the cell membrane due to partial cooking of tissues which allowed moisture to escape during drying. The study showed a decrease in pH value of raw yam (6.02) to a range of 5.63 to 5.70 after drying blanched yam (Table 3.5). The lightness of raw yam was 61.37 (Table 3.5), it increased in value after blanching and drying thus, BY3K2L25 recorded the highest L* value (79.92). Color difference of varying proportions of blanched yam increased after drying with BY3K2L25 (18.80) recording the highest value (Table 3.5).

The physicochemical analysis of unblanched yam flour is shown in Table 3.6.

Table 3.6: Physiochemical analysis of Unblanched Yam Flour (UYF)

Treatment	% Moisture	pH	Color			
			L*	**a***	**b***	**ΔE**
UY3K1L25	4.92±0.04	5.77±0.01	64.48±0.11	1.74±0.04	8.43±0.15	3.43±0.16
UY3K2L25	4.57±0.25	5.84±0.01	67.03±0.40	1.59±0.02	8.11±0.10	5.94±0.41
UY3K3L25	6.55±0.34	5.10±0.01	67.01±0.57	1.65±0.04	8.52±0.48	5.80±0.46

UY3K1L25=3kg of unblanched Yam to 1 litre water; speed=25rpm^{-1}**,**UY3K2L25= 3kg of unblanched Yam to 2 litre water; speed=25rpm^{-1}, UY3K3L25= 3kg of unblanched Yam to 3 litres water; speed=25rpm^{-1} **L**=lightness; **a**=red(+) /green(-); **b**=yellow(+)/ blue(-); **ΔE=** Color difference

Unblanched yam flour had percentage moisture ranging from 4.57 to 6.55 (Table 3.6). From table 3.6, unblanched yam flour with the proportion of UY3K3L25 had the highest moisture value of 6.55%. pH value of raw yam (6.02) decreased after drying varying proportions of unblanched yam to a range of 5.10 to 5.84. The study showed that, lightness (L*) of raw yam decreased (49.54) after mashing but showed higher values after drying varying proportions of unblanched mashed yam ranging from 64.48 to 67.03 (Table 3.6). Color difference of UYF recorded lower values after drying varying proportions which ranged from 3.43 to 5.94 (Table 3.6).

Table 3.7: Physiochemical analysis of Formulated Blanched yam flour (BYF), Unblanched Yam Flour and Cassava Starch (UYFCS)

Treatment	% Moisture	pH	Color			
			L*	a*	b*	ΔE
BY3K3L25	8.21±0.25	5.35±0.01	85.77±0.41	0.91±0.00	29.15±0.02	24.42±0.41
BY3K2L25	8.66±0.42	5.31±0.01	87.46±0.23	0.97±0.02	9.24±0.15	26.10±0.22
UY3K1L25	8.32±0.20	5.43±0.01	76.90±0.75	1.59±0.05	7.55±0.31	15.38±0.79
UY3K2L25	8.34±0.24	5.54±0.02	76.58±0.27	1.59±0.07	7.54±0.12	15.38±0.25
UY3K3L25	8.76±0.26	5.71±0.04	76.78±0.33	1.57±0.04	7.36±0.21	15.62±0.30

BY3K3L25= 3kg of blanched Yam to 3 litres water; speed=25rpm^{-1}, **BY3K2L25**= 3kg of blanched Yam to 2 litres water; speed=25rpm^{-1}, **UY3K1L25**= 3kg of unblanched Yam to 1 litre water; speed=25rpm^{-1}**UY3K2L25**= 3kg of unblanched Yam to 2 litres water; speed=25rpm^{-1}**UY3K3L25**= 3kg of unblanched Yam flour to 3 litres water; speed=25rpm^{-1}; **L**=lightness; **a**=red(+) /green(-); **b**=yellow(+)/ blue(-);**ΔE =**Color difference

Formulation of Blanched and unblanched yam flour with cassava starch flour showed increase in percentage moisture from the range of 2.10- 6.55 to 8.21 – 8 (Table 3.7). pH of formulated flour (Blanched yam flour and Unblanched Yam Flour) showed similar values for varying proportions of blanched and unblanched yam flour (Table 3.7). The study showed increase in L* values of BYFCS and UYFCS which ranged from 76.58 to 87.46, with BYF3K2L25 recording the highest value (87.46). Its color difference increased in value ranging from 15.38 to 26.10 with BYF3K2L25 recording the highest (26.10) (Table 3.7).

Functional properties of blanched yam flour (BYF) and formulated blanched yam flour and Cassava Starch (BYFCS) is shown in figure 3.8 to 3.11.

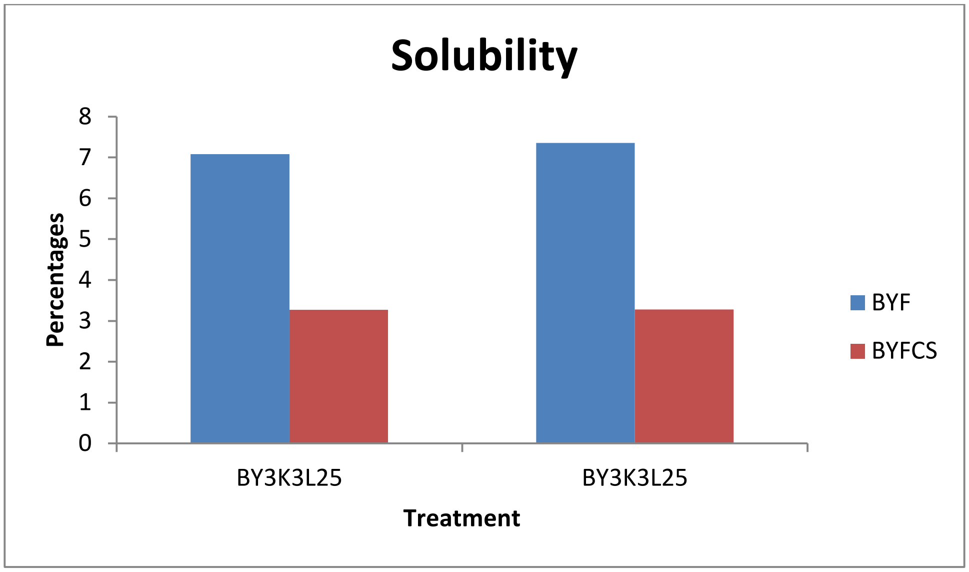

Figure 3.8: Solubility of Blanched Yam Flour (**BYF**) and Formulated Blanched Yam Flour and Cassava Starch (**BYFCS**); **BY3K3L25**= 3kg of blanched Yam to 3 litres water; speed=25rpm^{-1}, **BY3K2L25**=3kg of blanched Yam to 2 litres water; speed=25rpm^{-1}

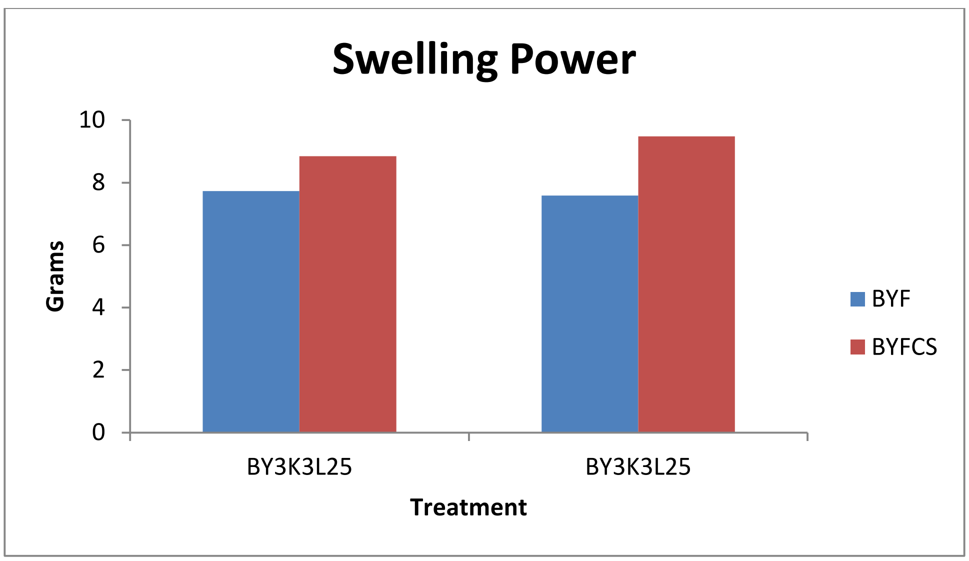

Figure 3.9: Swelling Power of Blanched Yam Flour (**BYF**) and Formulated Blanched Yam Flour and Cassava Starch (**BYFCS**); **BY3K3L25**= 3kg of blanched Yam to 3 litres water; speed=25rpm^{-1}, **BY3K2L25**=3kg of blanched Yam to 2 litres water; speed=25rpm^{-1}

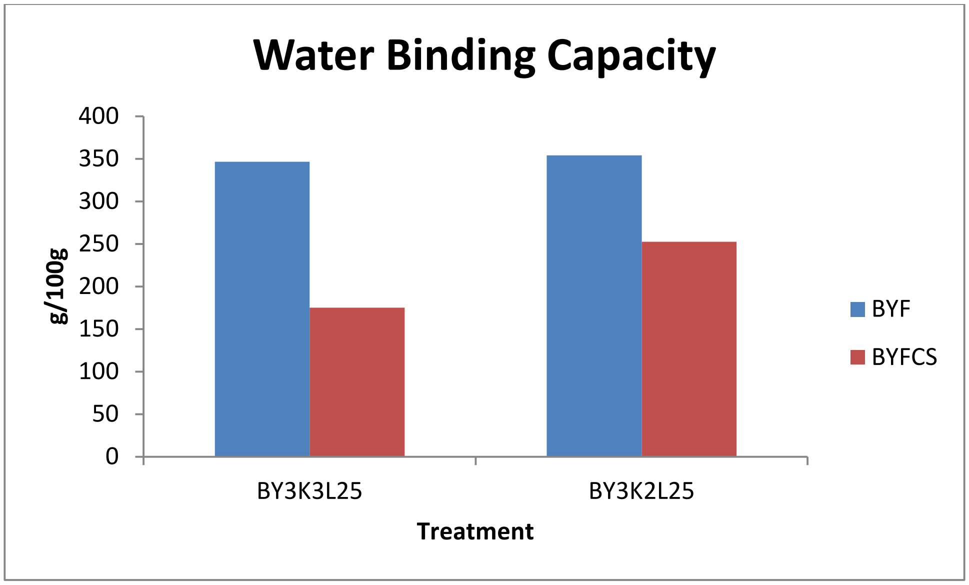

Figure 3.10: Water Binding Capacity of Blanched Yam Flour (**BYF**) and Formulated Blanched Yam Flour and Cassava starch (**BYFCS**); **BY3K3L25**= 3kg of blanched Yam to 3 litres water; speed=25rpm^{-1}, **BY3K2L25**=3kg of blanched Yam to 2 litres water; speed=25rpm^{-1}

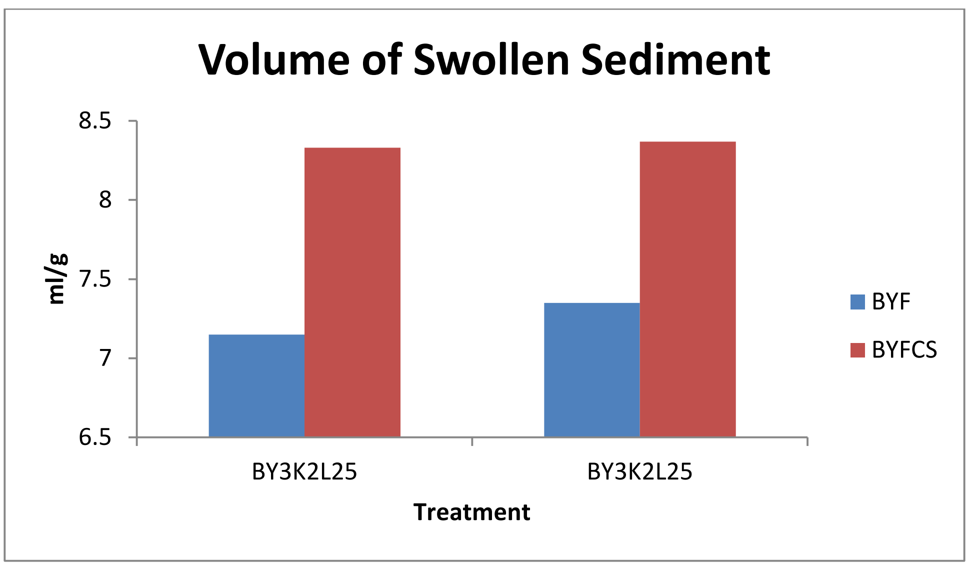

Figure 3.11: Volume of Swollen Sediment of Blanched Yam Flour (**BYF**) and Formulated Blanched Yam Flour and Cassava Starch (**BYFCS**); **BY3K3L25**= 3kg of blanched Yam to 3 litres water; speed=25rpm^{-1}, **BY3K2L25**=3kg of blanched Yam to 2 litres water; speed=25rpm^{-1}

Figure 3.8 to 3.11 shows the functional Properties of Blanched Yam flour and Formulated Yam Flour with Cassava Starch Flour. The solubility of blanched yam flour and formulated blanched yam flour ranged from 3.27 to 7.36% with blanched yam flour (BY3K2L25) recording the highest value of 7.36% (figure 3.8). Its swelling power (blanched yam flour and formulated blanched yam flour) ranged from 7.73 to 9.48 (figure 3.9). Formulated blanched yam flour of BY3K2L25 recorded the highest value of 9.48g and 8.37ml/g for both swelling power and volume of swollen sediment respectively (figure 3.9, 3.11). Water binding capacity ranged from 175.17 to 353.93 thus, BY3K2L25of blanched yam flour records the highest value of 353.93% (Figure 3.10).

Functional properties of Unblanched yam flour and formulated Unblanched yam flour and Cassava Starch is shown in figure 3.12 to 3.15.

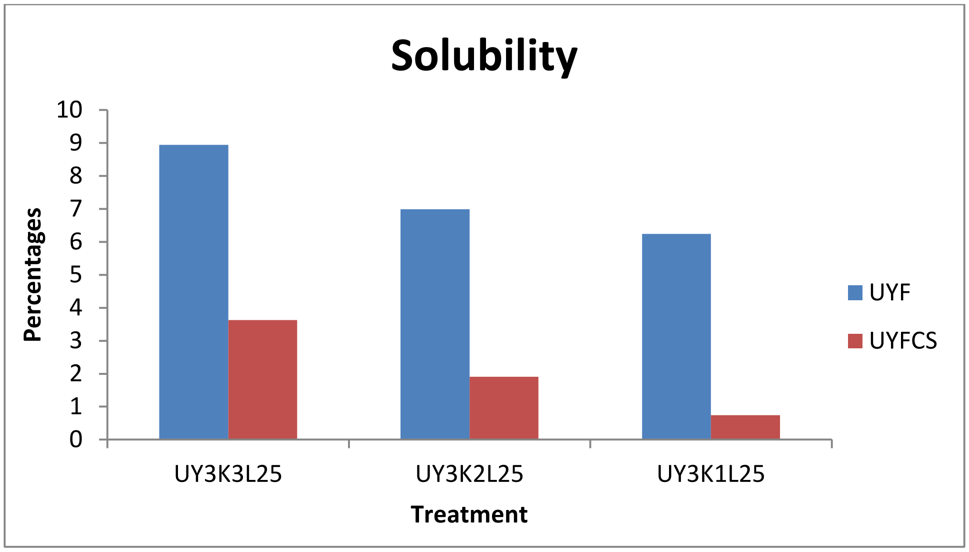

Figure 3.12: Solubility of Unblanched Yam Flour and Formulated Unblanched Yam Flour and Cassava Starch (UYFCS); **UY3K3L25**= 3kg of unblanched Yam to 1 litre water; speed=25rpm^{-1}**UY3K2L25**= 3kg of unblanched Yam to 2 litres water; speed=25rpm^{-1}**UY3K2L25**= 3kg of unblanched Yam flour to 3 litres water; speed=25rpm^{-1}

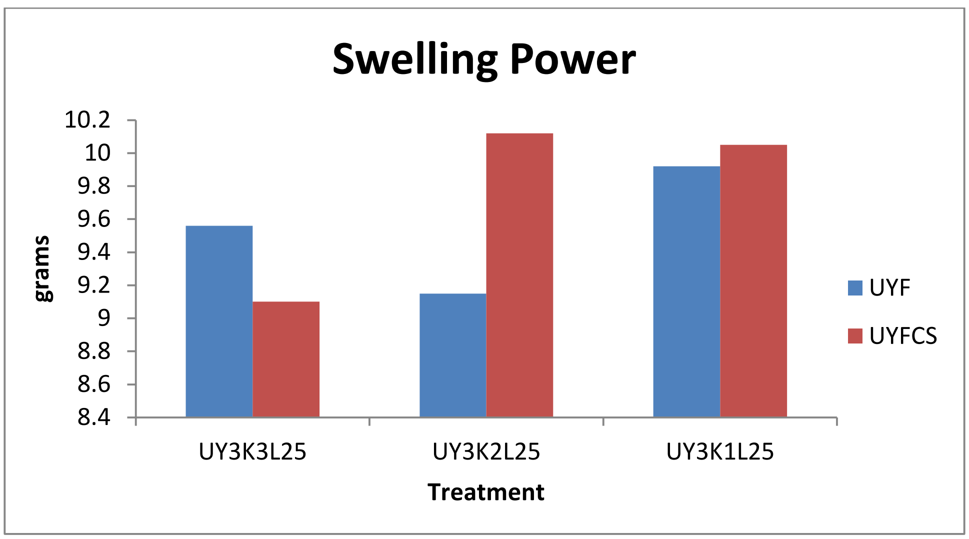

Figure 3.13: Swelling Power of Unblanched Yam Flour (**UYF**) and Formulated Unblanched Yam Flour and Cassava Starch (**UYFCS**); **UY3K3L25**= 3kg of unblanched Yam to 1 litre water; speed=25rpm^{-1}**UY3K2L25**= 3kg of unblanched Yam to 2 litres water; speed=25rpm^{-1}**UY3K2L25**= 3kg of unblanched Yam flour to 3 litres water; speed=25rpm^{-1}

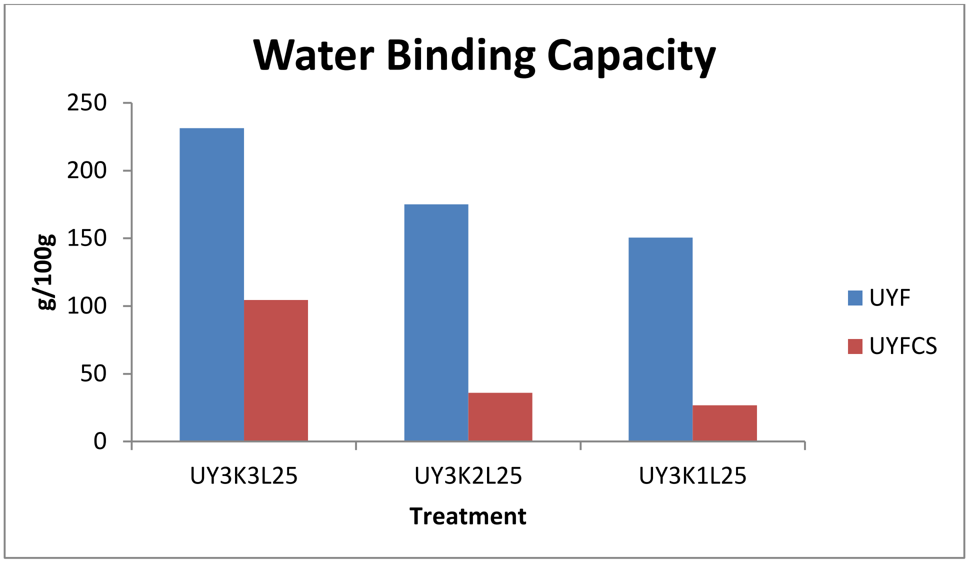

Figure 3.14: Water Binding Capacity of Unblanched Yam Flour (**UYF**) and Formulated Unblanched Yam Flour and Cassava Starch (**UYFCS**); **UY3K3L25**= 3kg of unblanched Yam to 1 litre water; speed=25rpm^{-1}**UY3K2L25**= 3kg of unblanched Yam to 2 litres water; speed=25rpm^{-1}**UY3K2L25**= 3kg of unblanched Yam flour to 3 litres water; speed=25rpm^{-1}

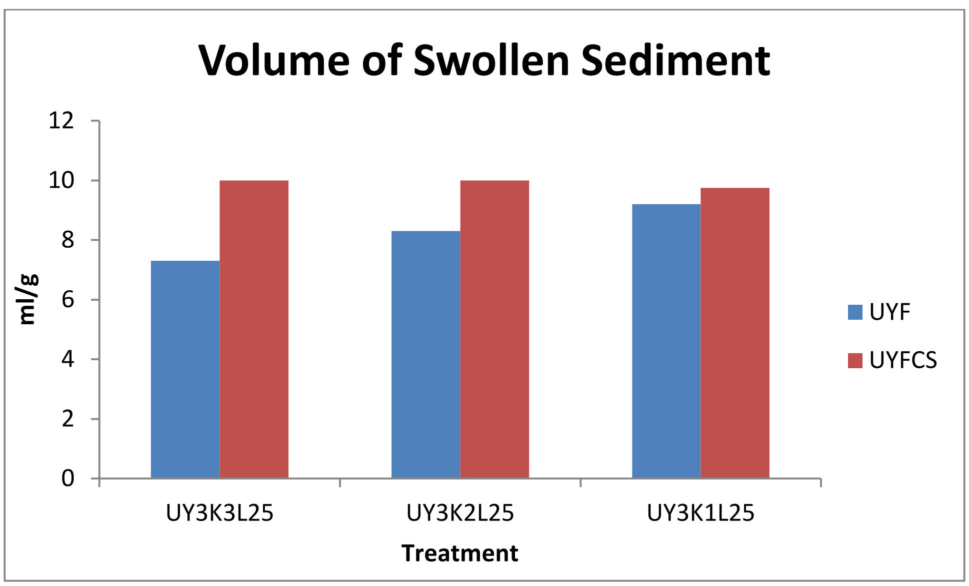

Figure 3.15: Volume of Swollen Sediment of Unblanched Yam Flour (**UYF**) and Formulated Unblanched Yam Flour and Cassava Starch (**UYFCS**); **UY3K3L25**= 3kg of unblanched Yam to 1 litre water; speed=25rpm^{-1}**UY3K2L25**= 3kg of unblanched Yam to 2 litres water; speed=25rpm^{-1}**UY3K2L25**= 3kg of unblanched Yam flour to 3 litres water; speed=25rpm^{-1}

Figure 3.12 to 3.15 shows the functional Properties of Blanched Yam flour and formulated blanched Yam Flour and Cassava Starch. Solubility and water binding capacity values ranged from 0.74 to 8.94% and 26.79 to 231.32% respectively (figure 3.12, 3.14). The study indicates lower values for solubility (0.74-3.63%) and water binding capacity (26.79-104.52%) of formulated unblanched yam flour. Swelling power and volume of swollen sediment increased after formulation and ranged from 9.10 - 10.12% and 9.75 to 10ml/g respectively (figure 3.13, 3.15).The results agreed with Bainbridge *et al*., (1996) who stated that, good quality starch with a high starch content and paste viscosity will have a low solubility and a high swelling volume and swelling power.

3.3 Physicochemical and Functional properties of Blanched and Unblanched Cocoyam

The moisture content, pH and color of raw and blanched cocoyam is shown in table 3.8 and 3.9.

Table 3.8: Physiochemical analysis of raw Cocoyam

Sample	% Moisture	pH	Color			
			L*	a*	b*	ΔE
Raw cocoyam	46.94±0.11	7.10±0.03	71.46±0.05	5.35±0.09	12.11±0.26	0.00±0.00
BMC	58.42±0.01	6.23±0.01	69.23±0.01	4.51±0.02	10.41±0.02	2.93±0.02
UMC	52.26±0.04	6.01±0.01	67.00±0.01	4.09±0.01	9.10±0.01	5.60±0.01

BMC= Blanched Mashed Cocoyam; **UMC**=Unblanched Mashed Cocoyam; **L**=lightness; **a**=red(+) /green(-); **b**=yellow(+)/ blue(-);**ΔE=**Color difference

Table 3.9: physiochemical analysis of Blanched and Unblanched cocoyam Flour

Treatment	% Moisture	pH	Color			
			L*	a*	b*	ΔE
BC2K3L25	3.71±0.16	5.91±0.01	73.22±0.37	2.79±0.02	8.40±0.08	4.11±0.01
BC2K2L25	2.23±0.28	5.98±0.01	74.07±1.74	2.77±0.07	8.17±0.11	4.73±0.01
BC2K1L25	1.93±0.05	6.15±0.01	75.12±0.52	2.75±0.08	7.49±0.03	5.89±0.01
UC3K2L25	3.26±0.10	5.9±0.06	75.62±0.08	3.00±0.13	11.65±0.03	4.46±0.04
UC3K1L25	2.72±0.77	5.65±0.09	73.35±0.02	2.90±0.06	11.43±0.18	2.40±0.01
UC3K1L15	3.30±0.23	5.63±0.07	72.44±1.04	3.31±0.21	13.55±0.04	1.74±0.01

BC2K3L25= 3kg of blanched cocoyam to 3 litres water; speed=25rpm^{-1}, **BC2K2L25**= 3kg of blanched cocoyam to 2 litres water; speed=25rpm^{-1}, **BC2K1L25**= 2kg of unblanched cocoyam to 1 litre water; speed=25rpm^{-1}**UCF3K2L25**= 3kg of unblanched cocoyam to 2 litres water; speed=25rpm^{-1}**UC3K1L25**= 3kg of unblanched cocoyam to 1 litre water; speed=25rpm^{-1}**UC3K1L15**= 3kg of unblanched cocoyam to 1 litre water; speed=15rpm^{-1}**L**=lightness; **a**=red(+) /green(-); **b**=yellow(+)/ blue(-); **ΔE=**Color difference

The moisture content of raw cocoyam is 46.94% (Table 3.8). Moisture increased after milling blanched (58.42%) and unblanched cocoyam (52.26%). There was a sharp decrease in percentage moisture after drying varying proportions of both blanched and unblanched cocoyam which ranged from 1.93 to 3.71 (Table 3.9). This could be attributed to the temperature employed which causes distortion of cell membrane thus allowing heat to penetrate the interior of the product being dried.

pH value for the raw cocoyam was 7.10 but recorded lower values after mashing (6.01-6.23) and drying (5.63-6.15) blanched and unblanched cocoyam (Table 3.8, 3.9). Raw cocoyam gave L* value of 71.46. L* values decreased after mashing but showed higher values after drying varying proportions of both blanched and unblanched cocoyam (Table 3.8, 3.9). Color difference increased after mashing and drying blanched cocoyam with the exception of unblanched cocoyam which showed otherwise after drying (Table 3.8, 3.9).

The physiochemical analysis of formulated cocoyam flour and cassava starch is shown in table 3.10.

Table 3.10: Physiochemical analysis of Formulated Cocoyam Flour and Cassava Starch

Treatment	% Moisture	pH	Color			
			L*	a*	b*	ΔE
BC2K3L25	7.98±0.14	6.07±0.01	83.07±0.26	2.63±0.04	6.50±0.12	13.43±0.01
BC2K2L25	7.17±0.13	6.06±0.01	83.49±0.15	2.66±0.06	6.04±0.08	13.88±0.01
BC2K1L25	7.14±0.07	6.04±0.01	83.55±0.21	2.84±0.07	5.81±0.26	14.01±0.01
UC3K2L25	7.67±0.17	6.10±0.01	81.75±0.38	3.05±0.06	8.86±0.09	11.20±0.01
UC3K1L25	8.55±0.22	6.17±0.04	81.44±0.61	2.82±0.09	8.76±0.18	10.53±0.01
UC3K1L15	8.07±0.08	6.02±0.02	80.38±0.98	3.14±0.12	10.68±0.15	9.03±0.02

BC2K3L25= 3kg of blanched cocoyam to 3 litres water; speed=25ms^{-1}, **BC2K2L25**= 2kg of blanched cocoyam to 2 litres water; speed=25rpm^{-1}, **BC2K1L25**= 2kg of unblanched cocoyam to 1 litre water; speed=25rpm^{-1}**UCF3K2L25**= 3kg of unblanched cocoyam to 2 litres water; speed=25rpm^{-1}**UC3K1L25**= 3kg of unblanched cocoyam to 1 litre water; speed=25rpm^{-1}**UC3K1L15**= 3kg of unblanched cocoyam to 1 litre water; speed=15rpm^{-1}**L**=lightness; **a**=red(+) /green(-); **b**=yellow(+)/ blue(-); **ΔE=**Color difference

The increased in percentage moisture after formulation ranged from 7.14 to 8.55 (Table 3.10). Similar pH values of formulated blanched and unblanched cocoyam flour were recorded which ranged from 6.02 to 6.17. L* values and color difference increased to a range of 80.38 to 83.55 and 9.03 to 14.01 respectively (Table 3.10).

Functional properties of Unblanched cocoyam flour and formulated Unblanched cocoyam flour and Cassava Starch is shown in figure 3.16 to 3.19.

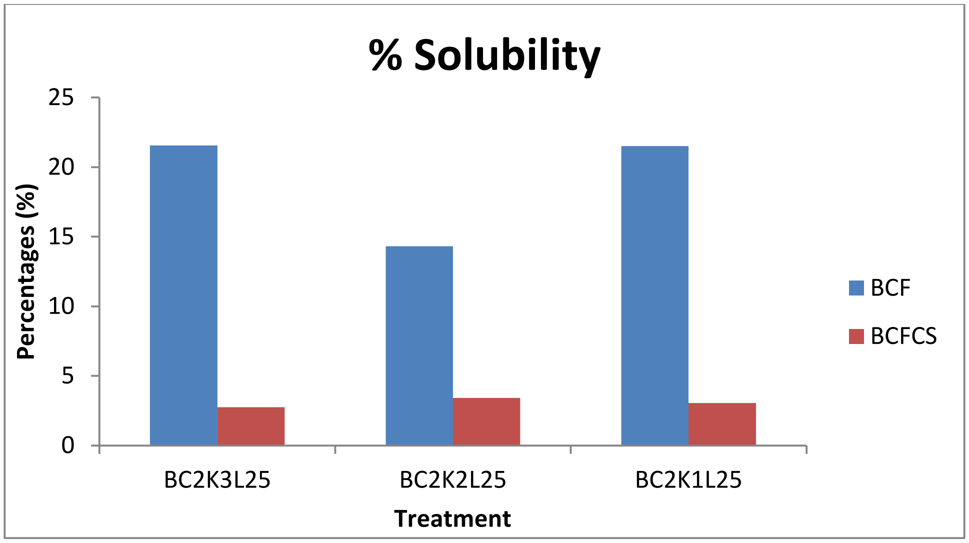

Figure 3.16:Solubility of Blanched Cocoyam Flour (**BCF**) and Formulated Blanched Cocoyam Flour and Cassava starch (**BCFCS**); **BC2K3L25**= 2kg of blanched cocoyam to 3 litres water; speed=25rpm^{-1}, **BC2K2L25**= 2kg of blanched cocoyam to 2 litres water; speed=25rpm^{-1}, **BC2K1L25**= 2kg of blanched cocoyam to 1 litre water; speed=25rpm^{-1}

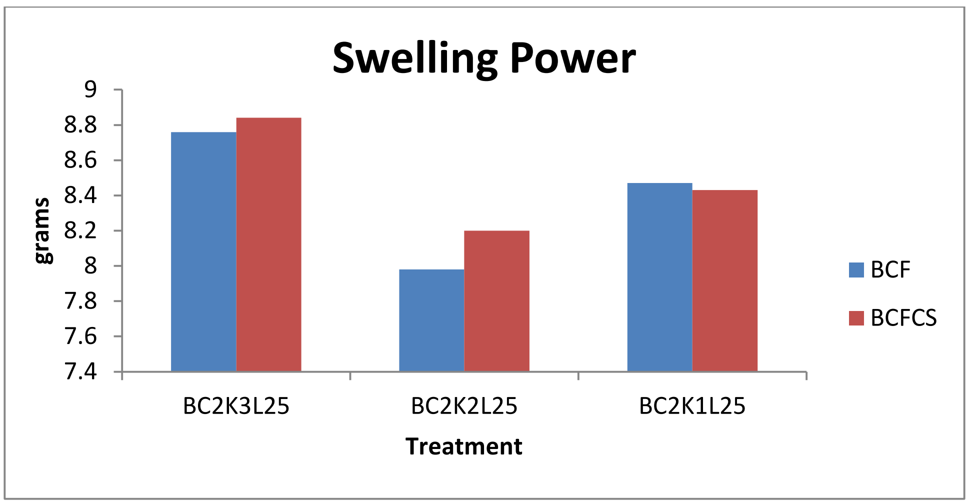

Figure 3.17: Swelling power of Blanched Cocoyam Flour (**BCF**) and Formulated Blanched Cocoyam Flour and Cassava Starch (**BCFCS**); **BC2K3L25**= 2kg of blanched cocoyam to 3 litres water; speed=25rpm^{-1}, **BC2K2L25**= 2kg of blanched cocoyam to 2 litres water; speed=25rpm^{-1}, **BC2K1L25=** 2kg of blanched cocoyam to 1 litre water; speed=25rpm^{-1}

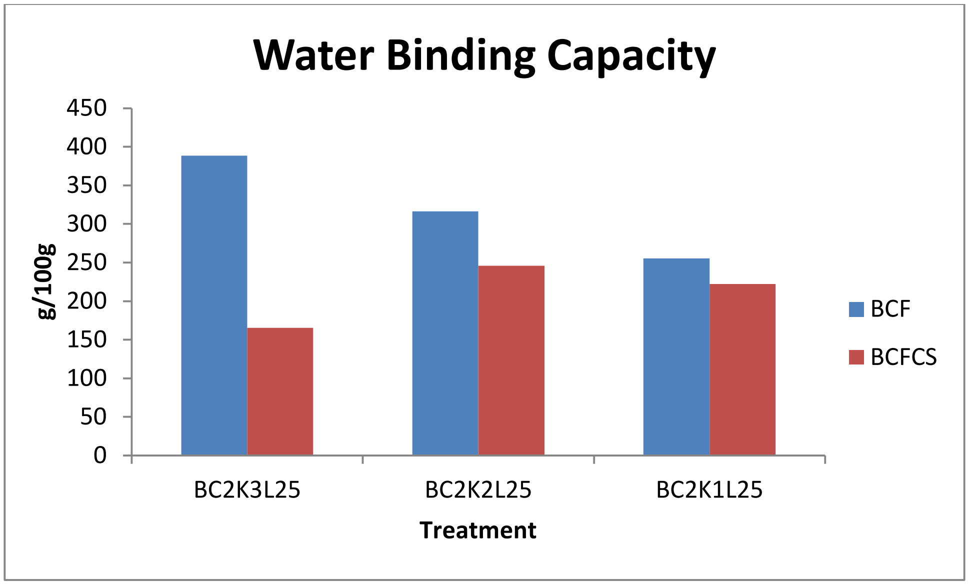

Figure 3.18: Water Binding Capacity of Blanched Cocoyam Flour (**BCF**) and Formulated Blanched Cocoyam Flour and Cassava Starch (**BCFCS**); **BC2K3L25**= 2kg of blanched cocoyam to 3 litres water; speed=25rpm^{-1}, **BC2K2L25**= 2kg of blanched cocoyam to 2 litres water; speed=25rpm^{-1}, **BC2K1L25=** 2kg of blanched cocoyam to 1 litre water; speed=25rpm^{-1}

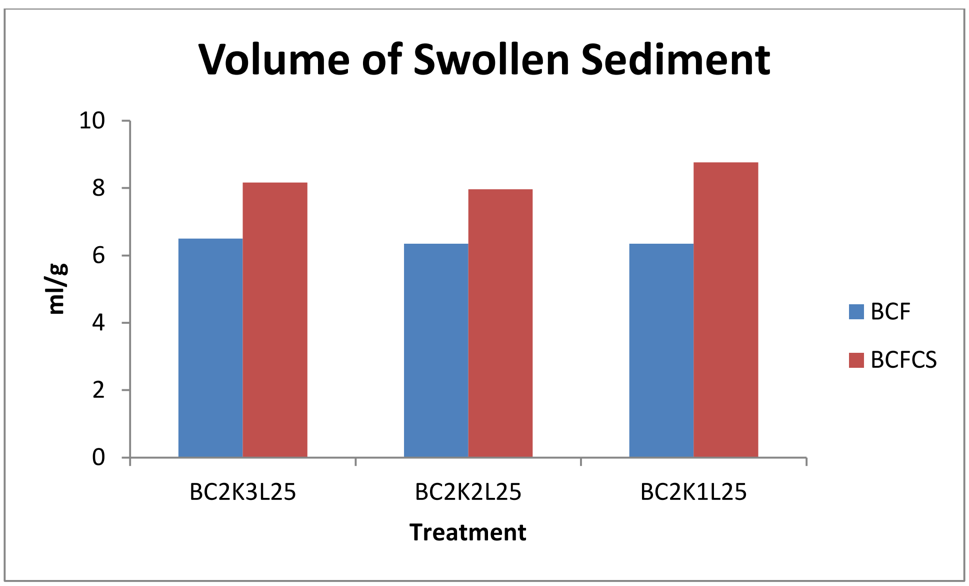

Figure 3.19: Volume of swollen sediment of Blanched Cocoyam Flour (**BCF**) and Formulated Blanched Cocoyam Flour and Cassava Starch (**BCFCS**); **BC2K3L25**= 2kg of blanched cocoyam to 3 litres water; speed=25rpm^{-1}, **BC2K2L25**= 2kg of blanched cocoyam to 2 litres water; speed=25rpm^{-1}, **BC2K1L25=** 2kg of blanched cocoyam to 1 litre water; speed=25rpm^{-1}

The study shows that, solubility of blanched cocoyam recorded higher values which ranged from 14.32 to 21.55% whereas formulated blanched cocoyam flour showed lower values ranging from 2.76 to 3.42% (Figure 3.16). Swelling power of blanched cocoyam flour and formulated blanched cocoyam and cassava starch showed similar values ranging from 7.98 to 8.84g (figure 3.17). Water binding Capacity of blanched cocoyam flour (255.48 to 388.50g/100g) showed lower values after formulating with cassava starch (165.53 to 246.03) (Figure 3.18). However, there was a slight increase in volume of swollen sediment after formulating blanched cocoyam flour and cassava starch (7.97 to 8.77ml/g (Figure 3.19).

Figure 3.20 to 3.23 shows the functional Properties of unblanched Cocoyam Flour (UCF) and Formulated Unblanched Cocoyam Flour and Cassava Starch (UCFCS)

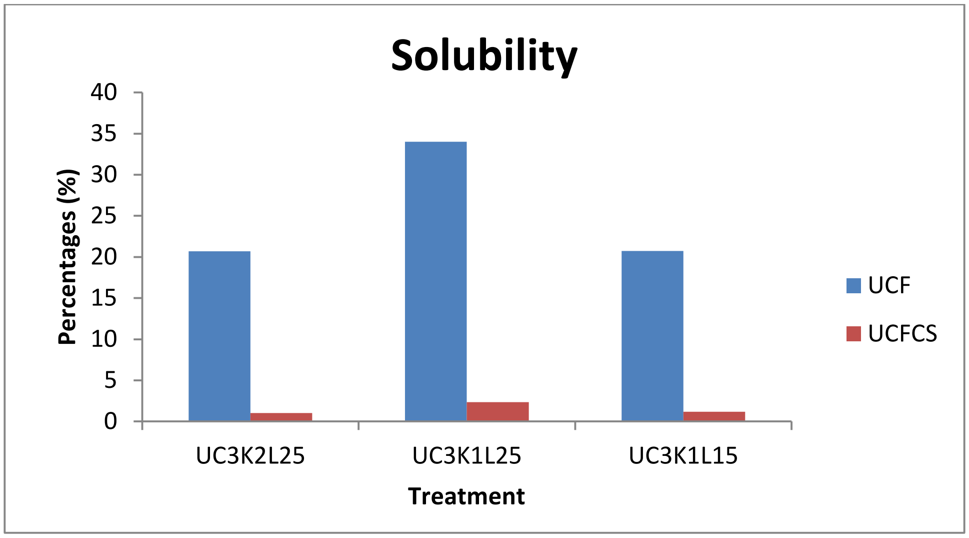

Figure 3.20: Solubility of unblanched Cocoyam Flour (**UCF**) and Formulated unblanched Cocoyam Flour and Cassava Starch (**UCFCS**); **UC3K2L25**= 3kg of unblanched cocoyam to 2 litres water; speed=25rpm^{-1} **UC3K1L25**= 3kg of unblanched cocoyam to 1 litre water; speed=25rpm^{-1} **UC3K1L15**= 3kg of unblanched cocoyam to 1 litre water; speed=15rpm^{-1}

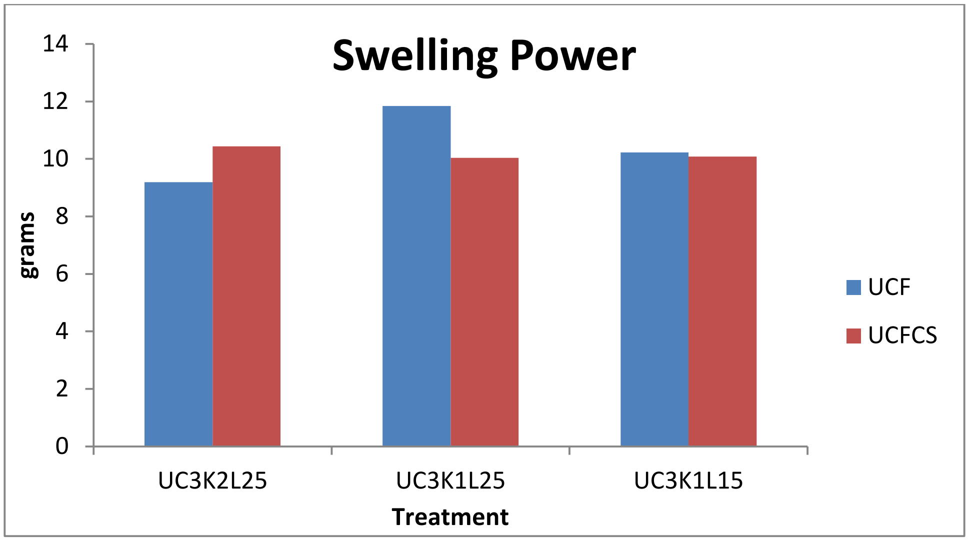

Figure 3.21: Swelling Power of unblanched Cocoyam Flour (**UCF**) and Formulated unblanched Cocoyam Flour and Cassava Starch (**UCFCS**); **UC3K2L25**= 3kg of unblanched cocoyam to 2 litres water; speed=25rpm^{-1} **UC3K1L25**= 3kg of unblanched cocoyam to 1 litre water; speed=25rpm^{-1} **UC3K1L15**= 3kg of unblanched cocoyam to 1 litre water; speed=15rpm^{-1}

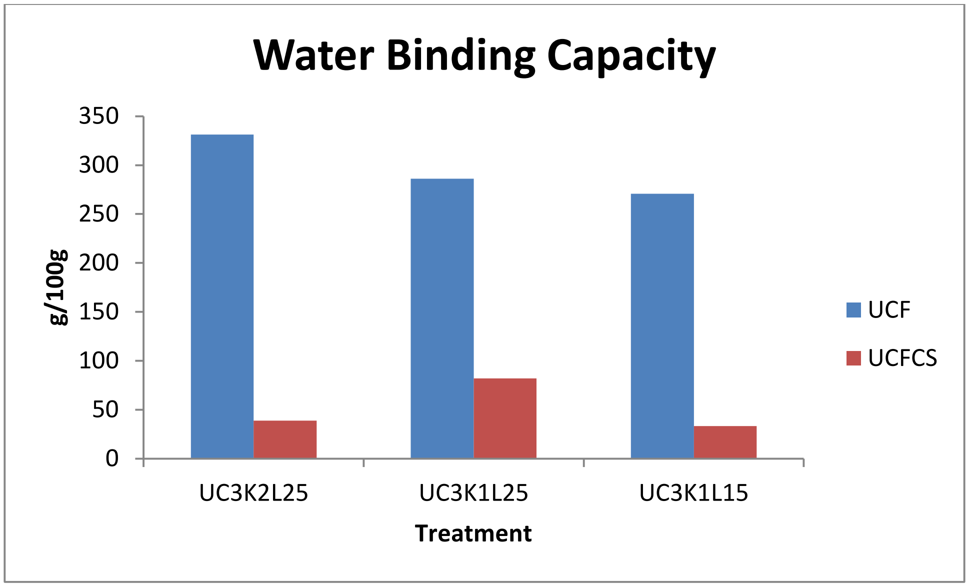

Figure 3.22: Water binding capacity of unblanched Cocoyam Flour (**UCF**) and Formulated unblanched Cocoyam Flour and Cassava Starch (**UCFCS**); **UC3K2L25**= 3kg of unblanched cocoyam to 2 litres water; speed=25rpm^{-1} **UC3K1L25**= 3kg of unblanched cocoyam to 1 litre water; speed=25rpm^{-1} **UC3K1L15**= 3kg of unblanched cocoyam to 1 litre water; speed=15rpm^{-1}

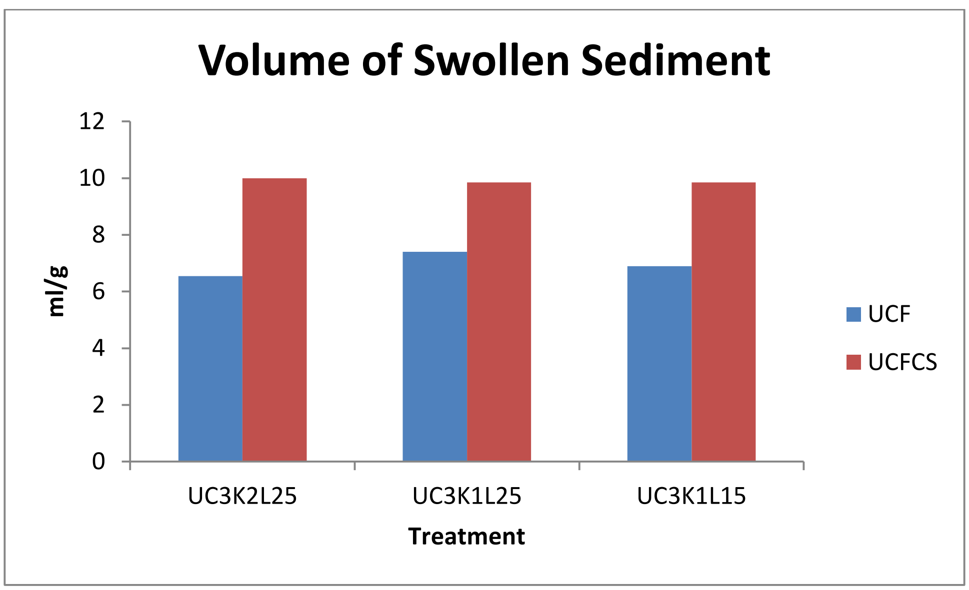

Figure 3.23: Volume of Swollen Sediment of unblanched Cocoyam Flour (**UCF**) and Formulated unblanched Cocoyam Flour (**UCFCS**); **UC3K2L25**= 3kg of unblanched cocoyam to 2 litres water; speed=25rpm^{-1} **UC3K1L25**= 3kg of unblanched cocoyam to 1 litre water; speed=25rpm^{-1} **UC3K1L15**= 3kg of unblanched cocoyam to 1 litre water; speed=15rpm^{-1}

The study showed a sharp decrease of solubility of formulated unblanched cocoyam and cassava starch to a range of 1.04 to 2.36% (figure 3.20). As a good quality starch with high starch content and paste viscosity will have a low solubility and high swelling volume and power. Similar results were recorded for swelling power which ranged from 9.19 to 11.84g (figure 3.21). Unblanched cocoyam flour recorded lower values for water binding capacity after formulation (33.37 to 81.93g/100g) figure 3.22). These lower values could be associated with lower carbohydrate content in these plantain flours whose complex molecule will demand less water during hydrolysis (Oduro *et al*., 2006). The volume of swollen sediment increased slightly after formulation which ranged from 9.85 to 10.00 ml/g (figure 3.23).

3.4 Physiochemical and Functional Properties of Maize

The physiochemical properties of raw maize are shown in table 3.11.

Table 3.11: Physiochemical analysis of Raw Maize

Treatment	% Moisture	Ph	Color			
			L*	a*	b*	ΔE
Raw maize	10.6 ± 0.06	6.07±0.02	83.06±0.12	-0.09±0.07	10.48±0.03	0.00±0.00
Maize meal	43.94 ± 0.60	3.91±0.02	82.54±1.18	0.36±0.06	11.86±0.38	1.84±0.27
Fermented(2days) dough	43.70 ± 0.18	3.63±0.01	81.91±1.20	0.65±0.16	12.51± 0.29	2.64±0.33

L=lightness; **a**=red(+) /green(-); **b**=yellow(+)/ blue(-);**ΔE=** Color difference

Raw maize recorded percentage moisture of 10.6. After steeping, the percentage moisture increased to a value of 43.94% but to 43.70% after two days fermentation. The lower values recorded for moisture content after fermentation could be due to increase in dry matter content as a result of microbial cell proliferation (Obadina *et al*., 2013). The pH value of raw maize was 6.07 but recorded a lower pH value of 3.91 and 3.63 after 3 days steeping and 2 days of fermentation respectively (Table 3.11). The decrease in pH could be attributed to the activities of some fermentative organisms such as lactic acid bacteria and yeasts (Obadina *et al*., 2013).The lightness (L*) of raw maize was 83.06. The result showed decrease in L* value after steeping (82.54) and fermentation (81.91) which could be due to the activities of fermentative organisms (Table 3.11).

Table 3.12 gives the physicochemical analysis of fermented maize flour.

Table 3.12: Physiochemical analysis of fermented maize flour

Treatment	% Moisture	Ph	Color			
			L*	**a***	**b***	**ΔE**
FM5K3L35	1.82±0.16	3.50±0.01	83.87±1.02	-0.07±0.01	14.37 ±0.36	4.05±0.55
FM5K3.5L35	1.47±0.49	3.54±0.01	83.56±0.97	-0.32±0.01	13.92±0.19	3.57±0.25
FM5K4L35	1.64±0.45	3.47±0.02	82.76±0.61	-0.33±0.04	13.76±0.17	3.38±0.10
FM5K5L35	1.29±0.40	3.53±0.01	81.09±0.78	-0.40±0.14	13.07 ±0.24	3.33±0.60

FM5K3L35=5kg of fermented maize to 3 litres water; speed=35rpm^{-1}, FM5K3.5L35=5kg of fermented maize to 3.5 litres water; speed=35rpm^{-1}, FM5K4L35= 5kg of fermented maize to 4 litres water; speed=35rpm^{-1}, FM5K5L35=5kg of fermented maize to 5 litres of water; speed=35rpm^{-1}**L**=lightness; **a**=red(+) /green(-); **b**=yellow(+)/ blue(-);**ΔE=**Color difference

The study showed that, FM5K5L35 recorded the lowest percentage moisture whereas FM5K5L35 recorded the highest percentage moisture (Table 3.12). It could be deduced that, lighter slurry has lower moisture content whereas thicker slurry has high moisture content which might be due to the speed employed during drying. Ph value increased from 3.47 to 3.54 after drying. The difference in pH could be attributed to depolymerization caused by the different thermal treatment, hence producing acid thermal residues in the starch molecules (Falade and Oyeyinka, 2014). L* values increased after drying with the exception of FM5K5L35 which recorded lower value (81.09). The result showed increase in color difference after drying varying proportions of fermented maize with FM5K3L35 recording the highest value (3.98). The differences in color after drying could be attributed to the effect of drying conditions.

Figure 3.24 to 3.27 shows the functional Properties of Fermented Maize Flour (FMF) and Formulated Fermented Maize Flour and Cassava Flour

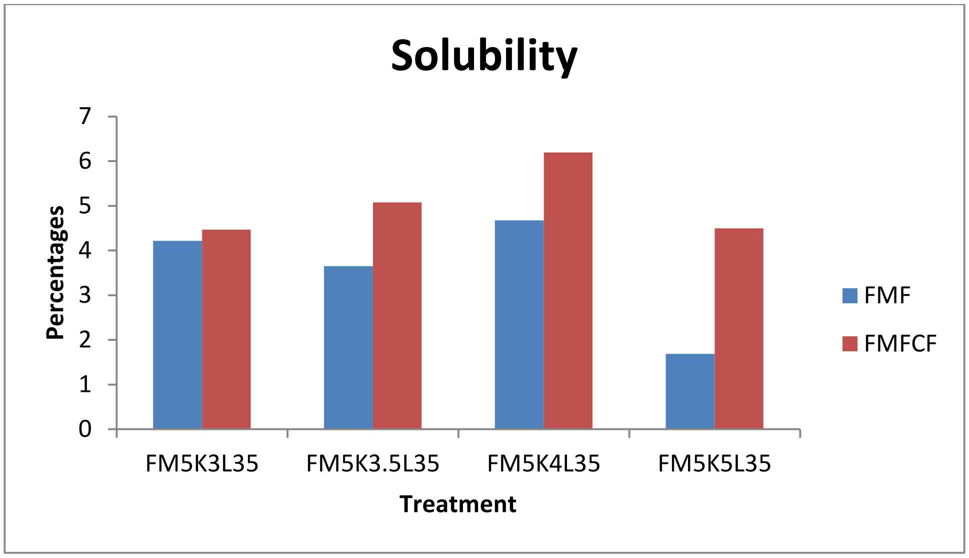

Figure 3.24: Solubility of Fermented Maize flour (**FMF**) and Formulated Fermented Maize Flour and Cassava Flour (**FMFCF**);**FM5K3L35**=5kg of fermented maize to 3 litres water; speed=35rpm^{-1}, **FM5K3.5L35**=5kg of fermented maize to 3.5 litres water; speed=35rpm^{-1}, **FM5K4L35**= 5kg of fermented maize to 4 litres water; speed=35rpm^{-1}, **FM5K5L35**=5kg of fermented maize to 5 litres of water; speed=35rpm^{-1}

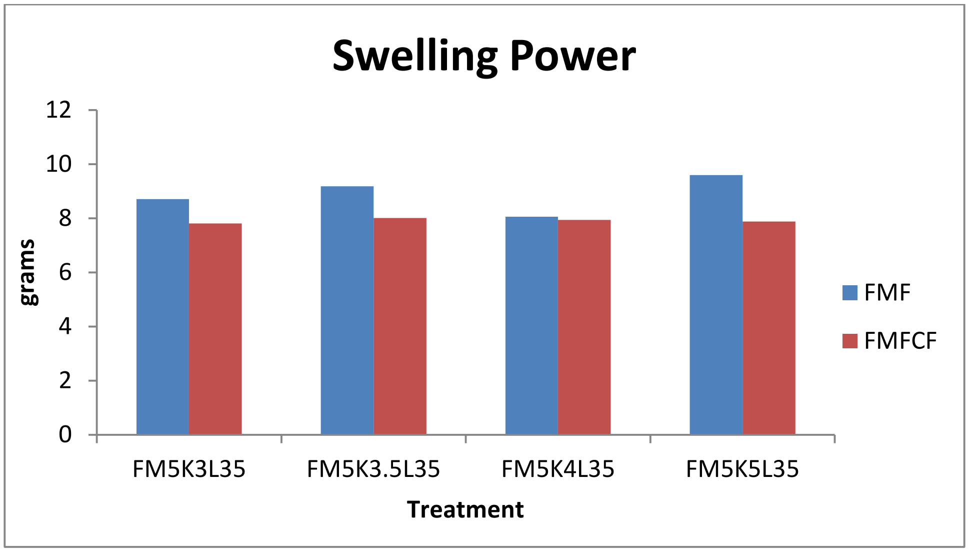

Figure 3.25: Swelling Power of Fermented Maize flour (**FMF**) and Formulated Fermented Maize Flour and Cassava flour (**FMFCF**);**FM5K3L35**=5kg of fermented maize to 3 litres water; speed=35rpm^{-1}, **FM5K3.5L35**=5kg of fermented maize to 3.5 litres water; speed=35rpm^{-1}, **FM5K4L35**= 5kg of fermented maize to 4 litres water; speed=35rpm^{-1}, **FM5K5L35**=5kg of fermented maize to 5 litres of water; speed=35rpm^{-1}

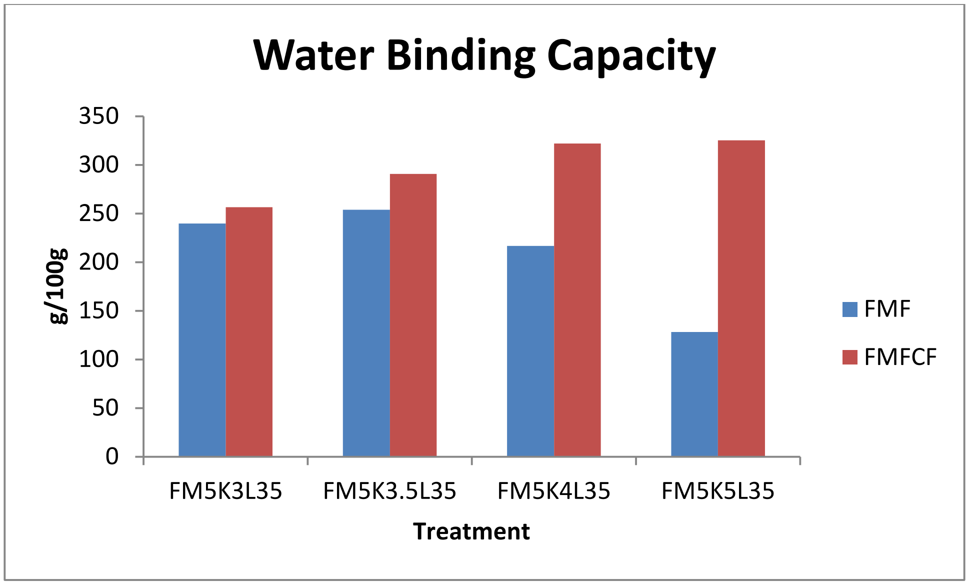

Figure 3.26: Water Binding Capacity of Fermented Maize flour (**FMF**) and Formulated Fermented Maize Flour and Cassava Starch (**FMFCS**) **FM5K3L35**=5kg of fermented maize to 3 litres water; speed=35rpm^{-1}, **FM5K3.5L35**=5kg of fermented maize to 3.5 litres water; speed=35rpm^{-1}, **FM5K4L35**= 5kg of fermented maize to 4 litres water; speed=35rpm^{-1}, **FM5K5L35**=5kg of fermented maize to 5 litres of water; speed=35rpm^{-1}

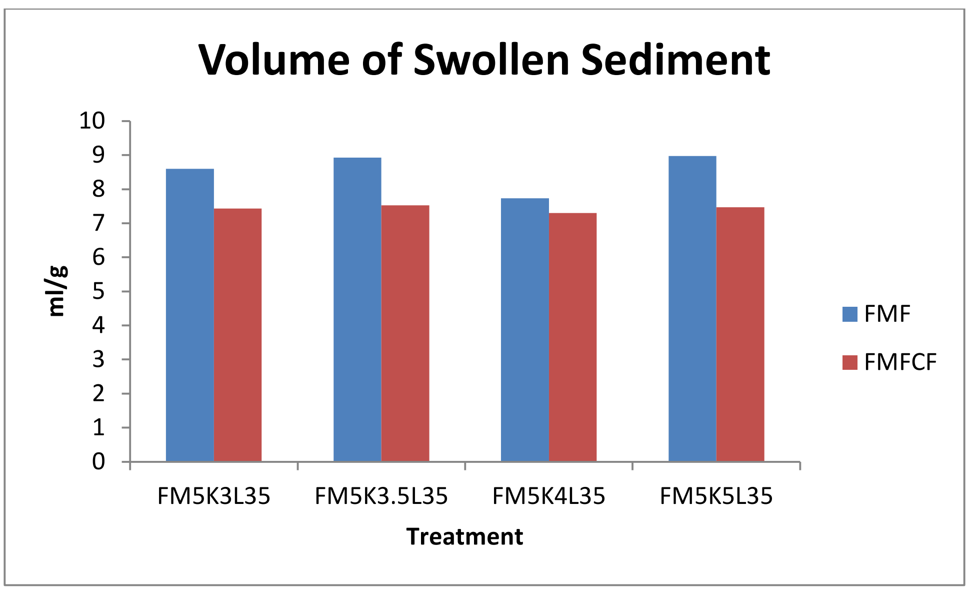

Figure 3.27: Volume of Swollen Sediment of Fermented Maize flour (**FMF**) and Formulated Fermented Maize Flour and Cassava Starch (**FMFCS**) FM5K3L35=5kg of fermented maize to 3 litres water; speed=35rpm^{-1}, **FM5K3.5L35**=5kg of fermented maize to 3.5 litres water; speed=35rpm^{-1}, **FM5K4L35**= 5kg of fermented maize to 4 litres water; speed=35rpm^{-1}, **FM5K5L35**=5kg of fermented maize to 5 litres of water; speed=35rpm^{-1}

The solubility values recorded for FMFCF showed higher values (4.47 to 6.20%) than FMF (1.69 to 4.68) figure 3.24. Swelling power of FMF ranged from 8.06 to 9.60g with FM5K5L35 showing the highest value (9.60) whereas FMFCF showed a slight decrease after formulation which ranged from 7.81 to 8.01g with FM5K3.5L35 recording the highest value (8.01g). FMFCF gave higher values for water binding capacity ranging from 256.29 to 325.18 with FM5K5L35(325.18) and FM5K3L35 (256.29) recording the highest and lowest respectively. Solubility values of FMF ranged from 128.05 to 253.68g/100g with FM5K3.5L35 (253.68g/100g) and FM5K5L35(128.05g/100g) recording the highest and lowest respectively (figure 3.26). Volume of swollen sediment showed a slight difference after formulation ranging from 7.30 to 7.53 whereas FMF ranged from 7.73 to 8.97ml/g (figure 3.27).

3.5 Central Location Test Sensory Evaluation

The sensory evaluation of formulated blanched and unblanched plantain fufu flour is represented in figures 3.28, 3.29.

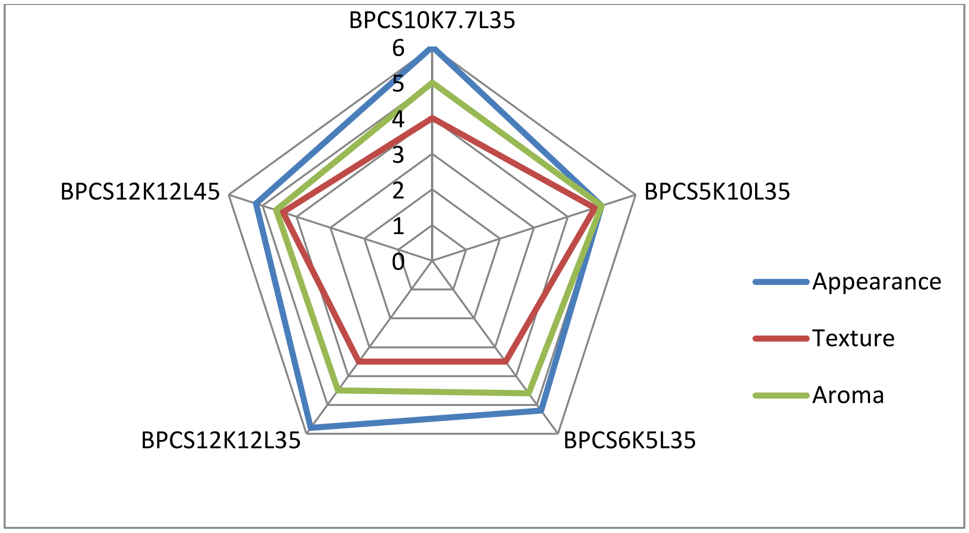

Figure 3.28: Sensory Evaluation of Formulated Blanched Plantain Fufu(**FBPF**); **BPCS10K7.7L35**=10kg of blanched plantain and cassava starch to 7.7 litres water; speed=35rpm^{-1}, **BPCS5K10L35**=5kg of blanched plantain and cassava starch to 10 litres water; speed=35rpm^{-1} , **BPCS6K5L35**=6kg of blanched plantain and cassava starch to 5 litres water; speed=35rpm^{-1}**, BPCS12K12L35**=12kg of blanched plantain and cassava starch to 12 litres water; speed= 35rpm^{-1}, **BPCS12K12L45**= 12kg of blanched plantain and cassava starch to 12 litres water; speed= 45rpm^{-1}

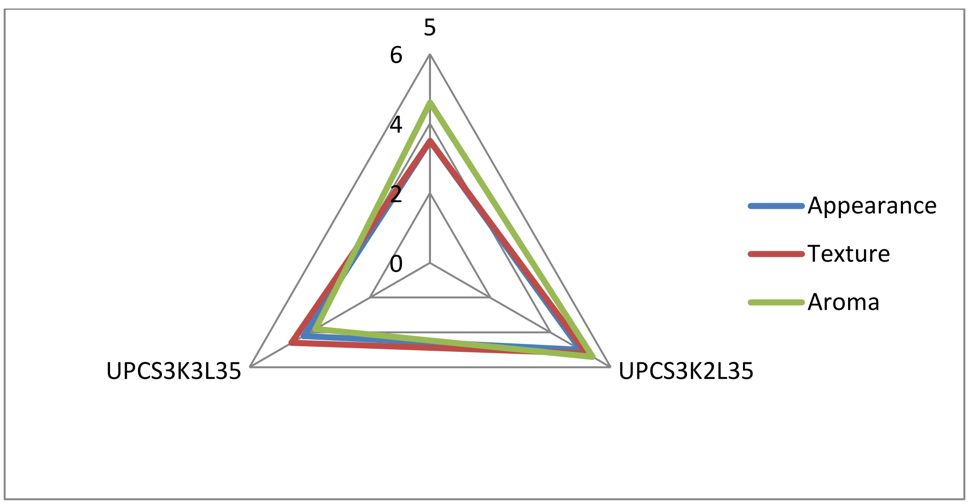

Figure 3.29: Sensory Evaluation of Formulated Unblanched Plantain Fufu(**FUPF**);**UPCS3KIL35**=Unblanched plantain and cassava starch; speed=35rpm^{-1}, **UPCS3K2L35**=Unblanched plantain and cassava starch; speed=35rpm^{-1}, **UPCS3K3L35**= Unblanched plantain and cassava starch; speed=35rpm^{-1}

The study shows that, blanched plantain fufu was preferred to unblanched plantain fufu as it had the highest score (Figure 4.28, 4.29). Blanched plantain fufu had a score ranging from 5.20- 6.00, 3.50- 4.80 and 4.50 – 5.00 for appearance, texture and aroma respectively (figure 4.28) whereas unblanched plantain fufu had a score ranging from 3.50-5.00, 3.50-5.20 and 3.80 – 5.40 respectively (figure 3.29). Although blanched plantain fufu was preferred, fufu made from BPCS10K7.7L35 was most preferred by the panelists. However, unblanched plantain fufu made from UPCS3K2L35 was most preferred as it had a higher score than the other unblanched plantain fufu (Figure 3.29).

The sensory evaluation of formulated blanched and unblanched Yam fufu is represented in figure 3.30.

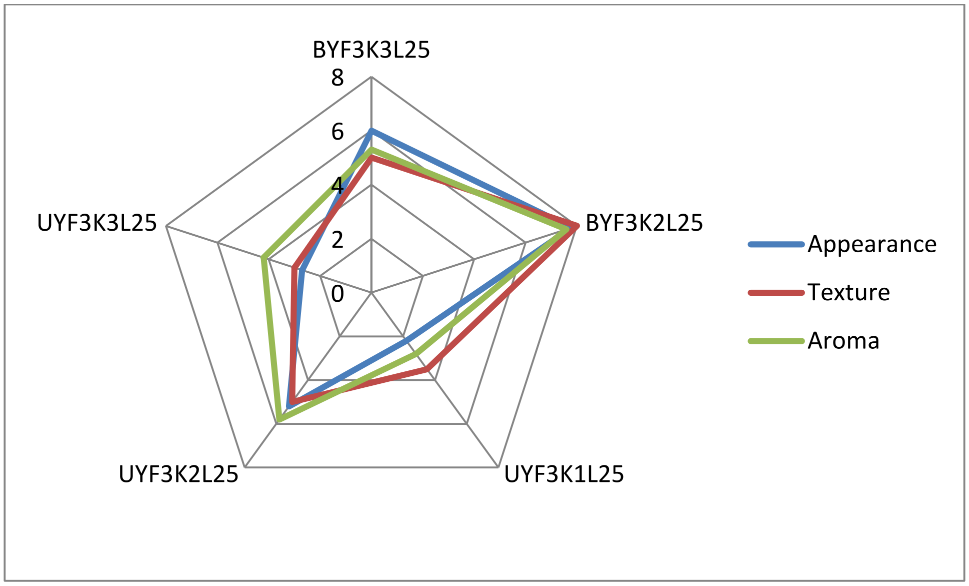

Figure 3.30: Sensory Evaluation of Formulated blanched and unblanched Yam Fufu;**BY3K3L25**= 3kg of blanched Yam to 3 litres water; speed=25rpm^{-1}, **BY3K2L25**= 3kg of blanched Yam to 2 litres water; speed=25rpm^{-1}, **UY3K1L25**= 3kg of unblanched Yam to 1 litre water; speed=25rpm^{-1}**UY3K2L25**= 3kg of unblanched Yam to 2 litres water; speed=25rpm^{-1}**UY3K3L25**= 3kg of unblanched Yam to 3 litres water; speed=25rpm^{-1}

The study indicated that consumers had preference for blanched yam Fufu than unblanched yam fufu (figure 3.30). Blanched yam fufu recorded a value of 6.00-7.80 (appearance), 5.00-8.00 (texture) and 5.30- 7.60 (Aroma). Consumers preferred blanched yam fufu prepared from BY3K2L25 because it recorded the highest preference for appearance, texture and aroma. Fufu made from UY3K1L25 was the least preferred as it had a lower score for appearance (2.2) and aroma (2.8) (figure 3.30).

The sensory evaluation of formulated blanched and unblanched Cocoyam fufu is represented in figure 3.31.

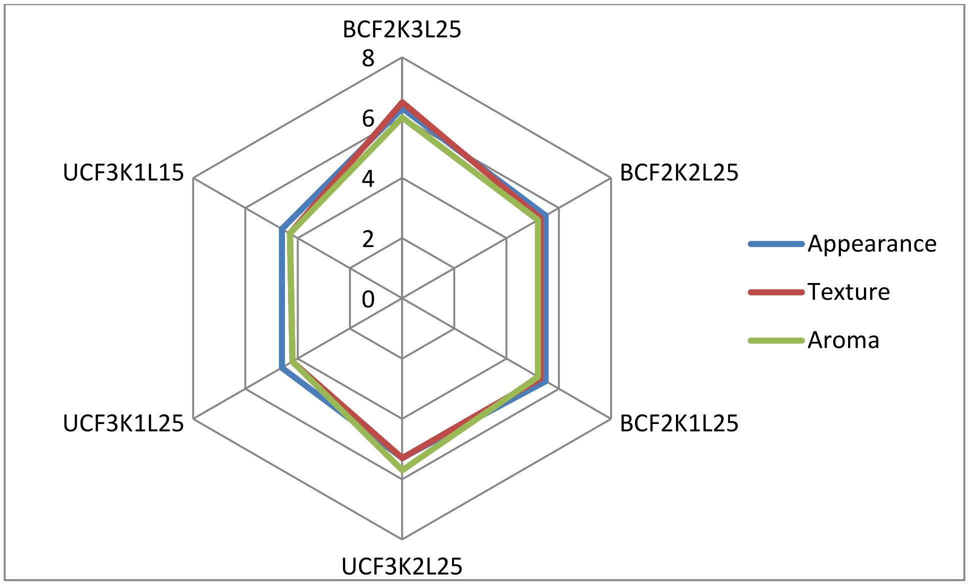

Figure 3.31: Sensory Evaluation of Formulated Blanched and Unblanched Cocoyam Fufu

BC2K3L25= 2kg of blanched cocoyam to 3 litres water; speed=25ms^{-1}, **BC2K2L25**= 2kg of blanched cocoyam to 2 litres water; speed=25rpm^{-1}, **BC2K1L25**= 2kg of unblanched cocoyam to 1 litre water; speed=25rpm^{-1}**UC3K2L25**= 3kg of unblanched cocoyam to 2 litres water; speed=25rpm^{-1}**UC3K1L25**= 3kg of unblanched cocoyam to 1 litre water; speed=25rpm^{-1}**UC3K1L15**= 3kg of unblanched cocoyam to 1 litre water; speed=15rpm^{-1}

The study shows that, blanched cocoyam fufu had a higher score than unblanched cocoyam fufu (Figure 3.31). Blanched cocoyam had a score ranging from 5.20- 6.30 for appearance, texture and aroma. Fufu made from BC2K3L25 had a higher score for appearance (6.30), texture (6.50) and aroma 96.00) whereas UC3K1L25 had the least score for texture (4.20) and aroma (4.20). Thus, blanched Cocoyam fufu made from BC2K3L25 was most preferred by the panelists.

The sensory evaluation of formulated Formulated Fermented Maize Banku is represented in figure 3.32.

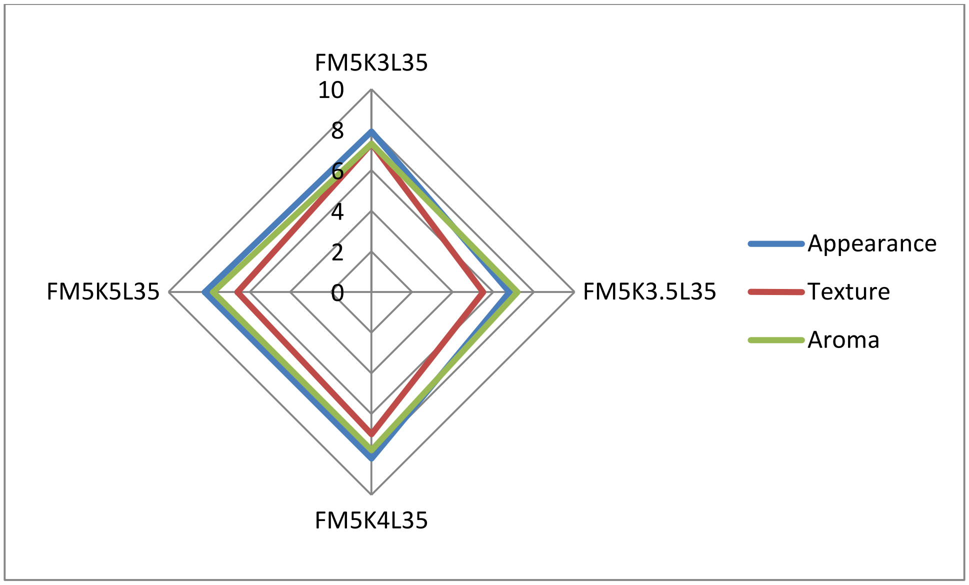

Figure 3.32: Sensory Evaluation of Formulated Fermented Maize Banku; **FM5K3L35**=5kg of fermented maize to 3 litres water; speed=35rpm^{-1}, **FM5K3.5L35**=5kg of fermented maize to 3.5 litres water; speed=35rpm^{-1}, **FM5K4L35**= 5kg of fermented maize to 4 litres water; speed=35rpm^{-1}, **FM5K5L35**=5kg of fermented maize to 5 litres of water; speed=35rpm^{-1}

Results showed that, banku had a score ranging from 6.80-8.20, 5.50-7.30, and 7.20-7.80 for appearance, texture and aroma respectively (Figure 3.32). Comparing the different formulations, banku prepared using FM5K4L35 and FM5K5L35 recorded high score for both appearance and aroma whereas FM5K3L35 had a high score for texture. Panelists gave higher score for banku made from FM5K4L35 because it was most preferred.

4.0 Conclusion and Recommendations

Production and export of plantain, roots and tubers contribute immensely to the socio-economic growth and development of Ghana. Curbing post-harvest losses of plantains, roots and tuber will directly reduce their shortage and improve food security. In an effort to extend its shelf life, plantains and root tubers are dried and used as fufu flours. Drum drying is very efficient for drying highly viscous foods as it rehydrates better. It operates by uniformly spreading slurry of the product onto pre-heated slowly rotating steel drums. The dried product on the drum is scrapped off by a blade in contact with the surface of the drum**.** However, to assess the efficacy of the dryer, fermented maize, blanched and unblanched mashed plantain, cocoyam and yam was dried and tested for it physiochemical, functional properties and acceptability.

The study showed that unblanched plantain recorded the lowest percentage moisture after drying. However, similar pH and L* values were recorded (Blanched and Unblanched). Both (blanched and unblanched plantain) showed increase in color difference after formulation. Blanched and unblanched plantain showed lower values of solubility after formulation indicating good quality starch.

Blanched yam recorded the lowest percentage moisture after drying. Its L* value and color difference increased after drying whereas similar pH values were recorded for blanched and unblanched yam. After formulation, L* values and color difference increased at varying proportions. Formulated blanched yam and unblanched yam flour recorded the lowest solubility and high swelling power indicating good quality flour.

Blanched and unblanched cocoyam showed sharp decrease in percentage moisture after drying. Similar values for pH and L* were recorded after drying, lower and high values for pH and L* respectively. Formulated blanched and unblanched cocoyam showed low and high values for solubility and swelling power respectively indicating good quality flour.

Fermented maize recorded low values after drying which might be due to the speed employed. It L* values increased after drying. Functional properties of formulated fermented maize showed otherwise as it recorded high and low values for solubility and swelling power respectively.

It was generally observed that drying conditions had an effect on the color difference and L* values as they increased after drying. Moreover, it was observed that, lighter slurry recorded the lowest percentage moisture which might be due to the speed employed during drum drying.

Central location sensory evaluation test on Fufu flours showed plantain and root tubers (blanched) to be most preferred. Blanched plantain fufu made from slurry of BPCS10K7.7L35 was most preferred by the panelists. Blanched cocoyam made from BC2K3L25 was most preferred. Panelist preferred blanched yam fufu prepared from BY3K2L25 as it recorded the highest preference. Comparing the different formulations, panelists gave the highest score for banku made from FM5K4L35.

The use of drum dryer is labor intensive therefore a mechanism needs to be put in place to feed the dryer with the slurry. Also space between the roller and scraper need to be adjusted as most of the dried products coming out are lost.

The blanching and milling processes before drum drying is time consuming compared to the preparation of fufu flour using the mechanical dryer where after blanching the sliced roots, it is dried outright.

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Appendix

Pictures showing some activities carried out during drum drying

Picture 1: Staff peeling Plantains **Picture 2**: A staff reading temperature for blanching

Picture 3: Staff preparing Slurry for drying **Picture 4**: slurry made from Blanched Plantain

Picture 5: Staff observing the drum dryer

Picture 6: Feeding slurry into drum dry dryer

Picture 7: Dried product coming out of the

Picture 8: Dried fermented maize

Picture 9: Blade scraping off dried product from the roller