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Factor Analysis and Age at Harvest Effect on the Quality of Flour from Four Cassava Varieties

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Abstract: Four varieties of cassava (Afisiafi, Tekbankye, Abasafitaa and Gblemoduade) were harvested each month from 9 months to 15 months after planting and processed into flour. Yield and selected physicochemical and functional properties of the flour were studied to determine the effect of age at harvest and varietal difference on these properties. The parameters studied were moisture, ash, pH, crude protein, crude fibre, swelling power, solubility, starch yield, amylose content and pasting properties. Afisiafi and Tekbankye had their peak flour yields (23 % and 22.4 %) at 13 months after planting while Abasafitaa and Gblemoduade had their peak flour yields (23.4 % and 20.0 %) at 12 months after planting. Afisiafi and Tekbankye had their flour yields increasing from 11 to 13 months after planting after which they fell while Abasafitaa and Gblemoduade had their flour yields increasing from 9 through 12 months after planting after which they fell. Moisture content ranged between 6.3 % and 14.6 % while ash content was between 0.7 % and 2.2 %. pH ranged between 5.1 and 6.7 indicating unfermented flour of high quality. All the cassava varieties had minimum crude protein of 0.2 %.; Afisiafi and Tekbankye had maximum values of 1.5 % and 1.7 % respectively at 9 months after planting while Abasafitaa and Gblemoduade had maximum values of 1.7 % and 1.5 % respectively at 15 months after planting. Starch yield ranged between 53.6 % and 76.0 % while solubility ranged between 7.8 % and 18.8 %. Age at harvest significantly affected ($p<0.05$) flour yield, crude protein, ash and moisture, while solubility and the pasting characteristics were all significantly affected ($p<0.05$) by varietal difference. pH, crude fibre, amylose and swelling power were neither affected significantly ($p<0.05$) by age at harvest nor by varietal difference. Starch content, fibre content and extent of dryness of the flour accounted for 65.3 % of the variability in the physicochemical and functional properties studied.

Key words: Cassava flour · Age at harvest · Physicochemical · Pasting

INTRODUCTION

Cassava (*Manihot esculenta*, Crantz) is one the most important root crops in the world, providing energy to consumers due to the large amount of carbohydrates in its roots. It contributes significantly to the economy of most tropical countries through its processing into various products [1-4]. In Ghana, its multiplication in the formal planting material sector started in the 1990s with the release of four varieties under the local names of Afisiafi, Tekbankye, Abasafitaa and Gblemoduade. These varieties were reportedly high yielders, disease and pest resistant compared to local varieties, and easy to identify [5]. Apart from Tekbankye, the three other varieties were not mealy and therefore their acceptability by farmers was low. In Ghana, cassava is mostly peeled and boiled in water and pounded into fufu which is a thick paste, and eaten with soup [2]. Fufu can, however, be prepared only from mealy cassava. There was the need to explore alternative uses for these varieties of cassava. Products from cassava include gari, starch, agbelima (fermented cassava dough) and flour to mention a few [2]. Little was, however, known about the physicochemical and functional properties of flour and starch from these cassava varieties in relation to

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how they are affected by age at harvest. The objective of the study, therefore, was to determine the effects that age at harvest and varietal difference had on selected physicochemical and functional properties of flour from these four cassava varieties.

MATERIALS AND METHODS

Source of Raw Materials: Cassava samples were obtained from experimental plots at the Wenchi Agricultural Research Station in the Brong Ahafo Region of Ghana. The varieties studied were Afisiafi, Tekbankye, Abasafitaa and Gblemoduade. Roots were harvested each month from 9 months after planting until 15 months after planting and processed into flour.

Processing of Roots in Flour: Fresh roots were harvested, peeled, washed with water and grated with mechanical cassava grater into a mash. The mash was packed into porous, woven polypropylene sacks and dehydrated by pressing with a manual screw-press. The cakes obtained were pulverized, sieved through nylon mesh and sun-dried by spreading thinly on raised wooden platforms lined with black high density polyethylene films, with periodic stirring. The dry granules obtained after two days of sun drying were milled and sieved through a 120 μm mesh. The resulting flour was packaged in transparent high density polyethylene bags and stored in a freezer for laboratory analyses (-12±2°C).

Physicochemical and Functional Properties Determination: Flour yield was determined by weighing the amount of flour obtained from 100 kg of fresh cassava roots and expressing as a percentage of the fresh roots. Moisture, total ash, crude protein and crude fibre contents of the flour were determined by official methods [6]. pH was determined by mixing 10 g of flour with 25 ml of distilled water, stirring thoroughly and measuring with a pH meter (HANNA Instruments, model 18521) at 20°C. Starch yield of flour was determined by preparing slurry with 10 g of flour in water in a beaker, and repeatedly washing out the starch with water through cheesecloth. The extracted starch was allowed to settle in the beaker, decanted, spread on petri dishes and dried in a hot-air oven at 50°C over at least 24 hours. It was weighed and expressed as percent of the flour weight. Swelling power and solubility were determined by the method of Barimah [7]. Pasting characteristics was determined using the Brabender Amylograph (700 cmg cartridge, Duisburg Germany) on a 6 % w/v aqueous flour suspension (corrected for moisture content).

Statistical Analysis: Two way analysis of variance was used to determine the effects of age at harvest and variety on the response variables. Significant difference was accepted at $p<0.05$. Least significant difference was used for mean separation. Factor analysis using the principal components method was used to study the factors that contributed most to the variability in the physicochemical and functional properties studied. Statgraphics Centurion XV statistical software was used for all data analyses.

RESULTS AND DISCUSSION

Flour Yield: Flour yield was between 8.0-23.0 % for Afisiafi, 10.6-22.4 % for Tekbankye, 13.0-23.4 % for Abasafitaa and 9.4-20.0 % for Gblemoduade (Table 1). Flour yield of Afisiafi fell from 9 months after planting through 11 months after planting (March to June) after which it rose uniformly reaching a peak at 13 months after planting, and then it fell again until 15 months after planting. Tekbankye had flour yield falling from 9 months after planting to 10 months after planting and then rising until 13 months after planting before falling again until the 15 month harvest. Abasafitaa and Gblemoduade had similar trend for the flour yield. Their flour yields rose from 9 months after planting through 12 months after planting where the values peaked, after which they fell until 15 months after planting. All the varieties had low flour yield in April. This is because the rains started in late March and by April, the plants mobilized most of the starch stored in the roots for new shoot formation [8]. This shows that apart from age at harvest of the plant, other factors such as the month in which harvesting occurred may also affect yield of the flour. Afisiafi and Tekbankye had optimum yields at 13 months after planting while Abasafitaa and Gblemoduade had optimum yields at 12 months after planting. Flour yield was significantly affected ($p<0.05$) by age at harvest but not by variety. Cassava roots harvested at 12 months and 13 months after planting gave significantly higher flour yields than roots harvested at 9, 10, 11 and 15 months after planting. The results from this study have implication on the practice where cassava roots are left unharvested in the soil until when needed. To obtain optimal flour yield, cassava roots from these four varieties studied should not be left unharvested beyond 14 months after planting.

Moisture: Moisture content of the flour ranged between 6.34-14.58 % (Table 2). Flour samples were sun-dried from March to December, when the rainfall and sunshine patterns were unpredictable and non-uniform. It is worth noting that moisture content of the flour is influenced by

Table 1: Flour yield from four cassava varieties at different ages at harvest

Flour yield (%)	Afisiafi	Tekbankye	Abasafitaa	Gblemoduade	Mean of Ages
9 months	13.8	14.4	13.0	9.4	12.65^{a}
10 months	14.4	10.6	15.5	12.6	13.28^{a}
11 months	8.0	14.8	16.4	16.2	13.85^{a}
12 months	14.2	21.0	23.4	20.0	19.65^{b}
13 months	23.0	22.4	20.0	14.0	19.85^{b}
14 months	14.0	21.0	15.5	13.6	16.03^{ab}
15 months	12.6	19.4	13.6	10.0	13.90^{a}

Mean values in a column with same superscript are not significantly different (p>0.05) from each other.

Table 2: Moisture content of flour from four cassava varieties at different ages at harvest

Moisture (%)	Afisiafi	Tekbankye	Abasafitaa	Gblemoduade	Overall Mean of Ages
9 months	9.90 (0.01)	9.53 (0.03)	12.10 (0.01)	10.64 (0.02)	10.54^{cde}
10 months	8.89 (0.02)	12.47 (0.11)	10.84 (0.00)	10.64 (0.01)	10.71^{cde}
11 months	11.26 (0.02)	13.20 (0.01)	12.37 (0.01)	14.58 (0.00)	12.85^{e}
12 months	11.47 (0.01)	13.18 (0.00)	11.00 (0.04)	11.52 (0.01)	11.79^{de}
13 months	10.96 (0.00)	10.15 (0.01)	6.68 (0.01)	6.34 (0.01)	8.53^{c}
14 months	11.14 (0.01)	7.24 (0.01)	7.80 (0.02)	12.23 (0.00)	9.60^{cd}
15 months	11.37 (0.00)	11.75 (0.00)	11.34 (0.00)	11.29 (0.00)	11.44^{de}

Mean of three replicates with standard deviation in parentheses. Overall means in a column with same superscript are not significantly different (p>0.05) from each other.

Table 3: Ash content of flour from four cassava varieties at different ages at harvest

Ash (%)	Afisiafi	Tekbankye	Abasafitaa	Gblemoduade	Overall Mean of Ages
9 months	0.80 (0.00)	0.70 (0.00)	1.36 (0.00)	1.21 (0.00)	1.02^{h}
10 months	1.21 (0.00)	1.26 (0.00)	1.00 (0.00)	1.31 (0.00)	1.20^{h}
11 months	1.15 (0.00)	1.12 (0.00)	1.17 (0.00)	0.95 (0.00)	1.10^{h}
12 months	1.47 (0.00)	1.06 (0.00)	2.21 (0.00)	1.94 (0.01)	1.67^{g}
13 months	1.23 (0.00)	0.83 (0.00)	1.15 (0.00)	0.99 (0.00)	1.05^{h}
14 months	0.82 (0.00)	0.83 (0.00)	1.24 (0.00)	0.88 (0.00)	0.94^{h}
15 months	0.82 (0.00)	0.79 (0.00)	0.87 (0.00)	0.99 (0.00)	0.87^{h}

Mean of three replicates with standard deviation in parentheses. Overall means in a column with same superscript are not significantly different (p>0.05) from each other.

the extent of drying and relative humidity during the period of sun-drying. Statistical analysis revealed that age at harvest significantly affected (p<0.05) moisture content of the flour samples. It is, however, worth noting that climatic factors such as rainfall pattern confounded the effect of age at harvest on moisture content of the flour. This is because the pressed cassava mash was sun dried and therefore the moisture of mash was dependent on the relative humidity of the atmosphere. The 9 months harvest was done in late March when the rains had just started. Moisture content of flour was generally highest at the 11 month of harvest which was done in May, by which period there was frequent rainfall and relative humidity was high (>90%). Codex standard [9] for edible cassava flour specifies a maximum of 13 % for moisture content. Apart from the Gblemoduade 11 month harvest, all the other samples had moisture content within the range specified by Codex Alimentarius Commission for edible cassava flour.

Ash: Ash content of Afisiafi ranged between 0.80-1.47 % while that of Tekbankye was between 0.70-1.26 % with the lowest value occurring at 9 months after planting while the highest value was at 10 months after planting. Abasafitaa had ash content ranging between 0.87-2.21 %, representing 15 months and 12 months after planting respectively, while Gblemoduade had ash values in the range of 0.88-1.94 %, with the lower and upper limits at 14 months and 12 months after planting, respectively. With the exception of Tekbankye which had its peak ash content at 10 months after planting, all the other varieties had it at 12 months after planting (Table 3). Ash content of Tekbankye fell sequentially from 10 months after planting until 15 months after planting. There was, however, inconsistent trend for the other varieties. Age at harvest significantly affected (p<0.05) ash content of the flour samples. Ash content of flour at the 12 month harvest was significantly higher than that of all the other ages at harvest. Ash content values obtained in

Table 4: pH of flour from four cassava varieties at different ages at harvest

pH	Afisiafi	Tekbankye	Abasafitaa	Gblemoduade
9 months	5.86 (0.01)	5.46 (0.00)	5.53 (0.00)	5.47 (0.00)
10 months	5.49 (0.01)	5.13 (0.01)	6.21 (0.00)	6.61 (0.01)
11 months	5.63 (0.00)	6.51 (0.01)	5.27 (0.00)	5.30 (0.00)
12 months	6.40 (0.01)	5.31 (0.01)	6.15 (0.00)	6.54 (0.01)
13 months	5.07 (0.00)	6.65 (0.00)	5.67 (0.00)	5.97 (0.01)
14 months	6.27 (0.02)	6.02 (0.01)	5.32 (0.00)	5.55 (0.01)
15 months	5.28 (0.00)	5.11 (0.00)	5.49 (0.00)	5.31 (0.00)

Table 5: Crude protein of flour from four cassava varieties at different ages at harvest

Crude protein (%)	Afisiafi	Tekbankye	Abasafitaa	Gblemoduade	Overall Mean of Ages
9 months	1.53 (0.00)	1.68 (0.06)	0.51 (0.06)	0.66 (0.00)	1.095^{ij}
10 months	0.80 (0.06)	0.66 (0.00)	0.66 (0.00)	0.36 (0.06)	0.620^{ikl}
11 months	0.66 (0.00)	0.22 (0.00)	0.66 (0.00)	0.66 (0.00)	0.550^{kl}
12 months	0.22 (0.00)	0.66 (0.00)	0.66 (0.00)	0.22 (0.00)	0.440^{l}
13 months	0.36 (0.06)	0.66 (0.00)	0.22 (0.00)	0.22 (0.00)	0.365^{l}
14 months	1.09 (0.00)	0.66 (0.00)	1.09 (0.00)	1.24 (0.06)	1.020^{ijk}
15 months	1.52 (0.00)	0.95 (0.00)	1.68 (0.06)	1.53 (0.00)	1.420^{j}

Mean of three replicates with standard deviation in parentheses. Overall means in a column with same superscript are not significantly different (p>0.05) from each other

Table 6: Crude fibre of flour from four cassava varieties at different ages at harvest

Crude fibre (%)	Afisiafi	Tekbankye	Abasafitaa	Gblemoduade
9 months	1.90 (0.00)	1.45 (0.00)	2.11 (0.00)	2.56 (0.00)
10 months	2.22 (0.00)	2.07 (0.00)	1.84 (0.00)	2.54 (0.00)
11 months	2.62 (0.00)	1.57 (0.00)	1.92 (0.00)	1.82 (0.00)
12 months	2.52 (0.00)	1.67 (0.00)	1.27 (0.00)	1.69 (0.00)
13 months	1.89 (0.00)	1.52 (0.00)	1.69 (0.00)	1.62 (0.00)
14 months	0.77 (0.01)	1.46 (0.00)	1.47 (0.00)	1.78 (0.00)
15 months	1.98 (0.00)	1.58 (0.00)	1.76 (0.00)	1.99 (0.00)

the current study were all lower than the maximum of 3 % specified by Codex Alimentarius Commission for edible cassava flour [9].

pH: pH is an important parameter in determining the quality of cassava flour since pH of 4 or less indicates appreciable level of fermentation and hence starch breakdown. Fermentation also imparts characteristic aroma, flavour and sour taste to the flour and this makes it less preferred for use in baking. The flour samples had pH ranging between 5.07 and 6.65 (Table 4), indicating that they were of good quality. pH was not significantly affected (p>0.05) by age or varietal difference.

Crude Protein: Crude protein of both Afisiafi and Gblemoduade ranged between 0.22 % and 1.53 % while for Tekbankye and Abasafitaa, it ranged between 0.22 % and 1.68 %. For Afisiafi and Tekbankye, the peak protein content was at 15 months after planting, while for Abasafitaa and Gblemoduade, it was at 9 months after planting. Even though the effect of varietal difference was not significant (p>0.05), it is observed that the varieties showed differences in their crude protein profile over the harvesting times. Age significantly affected (p<0.05) crude protein content. This may be due to differing rates of nitrogen metabolism in the growing plants resulting in differing trends in crude protein content (Table 5) at the times of harvest. Balagopalan [2] reported protein content of cassava roots to be between 0.7 % and 1.3 %. Values obtained in the current study compare well with the reported range of values.

Crude Fibre: Afisiafi had crude fibre content of between 0.77-2.62 %, with the lower and upper limits respectively at 14 months and 11 months after planting while that of Tekbankye was between 1.45-2.07 % with the lower and upper limits at 9 months and 10 months after planting respectively. Abasafitaa on the other hand, had values between 1.27-2.11 % with the lowest value at 12 months and the highest at 9 months after planting, while that of Gblemoduade ranged between 1.62-2.56 % with the lower and upper limits at 13 months and 9 months after planting respectively (Table 6). The effects of age at harvest and varietal difference on crude fibre was not statistically

Table 7: Starch yield of flour from four cassava varieties at different ages at harvest

Starch yield (%)	Afisiafi	Tekbankye	Abasafitaa	Gblemoduade
9 months	53.60 (0.05)	71.55 (0.47)	68.46 (0.18)	70.36 (0.23)
10 months	75.50 (1.01)	67.33 (0.13)	71.24 (0.20)	69.95 (0.37)
11 months	63.94 (0.18)	73.65 (0.14)	64.06 (0.89)	68.16 (0.22)
12 months	72.40 (0.09)	71.72 (0.03)	72.93 (0.24)	75.35 (0.03)
13 months	69.63 (0.85)	73.83 (0.07)	74.24 (0.03)	76.01 (0.13)
14 months	66.19 (0.65)	72.45 (0.43)	75.69 (0.15)	63.75 (0.06)
15 months	67.71 (0.00)	73.45 (0.25)	68.63 (0.27)	73.87 (0.03)

Table 8: Amylose content of flour from four cassava varieties at different ages at harvest

Amylose (%)	Afisiafi	Tekbankye	Abasafitaa	Gblemoduade
9 months	16.48 (0.00)	21.71 (0.00)	36.00 (0.00)	34.57 (0.00)
10 months	22.19 (0.00)	36.00 (0.00)	30.29 (0.00)	34.57 (0.00)
11 months	30.29 (0.00)	26.48 (0.00)	32.19 (0.00)	28.86 (0.00)
12 months	34.57 (0.00)	31.71 (0.00)	23.14 (0.00)	23.62 (0.00)
13 months	26.00 (0.00)	23.62 (0.00)	27.43 (0.00)	23.14 (0.00)
14 months	20.29 (0.00)	20.29 (0.00)	20.76 (0.00)	34.57 (0.00)
15 months	23.49 (0.00)	22.67 (0.00)	23.14 (0.00)	34.57 (0.00)

significant ($p>0.05$) probably due to the fine sieving of flour, after milling, which removed most of the fibre [2]. Values in this study were lower than the 2 % upper limit specified for edible cassava flour by Codex [9].

Starch Yield: Starch yield of Afisiafi was between 53.6-75.5 % with the lowest value at 9 months and the highest at 10 months, while that of Tekbankye was between 67.3-73.8 % with the lower and upper limits occurring at 10 months and 13 months after planting. Abasafitaa had starch yield ranging between 64.1-75.7 % with the lowest value at 11 months and the highest at 14 months, while Gblemoduade had values between 63.8-76.0 % with lower and upper limits, respectively at 14 months and 13 months after planting (Table 7). The effects of age at harvest and varietal difference on starch yield of the flour was not statistically significant ($p>0.05$).

Amylose: Amylose content of variety Afisiafi ranged between 16.5-34.6 % with the lower and upper limits respectively at 9 and 12 months after planting while Tekbankye had values between 20.3-36.0 % with the lowest value at 14 months and the highest at 10 months after planting. Abasafitaa had amylose content between 20.8-36.0 % with lower and upper limits at 14 months and 9 months after planting respectively while Gblemoduade had values between 23.1-34.6 %, with the lowest and highest values at 13 months and 15 months after planting respectively. The values for Afisiafi rose uniformly from 9 months after planting reaching a peak at 12 months after planting and then falling until 14 months after planting. Other varieties showed no consistent trend in amylose content (Table 8). Amylose content of fresh cassava starch was reported to range between 22.6-26.2% for five Indian cassava varieties [10]. When the amylose content of six cassava varieties was compared during growth period, there were insignificant differences among them [11]. Barimah [7] reported amylose content of starch from dry chips to range between 22.3-24.5 % for the varieties Afisiafi, Abasafitaa, Gblemoduade and Isu-white. These values were recorded only at one harvesting time. Rickard *et al.* [12] reported amylose content of 13.6-23.8 % in some cassava accessions studied. It is observed that the highest values obtained from the current study were slightly higher than that reported in other earlier studies. However, neither age at harvest nor varietal difference significantly affected ($p>0.05$) amylose content of flour from the varieties studied and this is in agreement with the observation reported by Moorthy [11] of insignificant differences between the amylose content of six cassava varieties. Amylose content of cassava is believed to be influenced genetically and that neither age of the plant nor environmental factors play a major role in determining it [13].

Swelling Power: Swelling power of Afisiafi ranged between 17.2-28.0 with the lower and upper limits at 13 months and 9 months after planting respectively. For Tekbankye the values were 18.1-31.1, with the lowest value at 12 months and the highest at 9 months after planting. Abasafitaa had swelling power in the range of 20.7-28.5 with the lower and upper limits at 11 months and

Table 9: Swelling power of flour from four cassava varieties at different ages at harvest

Swelling power	Afisiafi	Tekbankye	Abasafitaa	Gblemoduade
9 months	28.95 (0.15)	31.07 (0.35)	24.26 (0.54)	30.40 (0.25)
10 months	27.80 (0.35)	25.21 (0.07)	21.92 (0.28)	31.65 (0.07)
11 months	20.30 (0.31)	21.98 (0.21)	20.71 (0.14)	18.74 (0.23)
12 months	28.41 (0.09)	18.13 (0.13)	26.10 (0.14)	30.08 (0.27)
13 months	17.15 (0.17)	26.61 (0.29)	28.23 (0.19)	31.97 (0.21)
14 months	27.24 (0.39)	29.85 (0.38)	21.41 (0.40)	28.03 (0.38)
15 months	27.40 (0.00)	30.39 (0.34)	28.45 (0.16)	26.16 (0.24)

15 months respectively, while Gblemoduade had values between 18.7-32.0 with the lowest value at 11 months and highest value at 13 months. Tekbankye had swelling power falling from a peak at 9 months until 12 months after planting, after it began to rise (Table 9). Age at harvest and varietal difference had no significant effect ($p>0.05$) on swelling power of the flour. There was a positive correlation between swelling power and peak temperature for Abasafitaa ($r^2=0.509$) and Gblemoduade ($r^2=0.883$). A strong correlation between swelling power and peak viscosity has been reported for starch from dried cassava chips [7]. Starches capable of high swelling are reportedly less resistant to break down [14]. Even though there was a relationship between swelling power and peak viscosity for Afisiafi and Tekbankye, correlation between them was weak ($r^2=0.378$ and 0.135 respectively). Similarly, a weak correlation was observed between swelling power and paste break down for Afisiafi, Tekbankye and Abasafitaa.

Solubility: The solubility of Afisiafi ranged between 8.1-17.4 % with the lowest at 12 months after planting and highest at 14 months after planting, while values for Tekbankye ranged between 7.8-11.9 % with the lower and highest values at 11 months and 14 months after planting respectively. Solubility of Abasafitaa was between 13.1-18.7 % with the lowest and highest values at 11 months and 9 months respectively while that of Gblemoduade was between 11.7-18.8 % with the lowest and highest values at 11 months and 12 months after planting respectively. With the exception of Afisiafi, all the other three varieties had the lowest solubility at 11 months after planting and this parameter is important since it has application in preparation of products such as pasta and in baking. Flour with high solubility may yield soggy dough with low cohesiveness. Tekbankye had the lowest solubility followed by Afisiafi and then Gblemoduade, while Abasafitaa had the highest solubility values. Solubility values between 9.6-14.7 % has been reported on the four cassava varieties Afisiafi, Isu-white, Abasafitaa and Gblemoduade, with the lowest and highest values obtained in Gblemoduade and Abasafitaa respectively [7]. For starch from dried cassava chips, values between 11.4-19.7 % have been reported for the varieties Afisiafi, Isu-white, Abasafitaa and Gblemoduade with the lowest and highest values in Gblemoduade and Abasafitaa respectively [7]. Values obtained from the current study compare well with those reported [7]. However, in the current study Tekbankye had the lowest solubility and not Gblemoduade. There was no significant difference ($p>0.05$) in solubility between ages, but significant difference ($p<0.05$) existed among varieties.

There was weak correlation between solubility and moisture content for Tekbankye and Gblemoduade ($r^2=0.447$ and $r^2=0.285$ respectively). Gblemoduade showed correlation ($r^2=0.502$) between solubility and starch yield while Afisiafi showed correlation ($r^2=0.518$) between solubility and amylose content. Solubility correlated with swelling power in Tekbankye, Abasafitaa and Gblemoduade ($r^2=0.658$, 0.428 and 0.568 respectively). Solubility correlated strongly with gelatinization temperature in Tekbankye ($r^2=0.828$) but weakly in Afisiafi ($r^2=0.305$). In Tekbankye ($r^2=0.787$) and Afisiafi ($r^2=0.664$), solubility correlated with peak temperature. Even though a relationship existed between solubility and paste break down as well as retrogradation, correlation was weak. The starch loss during dehydration of the cassava mash in flour preparation as well as the presence of some fibre in cassava flour makes the flour behave differently from starch.

Pasting Characteristics: Pasting temperature is the temperature at which starch granules swell on heating in water, resulting in an initial slight increase in viscosity of the aqueous starch or flour suspension. Pasting temperature of flour from Afisiafi ranged between 67.7-70.0°C with the lowest and highest values at 13 months and 15 months after planting respectively while that of Tekbankye had values between 68.7-73.2°C representing 10 months and 11 months respectively. Abasafitaa had values between 69.0-71.0°C while Gblemoduade had

Table 10: Solubility of flour from four cassava varieties at different ages at harvest

Solubility (%)	Afisiafi	Tekbankye	Abasafitaa	Gblemoduade
9 months	12.73 (0.03)	10.37 (0.01)	18.65 (0.01)	16.87 (0.01)
10 months	12.85 (0.01)	10.37 (0.01)	15.27 (0.03)	16.33 (0.00)
11 months	10.70 (0.01)	7.81 (0.00)	13.11 (0.01)	11.72 (0.01)
12 months	8.02 (0.01)	8.84 (0.02)	14.87 (0.01)	18.80 (0.04)
13 months	8.58 (0.00)	10.04 (0.00)	17.06 (0.01)	16.22 (0.00)
14 months	17.42 (0.01)	11.89 (0.01)	13.44 (0.01)	12.38 (0.01)
15 months	12.61 (0.00)	11.86 (0.00)	16.91 (0.01)	14.57 (0.01)
Overall Mean of varieties	11.84^{m}	10.17^{m}	15.62^{n}	15.27^{n}

Mean of three replicates with standard deviation in parentheses. Mean values in a row with same superscript are not significantly different (p>0.05) from each other

Table 11: Pasting temperature of flour from four cassava varieties at different ages at harvest

Pasting temperature°C	Afisiafi	Tekbankye	Abasafitaa	Gblemoduade
9 months	67.85 (1.20)	72.80 (2.69)	70.45 (0.49)	68.25 (0.35)
10 months	69.25 (0.78)	68.70 (0.28)	70.15 (1.63)	69.80 (0.14)
11 months	68.05 (0.07)	73.20 (1.84)	71.00 (0.71)	71.00 (0.00)
12 months	69.55 (0.92)	71.05 (0.64)	69.80 (0.42)	70.50 (0.42)
13 months	69.95 (0.92)	69.80 (1.41)	69.60 (0.57)	68.55 (0.49)
14 months	69.10 (0.00)	69.10 (0.14)	69.00 (0.14)	68.80 (0.28)
15 months	67.69 (0.00)	69.50 (0.00)	68.95 (1.34)	68.00 (0.00)
Overall Mean of varieties	68.78^{a}	70.59^{b}	69.85^{ab}	69.27^{a}

Mean of two replicates with standard deviation in parentheses. Mean values in a row with same superscript are not significantly different (p>0.05) from each other

Table 12: Gelatinization temperature of flour from four cassava varieties at different ages at harvest

Gelatinization temperature°C	Afisiafi	Tekbankye	Abasafitaa	Gblemoduade
9 months	69.70 (1.13)	75.60 (0.99)	73.00 (0.85)	70.20 (0.00)
10 months	71.25 (0.64)	72.15 (0.49)	74.00 (0.71)	70.65 (0.21)
11 months	70.25 (0.07)	78.60 (0.57)	76.00 (0.71)	75.30 (0.14)
12 months	72.15 (0.07)	78.20 (0.28)	71.50 (0.28)	72.55 (0.92)
13 months	75.25 (1.34)	73.55 (1.06)	70.80 (0.28)	69.35 (0.07)
14 months	70.80 (0.42)	70.15 (0.07)	71.10 (0.28)	69.45 (0.07)
15 months	69.75 (0.00)	72.15 (0.07)	71.40 (0.99)	69.70 (0.00)
Overall Mean	71.31^{c}	74.34^{d}	72.54^{cd}	71.03^{c}

Mean of two replicates with standard deviation in parentheses. Mean values in a row with same superscript are not significantly different (p>0.05) from each other

values between 68.0-71.0°C. For both Abasafitaa and Gblemoduade, the lowest and highest values were at 15 months and 11 months after planting respectively (Table 11). There was no significant difference (p>0.05) in pasting temperature between the ages at harvest but significant difference (p<0.05) existed among varieties. Tekbankye had significantly higher pasting temperature than Afisiafi and Gblemoduade, while Afisiafi, Abasafitaa and Gblemoduade had significantly comparable pasting temperatures. The pasting temperature of Abasafitaa was also not significantly different from that of Tekbankye. In effect therefore, a higher temperature is required to cause flour from Tekbankye to undergo pasting, than is required for Afisiafi and Gblemoduade (Table 11).

A similar trend was observed for gelatinization temperature (Table 12). Gelatinization temperature is the temperature at which swollen starch granules rupture, on heating in water, to release starch molecules into the aqueous medium resulting in increase in viscosity of the paste. Gelatinization temperature was recorded, using the Brabender amylograph, as the temperature at which viscosity of the paste rose by 20 BU. This temperature was attained after the pasting temperature had been recorded. Gelatinization temperature for Afisiafi ranged between 69.7-75.3°C with the lowest and highest values at 9 months and 13 months after planting while values for Tekbankye were between 70.2-78.6°C with the lowest and highest values occurring at 14 months and 11 months

Table 13: Peak temperature of flour from four cassava varieties at different ages at harvest

Peak temperature°C	Afisiafi	Tekbankye	Abasafitaa	Gblemoduade
9 months	83.55 (0.35)	89.05 (0.49)	88.30 (2.69)	80.35 (0.07)
10 months	85.50 (0.85)	86.10 (0.00)	88.55 (0.07)	78.80 (0.00)
11 months	84.10 (0.42)	91.05 (0.35)	90.75 (1.91)	92.10 (0.42)
12 months	86.55 (0.92)	90.60 (1.70)	84.65 (1.20)	80.25 (1.91)
13 months	89.20 (0.14)	87.05 (0.78)	80.70 (1.56)	77.60 (0.71)
14 months	82.20 (0.00)	82.60 (0.00)	83.80 (0.85)	78.40 (0.57)
15 months	83.98 (0.00)	85.85 (0.21)	84.00 (1.41)	81.65 (0.21)
Overall Mean	85.01^{e}	87.47^{e}	85.82^{e}	81.31^{f}

Mean of two replicates with standard deviation in parentheses. Mean values in a row with same superscript are not significantly different (p>0.05) from each other

Table 14: Peak viscosity of flour from four cassava varieties at different ages at harvest

Peak viscosity BU	Afisiafi	Tekbankye	Abasafitaa	Gblemoduade
9 months	280 (14.14)	300 (0.00)	155 (7.07)	190 (0.00)
10 months	305 (7.07)	220 (14.14)	145 (7.07)	210 (0.00)
11 months	245 (7.07)	290 (0.00)	180 (14.14)	175 (7.07)
12 months	290 (0.00)	235 (7.07)	225 (7.07)	160 (14.14)
13 months	215 (7.07)	280 (14.14)	180 (14.14)	220 (0.00)
14 months	210 (0.00)	270 (0.00)	210 (0.00)	220 (0.00)
15 months	261 (0.00)	250 (0.00)	185 (21.21)	220 (0.00)
Overall Mean	258.0^{g}	263.57^{g}	182.86^{h}	199.29^{h}

Mean of two replicates with standard deviation in parentheses. Mean values in a row with same superscript are not significantly different (p>0.05) from each other

after planting respectively. Abasafitaa had values ranging between 70.8°C (13 months) and 76.0°C (11 months) while Gblemoduade had values between 69.3°C and 75.3°C with the lowest and highest values at 13 months and 11 months after planting respectively. Both Abasafitaa and Gblemoduade had lowest and highest values respectively at 13 months and 11 months after planting. There was no significant difference (p>0.05) between ages at harvest, but significant difference (p<0.05) existed among varieties for gelatinization temperature (Table 12).

Peak temperature for Afisiafi was between 82.2-89.2°C with 14 months and 13 months having the lowest and highest values respectively, while Tekbankye had values between 82.6-91.1°C with the lowest and highest values at 14 months and 11 months after planting respectively. Abasafitaa had peak temperatures ranging between 80.7-90.7°C with 13 months and 11 months having the lowest and highest values respectively, while Gblemoduade had values between 77.6-92.1°C with the lowest and highest values at 13 months and 11 months after planting respectively. Both Afisiafi and Tekbankye had their lowest peak temperatures at 14 months after planting while Abasafitaa and Gblemoduade had their lowest and highest values at 13 months and 11 months after planting respectively. Apart from Afisiafi whose highest peak temperature was at 13 months, all the other varieties had their highest values at 11 months after planting. There was no significant difference (p>0.05) in peak temperature between ages or harvesting time but significant difference (p<0.05) existed among varieties (Table 13). Afisiafi, Tekbankye and Abasafitaa all had significantly higher peak temperature than Gblemoduade, implying that an aqueous flour suspension from Gblemoduade will require lesser heating to attain its peak viscosity than the other three varieties.

Peak temperatures between 73.7-74.8°C has been reported for flour from the same varieties prepared from cassava chips [7]. This may suggest that flour prepared from dried cassava mash may have higher peak temperature than flour prepared from dried cassava chips. It is worth noting that during dehydration of the cassava mash, some starch is lost while pressing to dehydrate the mash. Processing method of cassava flour may therefore possibly affect the functional properties of the flour. Peak temperatures of flour from thirty-one cassava varieties has been reported to range between 73.1-84.5°C [15].

Peak viscosity of Afisiafi was between 210-305 BU with the lowest and highest values at 14 months and 10 months after planting respectively while Tekbankye had values between 220-300 BU with the lower and upper limits at 10 months and 9 months after planting respectively. Abasafitaa had peak viscosity ranging between 145-225 BU with the lowest and highest values respectively at 10 months and 12 months after planting while Gblemoduade had values between 160-220 BU (Table 14). Peak viscosity significantly differed (p<0.05)

Table 15: Hot Paste Breakdown of flour from four cassava varieties at different ages at harvest

Hot Paste Breakdown BU	Afisiafi	Tekbankye	Abasafitaa	Gblemoduade
9 months	75	105	10	80
10 months	85	60	40	95
11 months	60	90	50	85
12 months	70	80	75	70
13 months	70	80	80	105
14 months	80	100	60	110
15 months	85	85	65	115
Overall Mean	75.0^{i}	85.7^{ik}	54.3^{j}	94.3^{k}

Mean values in a row with same superscript are not significantly different (p>0.05) from each other.

Table 16: Retrogradation of flour from four cassava varieties at different ages at harvest

Retrogradation	Afisiafi	Tekbankye	Abasafitaa	Gblemoduade
9 months	40	45	0	5
10 months	50	10	5	0
11 months	0	20	5	0
12 months	30	15	5	10
13 months	5	20	0	-5
14 months	5	5	0	0
15 months	12	5	-5	-5
Overall Mean	20.29^{m}	17.14^{m}	1.43^{n}	0.71^{n}

Mean values in a row with same superscript are not significantly different (p>0.05) from each other

among the varieties studied. Afisiafi and Tekbankye had significantly higher peak viscosities than Abasafitaa and Gblemoduade.

Hot paste breakdown for Afisiafi ranged between 60.0-85.3 BU, with the lowest and highest values respectively at 11 months and 15 months after planting while that of Tekbankye was between 60.0-105.0 BU, with the lowest and highest values at 10 months and 9 months respectively. Abasafitaa had values between 10.0-80.0 BU, with the lowest and highest at 9 months and 13 months after planting while Gblemoduade had values between 70.0 BU (12 months) and 115.0 BU (15 months). Hot paste breakdown was significantly affected ($p<0.05$) by variety but not by age at harvest. Abasafitaa had the lowest paste breakdown while Gblemoduade had the highest. Hot paste breakdown of Tekbankye was, however, not significantly different from that of Gblemoduade (Table 15). There was a relationship with strong correlation (r^2=0.717 and 0.807 respectively) between paste breakdown and both amylose and crude fibre for Tekbankye. A similar relationship (r^2=0.594 and 0.593) existed for Abasafitaa. Amylose, the helical polymer of starch, interacts with water molecules through hydrogen bonding in an aqueous starch or flour suspension when heated. This results in gelatinization and subsequent increase in viscosity of the paste. When the hot paste is agitated for an extended period at high temperature, as is caused by the rotation of the Brabender amylograph bowl, the weak hydrogen bonds (adhesive forces) break and the amylose molecules coil up forming intramolecular hydrogen bonds (cohesive forces) and intermolecular hydrogen bonds between adjacent amylose molecules. This causes a sharp decrease in viscosity and a consequent breakdown of the hot paste. Molecules of the crude fibre (cellulose) may also interact with water molecules in like manner, thereby contributing to hot paste breakdown.

Retrogradation values of Afisiafi ranged between 0-50 BU while that for Tekbankye was between 5-45 BU. Abasafitaa and Gblemoduade had retrogradation values between (-5)-5 BU and (-5)-10 BU respectively. Retrogradation was significantly affected ($p<0.05$) by variety but not by age at harvest (Table 16). Afisiafi and Tekbankye had significantly higher retrogradation values than Abasafitaa and Gblemoduade. The implication is that gels produced from flour of Afisiafi and Tekbankye have higher tendency to retrograde or undergo syneresis (setback) on cooling, than gels from Abasafitaa and Gblemoduade. Flours from the varieties Abasafitaa and Gblemoduade will therefore perform better as adhesive gels than flours from Afisiafi and Tekbankye.

Barichello and Yada [16] suggested that pasting and other physicochemical properties of starches vary with genotype and cultural practices. Varietal differences in pasting characteristics of starch have been attributed to the differences in amylopectin molecular structure rather than amylose [17]. In rice it was reported that differences in the amylopectin chain length and the degree of polymerization resulted in significant differences in gel consistency, gel viscosity and gel strength [18, 19].

Table 17: Factor analysis of physicochemical and functional properties of cassava flour showing Eigen value and Percentage of Variance

Factor Number	Eigen value	Percent of Variance	Cumulative Percentage
1	2.55884	25.588	25.588
2	2.2015	22.015	47.603
3	1.76723	17.672	65.276
4	0.925539	9.255	74.531
5	0.842374	8.424	82.955
6	0.562489	5.625	88.580
7	0.452088	4.521	93.101
8	0.340783	3.408	96.508
9	0.180567	1.806	98.314
10	0.168596	1.686	100.000

Table 18: Factor Loading Matrix of physicochemical and functional properties of cassava flour after Varimax Rotation

Variate	Factor 1	Factor 2	Factor 3
% Amylose	0.207035	0.827432	-0.260668
% Ash	0.767985	0.189271	-0.000368752
% Crude fibre	0.0485983	0.855767	-0.0113985
% Crude protein	-0.868201	-0.137744	0.11946
% Flour yield	0.463004	-0.730093	-0.258795
% Moisture	-0.0708469	0.386106	-0.657954
% Solubility	0.111471	0.133479	0.696817
% Starch yield	0.603227	-0.284377	0.166947
pH	0.530515	-0.120331	0.372214
Swelling power	-0.0572253	-0.0311218	0.869552

Factor Analysis: Factor analysis conducted on the ten physicochemical and functional properties of the cassava flour using the principal components method, resulted in the extraction of three factors based on their eigen values being greater than 1. Together they accounted for 65.3 % of the variability in the original data (Table 17). After varimax rotation of the factor loading matrix, it was observed under the first extracted factor that flour yield correlated positively with starch yield, pH and total ash but correlated negatively with the crude protein content of the flour (Table 18).

This is because starch is the major component of cassava flour and confers most of its functional properties to the flour. Fermentation causes substantial modification to the physicochemical characteristics of starch [3]. A relatively high pH is indicative of an unfermented starch or flour and therefore it is expected that pH will correlate positively with the starch yield of the flour. Under the second extracted factor, crude fibre correlated positively with amylose content but negatively with flour yield (Table 18). This is because of the similarity in the linear structures of cellulose, a major component of crude fibre, and amylose. Most of the fibre in cassava roots were removed and discarded when processing into flour. Therefore the higher the fibre content of flour, the lower is its quality. Under the third extracted factor, swelling power correlated positively with solubility and negatively with moisture content of the flour (Table 18). Swelling power and solubility of flour are conferred by the starch component of the flour. The higher the solubility of starch, the more are its granules able to swell in an aqueous suspension. The higher the moisture content of flour, the lesser is its ability to swell due to the higher amount of moisture already absorbed by the starch component of the flour. It is postulated from the results of the factor analysis that the three principal factors accounting for 65.3 % of the variability in the selected physicochemical and functional properties are the starch content of the flour, the fibre content and the extent of dryness of the flour.

Factor analysis conducted on the pasting properties of the cassava flour using the principal components method, resulted in the extraction of two factors based on their eigen values being greater than 1. Together they accounted for 78.3 % of the variability in the original data (Table 19).

Table 19: Factor analysis of pasting properties of cassava flour showing Eigen value and Percentage of Variance

Factor Number	Eigen value	Percent of Variance	Cumulative Percentage
1	2.79416	46.569	46.569
2	1.90315	31.719	78.288
3	0.809986	13.500	91.788
4	0.311905	5.198	96.987
5	0.12837	2.140	99.126
6	0.0524342	0.874	100.000

Table 20: Factor Loading Matrix of pasting properties of cassava flour after Varimax Rotation

Variate	Factor 1	Factor 2
Pasting Temp	0.86576	0.0770836
Gelatinization Temp	0.958427	-0.00488734
Peak Temp	0.919968	0.00895832
Peak Viscosity	0.0444372	0.943152
Breakdown	-0.373448	0.639495
Retrogradation	0.339584	0.788386

After varimax rotation of the factor loading matrix, it was observed under the first extracted factor that there was a positive correlation between pasting temperature, gelatinization temperature and peak temperature (Table 20). This suggests that heat application, which leads to rise in temperature of aqueous flour suspension, is an important factor in determining the rheological properties of the flour. Under the second extracted factor, there was a positive correlation between peak viscosity, hot paste break down and retrogradation (Table 20). This suggests that the second important factor associated with the rheological or pasting characteristics of cassava flour in aqueous suspension when heated, is the viscosity properties of the flour.

CONCLUSION

Age at harvest of the cassava roots had significant effect on flour yield, moisture, ash and crude protein content of the resulting flour, while variety significantly affected solubility and all the pasting characteristics of the flour. To obtain optimum flour yield from Afisiafi and Tekbankye, harvesting should be done at 13 months after planting while for Abasafitaa and Gblemoduade, harvesting should be done at 12 months after planting. From the pasting characteristics, it is concluded that, an aqueous flour suspension from Gblemoduade will require lesser heating to attain its peak viscosity than the other three varieties. Also, flours from the varieties Abasafitaa and Gblemoduade will perform better as adhesive gels than flours from Afisiafi and Tekbankye.

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