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FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

Influence of storage conditions and packaging materials on some quality attributes of water yam flour

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Abstract: The study investigated some quality attributes of water yam flour stored in three packaging materials [high and low density polyethylene and plastic container] under different storage conditions [relative humidity (36, 56, 75 and 96%), temperature (25 ± 2, 35 ± 2 and 45 ± 2°C)] for 24 weeks. The functional properties, proximate composition and microbial load of the samples were evaluated at 4 weeks interval. Significant differences ($p < 0.01$) were observed for proximate composition, functional properties and microbial load of the samples during storage. The interactive effect of storage conditions and packaging materials was significant ($p < 0.01$) on proximate composition and pasting properties (except trough viscosity). The yam flour samples were still shelf stable after the 24 weeks of storage.

Subjects: Food Chemistry; Food Engineering; Packaging

Keywords: water yam flour; storage conditions; packaging materials; functional properties

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PUBLIC INTEREST STATEMENT

Water yam is an important staple in West Africa and an important energy source for millions of people within the sub-region. Yam suffers considerable postharvest losses which could be up to 15% within the first 3 months after harvest. Postharvest losses of water yam can be minimized by drying and converting them into flour. This flour could be utilized as raw materials in pastry and confectionery industry. Variation in storage conditions could affect the storage stability of water yam flour. Deterioration of flour products are usually attributed to the type of packaging materials and spoilage organisms such as bacteria and fungi. Hence, findings from this study are important in determining the appropriate storage condition and packaging material for yam flour with little quality deterioration.

1. Introduction

Water yam, *Dioscorea alata*, is an important staple in West Africa. It is an important energy source, of many people (Ekwu, Ozo, & Ikegwu, 2005). The nutritional value of yam varies greatly between different species but water yam has a crude protein content of 7.4%, starch content of 75–84%, and Vitamin C content ranging from 13.0 to 24.7 mg/100 g (Djeri et al., 2015), but it is underutilized compared to white yam (*D. rotundata*) possibly because of its loose watery texture (Adegunwa, Alamu, & Omitogun, 2011).

Water yam tubers have been utilized traditionally in homes with little or no industrial application; however the traditional uses are diverse (Baah, 2009). Yams are eaten boiled, fried or baked. Yams are also processed into yam chips and flour that is used in the preparation of a paste (Karim, Kayode, Oyeyinka, & Oyeyinka, 2013; Osunde, 2008).

Yam suffers considerable postharvest losses which can be as high as between 10 and 15% within the first 3 months after harvest (Ansah, Tetteh, & Donkoh, 2017; Osunde, 2008). To minimize these losses yam is converted to local flour to prevent spoilage in the form of *gbodo,* which have limited industrial use. It is a well known fact that storage stability of food systems depends on the storage conditions, packaging materials and the water activity of the food material. Information on the influence of storage conditions on storage stability of yam flour meant for industrial applications is scanty. A number of deteriorative reactions which affect the quality attributes of foods (nutritional composition and functional properties) are initiated during processing; these reactions continue during storage at a rate proportional to variation in the storage conditions, therefore variation in storage conditions could affect the storage stability of many processed foods. Deterioration of flour products are usually attributed to the type of packaging materials and spoilage organisms such as bacteria and fungi (Ilouno, Ndimele, Adikwu, & Obiekezie, 2016; Okigbo, 2003). Hence, it is important to determine optimal storage conditions that would best maintain the flour quality attributes during storage. Therefore, the objective of this study was to determine the effect of storage conditions and packaging materials on some quality attributes of water yam flour.

2. Material and method

Freshly harvested wholesome water yam tubers were procured from Kuto market in Abeokuta, Ogun state, Nigeria.

2.1. Processing of water yam flour

The yam tubers were cleaned, hand peeled with stainless steel knife, washed and sliced into chips (using a vegetable slicer) inside water. The yam slices were pre-treated by soaking in 0.28% potassium metabisulphite solution for 15 min. The pre-treated slices were then drained and dried in a cabinet dryer at 60°C for 48 h. The dried chips were milled into flour using a laboratory hammer mill. The flour was packaged in plastic (PP) containers, high density polyethylene (HDPE) and low density polyethylene (LDPE) and stored in incubators at 4 relative humidities (36, 56, 75 and 96%) over three temperatures (25 ± 2, 35 ± 2 and 45 ± 2°C) for 24 weeks to study the effect of storage conditions on the flour. The functional properties, proximate and microbiological analyses of the samples were conducted at interval of 4 weeks during storage.

2.2. Determination of functional properties

The bulk density of the samples was determined using the method described by Abiodun, Adegbite, and Oladipo (2010), water binding capacity (WBC) was carried out using the Medcalf and Gillies (1965) method, oil absorption capacity (OAC) by the method of Sosulki (1962) while wettability was determined by the method described by Nwosu, Onuegbu, Kabuo, and Okeke (2010).

2.3. Determination of pasting properties

Pasting characteristics was determined with a Rapid Visco Analyser (RVA), (Tecmaster TCW3, Perten Instrument, Australia). A portion (3 g) of flour sample was weighed into a dried empty canister; 25 ml of distilled water was dispensed into the canister containing the sample. The solution was thoroughly mixed and the canister was well fitted into the RVA. The slurry was heated from 50 to 95°C with a holding time of 2 min followed by cooling to 50°C with a 2 min holding time. Heating and cooling were done at a constant rate of 11.25°C/min. Peak viscosity, trough, breakdown, final viscosity, set back, peak time, and pasting temperature were read from the pasting profile from a computer connected with the RVA (Newport Scientific, 1998).

2.4. Determination of proximate composition

The moisture, protein, fat and ash contents of the samples were determined using AOAC (2000) method.

2.5. Microbiological assay

Total bacteria and fungi counts were determined using the pour-plate procedure as described by ICMSF (1988). One gram from each sample was weighed into 9 ml of 0.1% (w/v) peptone water in a beaker and allowed to stand for 5 min with occasional stirring using a sterile glass rod. Aliquots (1 ml) of serial dilutions of 10^{-6} were aseptically inoculated on Nutrient Agar. This was used for the determination of total viable bacteria count. The determination of mould counts was enumerated on Potatoes Dextrose Agar supplemented with 0.01% chloramphenicol. Dilutions of 10^{-6} were incubated at 37°C for 24 h (total viable bacteria count) and 30°C for 4 days (mould count). The colonies were enumerated and expressed as colonies forming unit per gram (cfu/g).

2.6. Statistical analysis

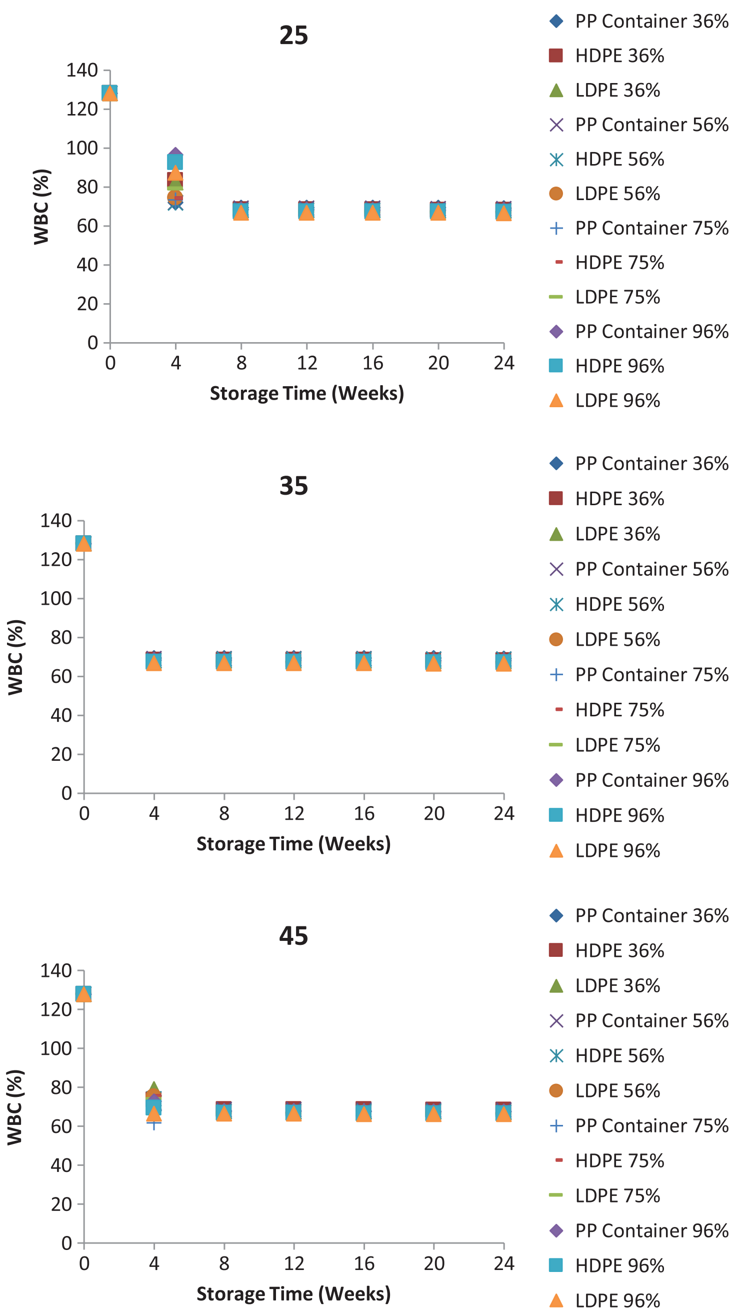
All experimental data obtained were subjected to the general linear model (GLM) procedure of SPSS (version 21) for the analysis of variance and Pearson's correlation was also determined. In all cases, $\alpha = 0.05$.

3. Results and discussion

3.1. Functional properties of water yam flour during storage

The effect of storage conditions and packaging materials on functional properties of water yam flour is presented in Figures 1–4 and Table 1. The mean values of bulk density, WBC, OAC and wettability ranged between 0.67 and 0.80 g/mls, 62.03 and 128.00%, 0.13 and 0.53 and 53.67 and 80.37 s, respectively. The bulk density, water absorption index, WBC and OAC decreased with storage period. The bulk density of food product is affected by particle size and it is an important parameter in determining packaging materials and material handling during food processing (Adebowale, Adegoke, Sanni, Adegunwa, & Fetuga, 2012; Adebowale, Sanni, & Awonorin, 2005). The decrease in bulk density was more prominent in samples stored in LDPE and HDPE, which could be due to increase in moisture content, which affects the flour particle size. Wettability of the flour was affected by storage temperature and packaging materials ($p < 0.01$).Wettability of flours is an important indicator of instant characteristics of dried flours. The slight increase in wettability of the flour samples irrespective of packaging materials and storage condition indicates a slight reduction in instant characteristics of the flour (Udensi, Oselebe, & Iweala, 2008). The decrease in WBC could be due to the loose association between amylose and amylopectin in the native granules of starch and weaker associative forces maintaining the granules structure (Adebowale et al., 2005; Adebowale, Sanni, & Onitilo, 2008). The reduction in OAC as storage progresses could probably be due to the reduced ability of the flour to entrap fat to its apolar end of its protein chain as a result of decrease in its protein content (Adeleke & Odedeji, 2010).

Figure 1. Effect of storage conditions and packaging materials on WBC of water yam flour at 25, 35 and 45°C.



3.2. Proximate composition of water yam flour during storage

The effect of storage conditions and packaging materials on the proximate composition of high quality water yam is presented in Figures 5–9 and Table 2. The mean values of moisture content, protein, fat, ash and carbohydrate ranged from 8.30 to 23.55%, 3.86 to 5.77%, 0.02 to 5.50%, 1.04 to 1.48% and from 68.11 to 84.37%, respectively.

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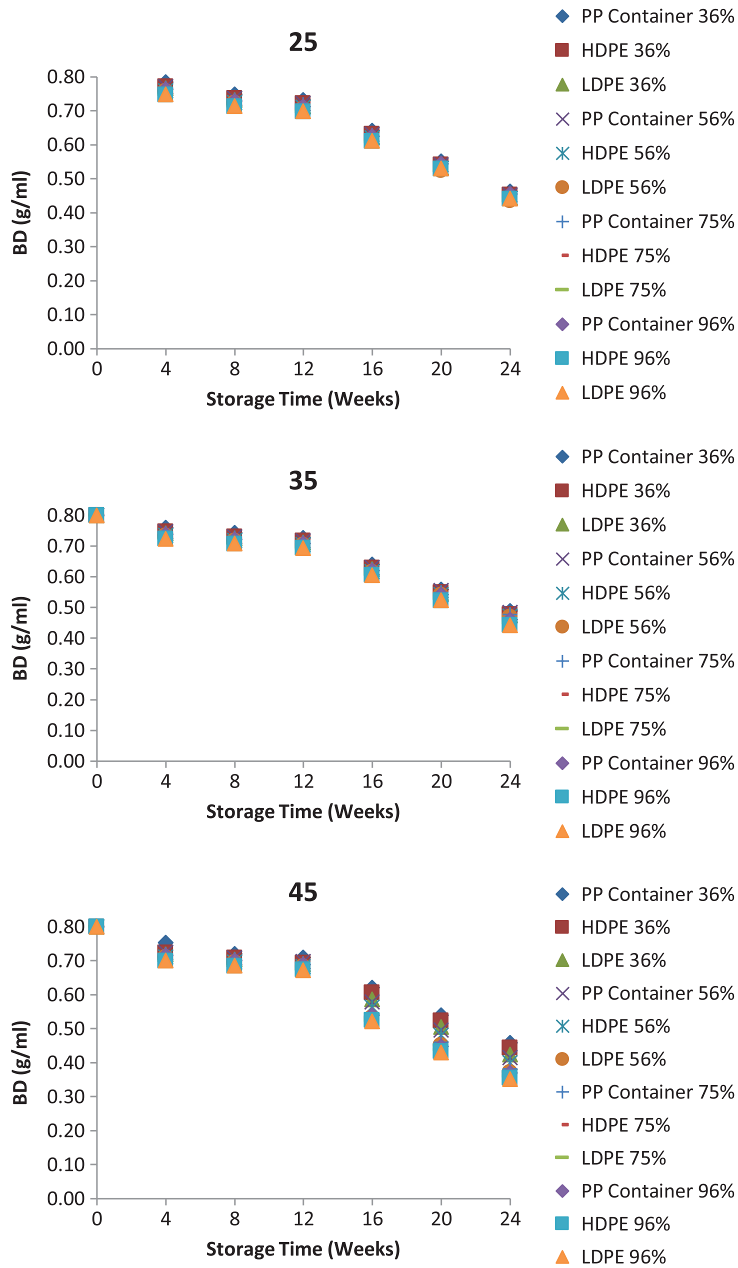
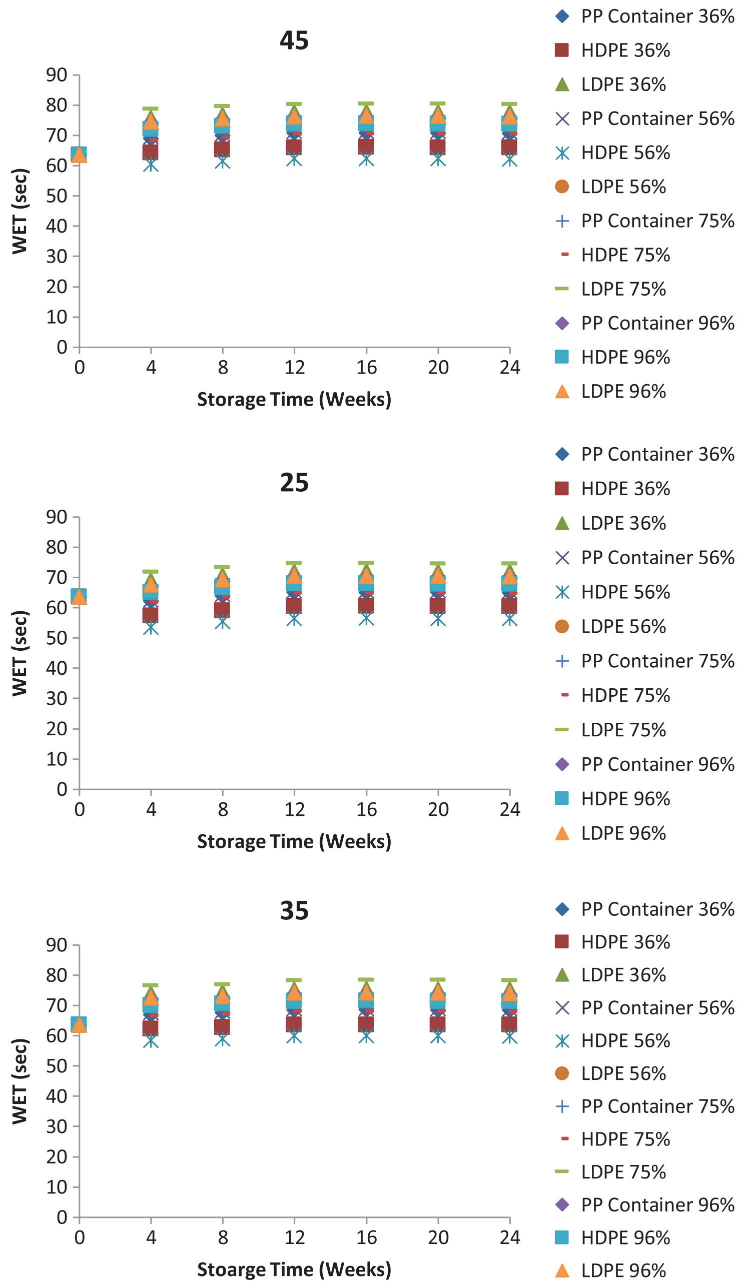
Figure 2. Effect of storage conditions and packaging materials on bulk density (BD) of water yam flour at 25, 35 and 45°C.



The steady but gradual change in the moisture content of the samples in all the packaging materials could be as a result of the relative moisture permeability of the packaging materials. For all the packaging materials, storage at 36 or 56% relative humidity produced little moisture increase while pronounced increases were noticed at 75 or 96% relative humidity (RH) especially at storage

Figure 3. Effect of storage conditions and packaging materials on wettability (WET) of water yam flour at 25, 35 and 45°C.



temperature of 35 and 45°C. Moisture content is an indicator of shelf stability; increase in moisture content can enhance microbial growth which leads to deterioration of foods (Adejumo, 2013). The recommended safe level of moisture content during storage of flours or food powder is between 12 and 14% (Sanni et al., 2005; Standard Organization of Nigeria, 2004). When storing in a plastic

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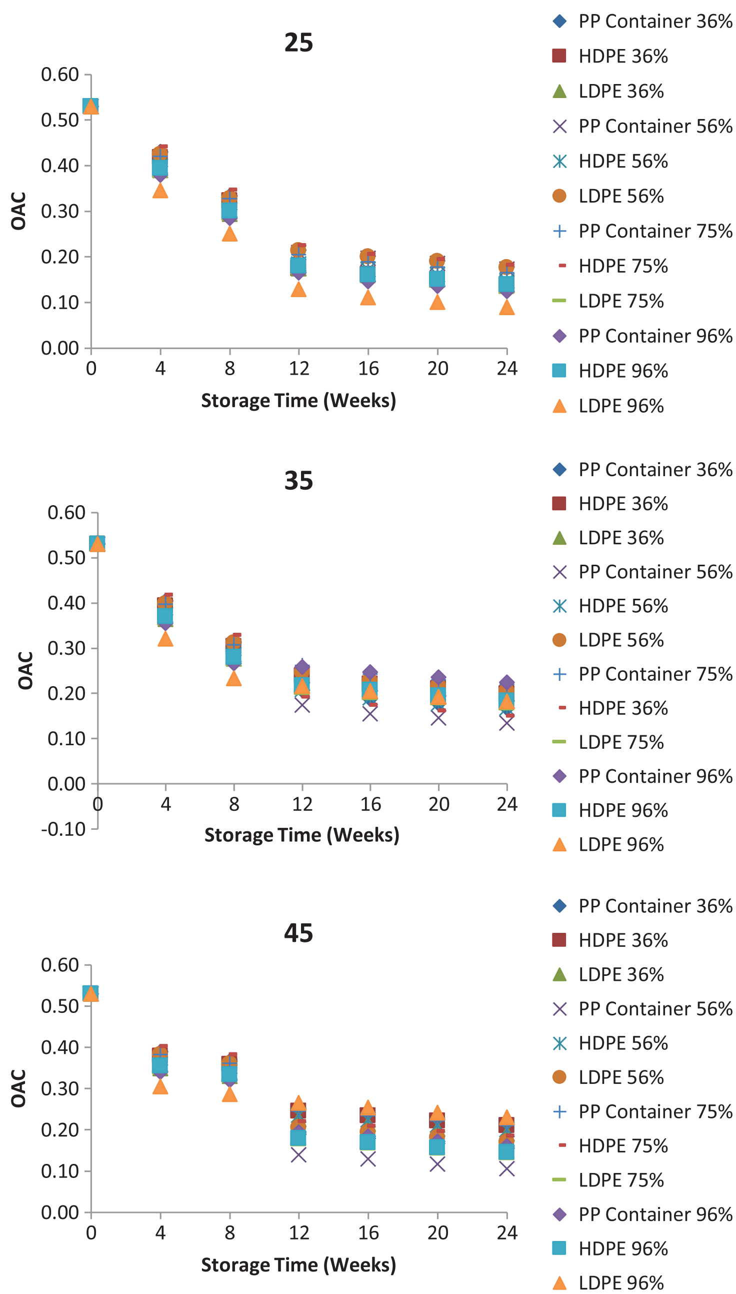
Figure 4. Effect of storage conditions and packaging materials on OAC of water yam flour at 25, 35 and 45°C.



container (LDPE) (up to 24 weeks) the moisture content increased from 8.30 to 12.04%, which still falls within the permissible range (Daramola, Idowu, Atanda, & Oguntona, 2010) and as such attracts minimal mould and bacteria attack during storage. For storage in high density polyethylene (HDPE), up to 16 weeks of storage, moisture contents of samples, stored at 36, 56 and 75%, RH under

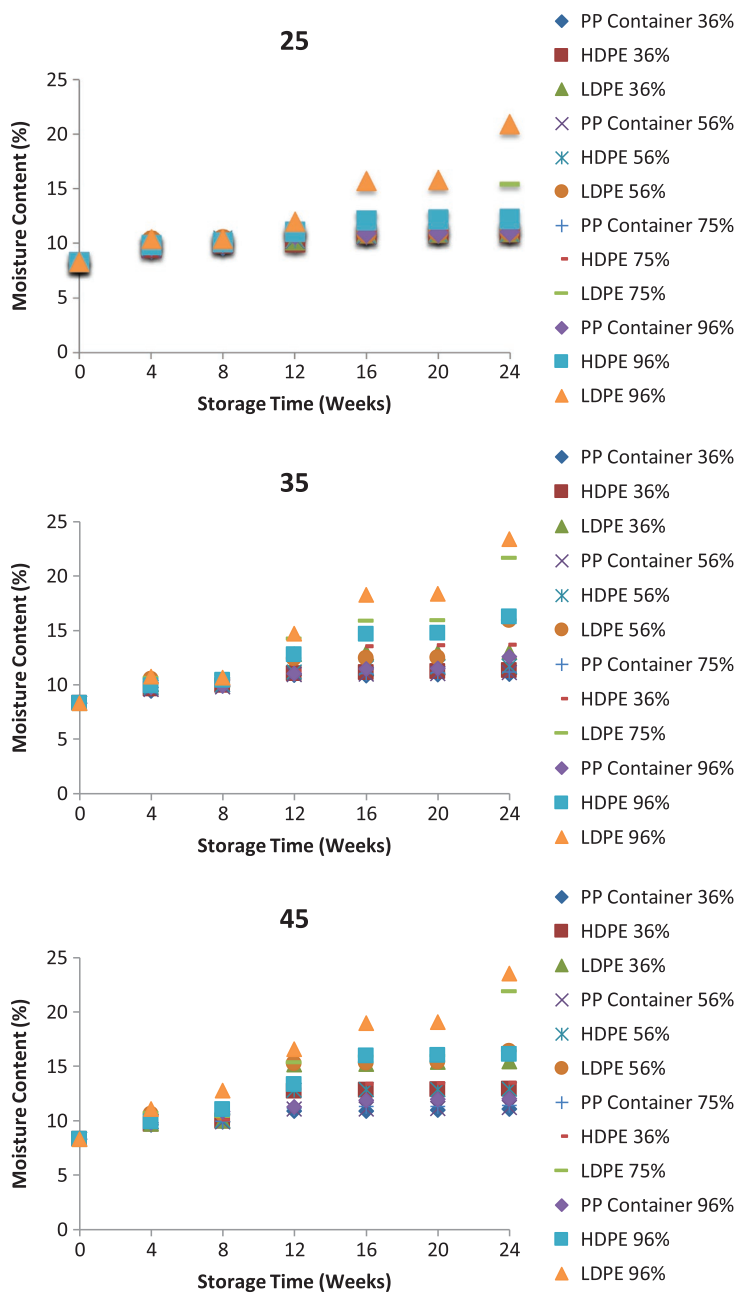
Table 1. Effect of storage conditions and packaging materials on functional properties of water yam flour

Statistical parameter	Water absorption index	Water binding capacity (%)	Oil absorption capacity	Bulk density (g/cm³)	Wettability (Min)
Range	1.09–2.24	62.03–128.00	0.09–0.53	0.35–0.80	53.67–80.52
Mean	1.439968	69.6475	0.241675	0.617685	69.70076
Standard deviation	0.19	6.13	0.09	0.12	5.57
Standard error	0.01	0.41	0.006	0.008	0.38
P of storage time (ST)	*	*	*	*	ns
P of temperature (T)	*	*	*	*	*
P of relativity humidity (RH)	*	*	*	*	*
P of packaging material (P)	ns	*	*	*	*
P of ST × T	*	*	*	*	ns
P of St × RH	ns	*	*	*	ns
P of ST × P	ns	ns	*	ns	ns
P of T × RH	ns	*	*	*	ns
P of T × P	ns	ns	*	ns	ns
P of RH × P	ns	ns	*	ns	ns
P of ST × T × RH	ns	*	ns	*	ns
P of ST × T × P	ns	*	ns	ns	ns
P of ST × RH × P	ns	ns	*	ns	ns
P of T × P × RH	ns	ns	*	ns	ns
P of ST × T × RH × P	ns	ns	ns	ns	ns

*Significant ($p < 0.01$); ns = not significant ($p < 0.01$).

all the storage temperatures were within acceptable level, which implies that the flour stored, within these conditions, will have little or no deterioration as a result of bacteria and mould attack. However, for low density polyethylene (LDPE), moisture content of samples was within permissible range, up to 16 weeks of storage, for samples stored at 36 and 56% RH under storage temperature of 25 and 35°C. Generally, the moisture content of samples stored in LDPE irrespective of storage temperature and relative humidity were higher than that of samples stored in HDPE and plastic containers, which are in agreement with earlier findings of Daramola et al. (2010) and Fasasi (2003) who reported higher moisture content for LDPE during storage for *pupuru* and African breadfruit seed flour, respectively. Hence, plastic container gave the best barrier protective ability under all the storage conditions studied.

Figure 5. Effect of storage conditions and packaging materials on Moisture content of water yam flour at 25, 35 and 45°C.



The protein and carbohydrate content of the samples decreased significantly with storage. Similar trends have been reported by Awoyale, Maziya-Dixon, and Menkir (2013) for Ogi stored under different storage condition. These reductions could be attributed to the rapid growth of microorganisms as a result of increased moisture content whose metabolic activities lead to production of enzymes

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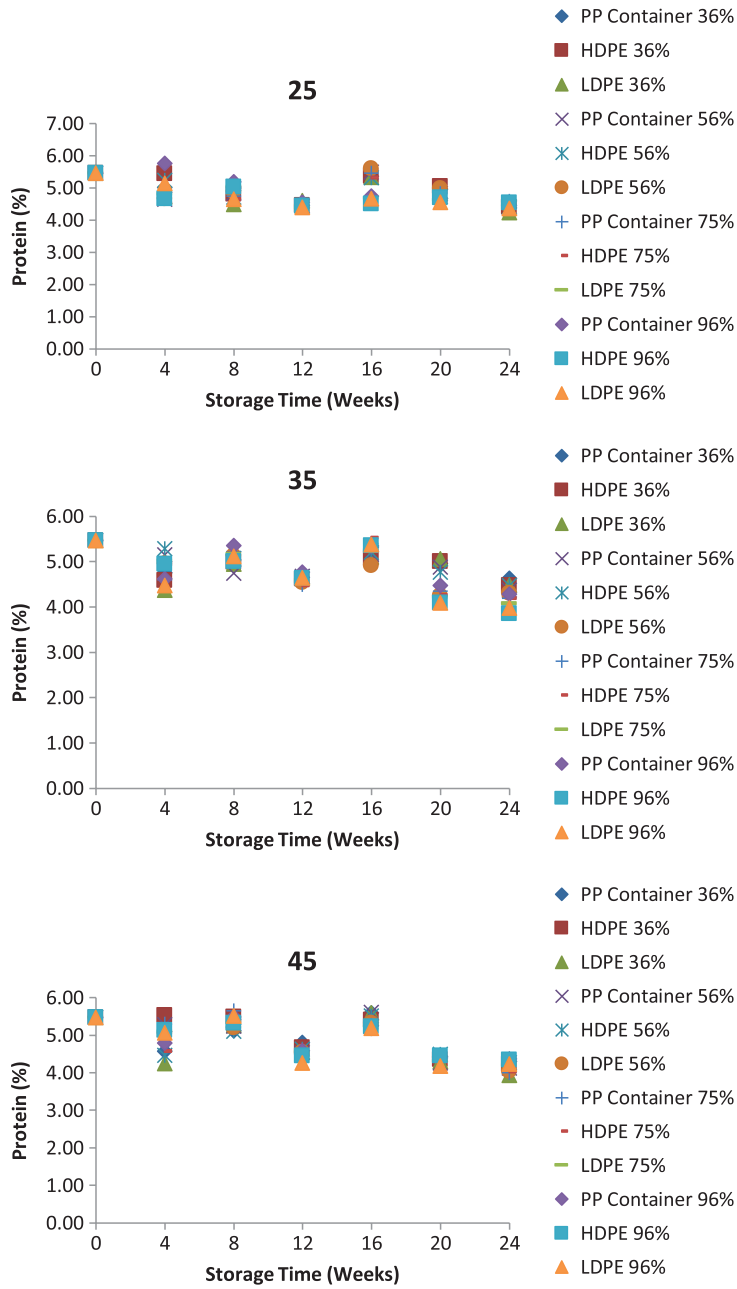

Figure 6. Effect of storage conditions and packaging materials on protein content of water yam flour at 25, 35 and 45°C.

(such as proteases and amylases) that catalyse biochemical reactions that breakdown nutrient in food (Achi & Akubor, 2000). Samples stored in plastic containers had the least protein and carbohydrate depletion at the end of storage. Protein content of food products has been related to final product quality such as texture and appearance (Adejumo, 2013). There were significant variations

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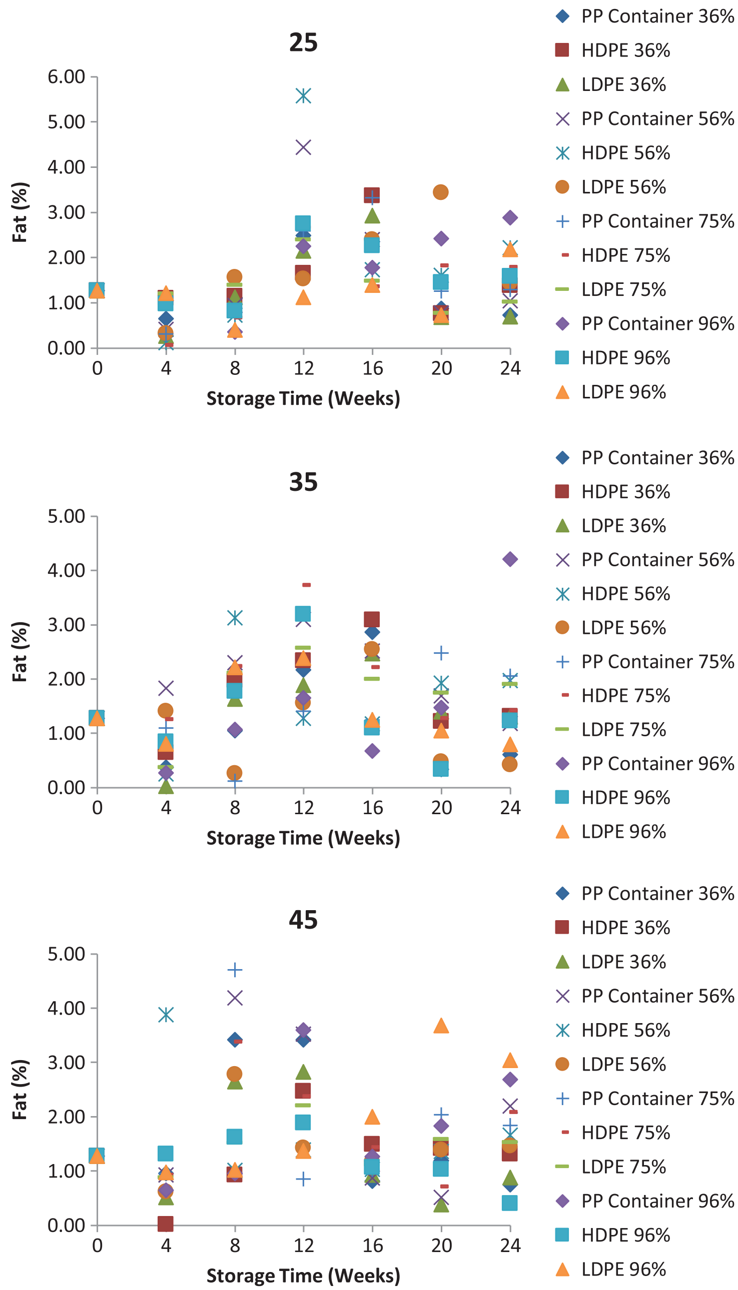
Figure 7. Effect of storage conditions and packaging materials on fat content of water yam flour at 25, 35 and 45°C.



in the fat content of the samples with respect to storage period. The increase and subsequent decrease in fat content could be due to the activities of the enzymes lipase and lipoxidase during storage, which are enhanced by the moisture content of the samples (Nasir, Butt, Anjum, Sharif, & Minhas, 2003). Similar trend was reported by Awoyale, Maziya-Dixon, and Menkir (2013) for Ogi

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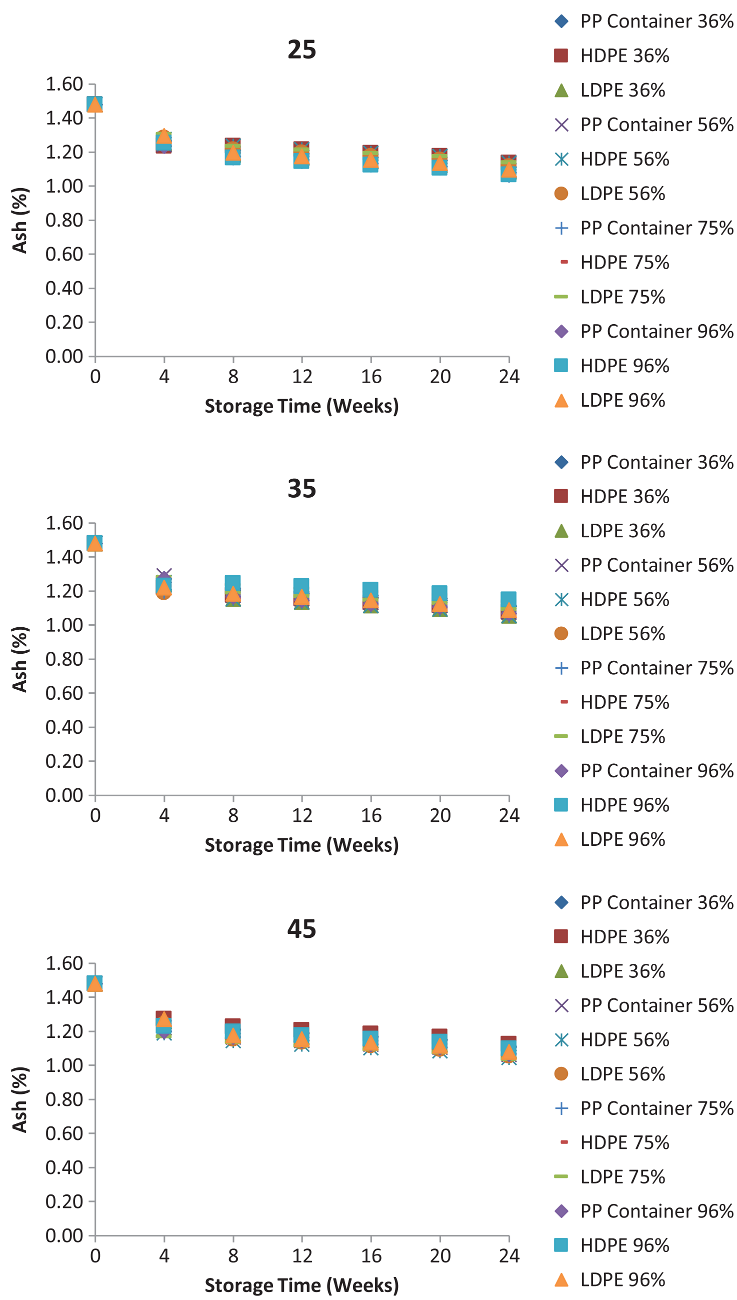
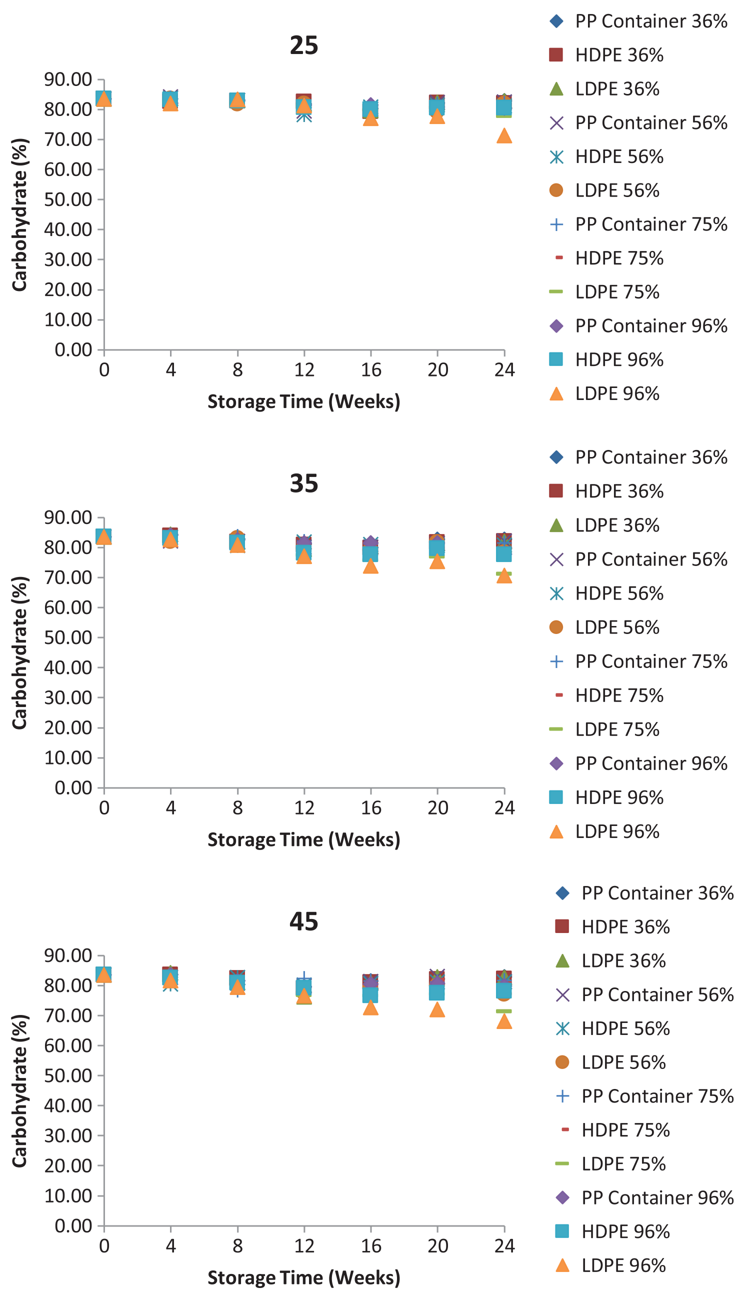
Figure 8. Effect of storage conditions and packaging materials on ash content of water yam flour at 25, 35 and 45°C.



stored under different storage conditions. The ash content, an indication of the mineral contents of food, decreased significantly with storage. The reduction could be as result of biochemical activities of microorganisms.

Figure 9. Effect of storage conditions and packaging materials on carbohydrate content of water yam flour at 25, 35 and 45°C.



3.3. Pasting properties of water yam flour during storage

Table 3 shows the effect of storage conditions and packaging materials on pasting properties of high quality water yam flour. The mean values of peak viscosity, trough viscosity, breakdown viscosity, final viscosity, setback viscosity, peak time and pasting temperature ranged from 47.31 to 429.42 RVU, 41.50 to 699.67 RVU, 2.15 to 115.40 RVU, 65.71 to 488.92 RVU, 13.52 to 160.92 RVU, 4.90 to 7.08 min and from 53.54 to 86.53°C, respectively. The interactive effect of storage conditions and packaging materials was significant ($p < 0.05$) on all the pasting properties except trough viscosity.

Table 2. Effect of storage conditions and packaging materials on proximate composition of water yam flour

Statistical parameters	Moisture content (%)	Protein (%)	Fat (%)	Ash (%)	Carbohydrate (%)
Range	8.30–23.55	3.86–5.77	0.02–5.58	1.04–1.48	68.11–84.37
Mean	11.92	4.78	1.59	1.16	80.70
Standard deviation	2.59	0.42	0.97	0.06	2.63
Standard error	0.176	0.029	0.066	0.004	0.179
P of storage time (ST)	*	*	*	*	*
P of temperature (T)	*	ns	*	*	*
P of relative humidity (RH)	*	*	*	*	*
P of packaging material (P)	*	*	*	*	*
P of ST × T	*	*	*	ns	*
P of St × RH	*	*	*	ns	*
P of ST × P	*	*	*	*	*
P of T × RH	*	*	*	*	*
P of T × P	*	ns	*	*	*
P of RH × P	*	*	*	*	*
P of ST × T × RH	*	*	*	*	*
P of ST × T × P	*	*	*	*	*
P of ST × RH × P	*	*	*	*	*
P of T × P × RH	*	*	*	*	*
P of ST × T × RH × P	*	*	*	*	*

*Significant ($p < 0.01$); ns = not significant ($p > 0.01$).

There were gradual decrease in peak, trough, breakdown, final and setback viscosities with storage time. The decrease was more pronounced in samples stored at 96% relative humidity for all the packaging materials investigated. Peak viscosity is the maximum viscosity attainable during heating of starch. It is a measure of the ability of starch to swell freely before breakdown (Sanni, Kosoko, Adebowale, & Adeoye, 2004). The reduction in peak viscosity with storage time indicates loose association between amylose and amylopectin in the native granules of starch and weaker associative forces maintaining the granules structure which is an indication of WBC of the flour and degradation of starch granules during storage. The peak viscosities obtained at the end of storage were comparable with those reported by Wireko-Manu, Ellis, Oduro, Asiedu, and Maziya-Dixon (2011) for water yam flour. The trough viscosity, an indicator of the ability of the paste or gel to withstand mechanical stress at constant temperature as more starch granules and amylose leach out into the solution, decreased with storage time. Also, the breakdown viscosity of the samples decreased significantly with storage. It is the minimum viscosity attained during the constant temperature phase, a measure of the ability of paste to withstand breakdown during cooling (Maziya-Dixon, Adebowale, Onabanjo, & Dixon, 2005). The pronounced reduction in the breakdown viscosity of the samples at the end of storage indicate significant breakdown of starches during storage. The ability of paste to withstand heating and shear stress is an important factor for many processes especially those requiring stable paste. The final viscosity gives the ability of starchy foods to form viscous paste after cooking and cooling. Result obtained in this study indicates a significant reduction of final viscosity of the samples with storage. The values obtained at the end of storage are comparable to those reported by Wireko-Manu et al. (2011) for water yam flour. Setback viscosity is the stage at which retrogradation or re-ordering of starch molecules occurs. High setback is associated with syneresis or weeping, during freeze/thaw cycles. Low setback values obtained for the samples at the end of storage showed a low tendency to undergo retrogradation during freeze/thaw cycles (Maziya-Dixon et al., 2005). Peak

Table 3. Effect of storage conditions and packaging materials on pasting properties of water yam flour

Storage time (Weeks)	Temperature (°C)	Relative humidity (%)	Packaging material	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown viscosity (RVU)	Final viscosity (RVU)	Setback viscosity (RVU)	Peak time (Min)	Pasting temperature (°C)
0	Zero week	Zero week	Zero week	429.42	328.00	101.42	488.92	160.92	5.14	81.95
4	25	36	PP container	281.29	230.42	69.58	284.16	71.53	5.32	82.28
			HDPE	285.21	238.75	71.58	290.08	69.12	5.26	83.08
			LDPE	287.29	243.67	69.25	296.08	70.20	5.26	82.18
		56	PP container	261.38	220.58	67.42	262.41	59.62	5.25	82.23
			HDPE	279.38	241.78	62.67	290.16	66.12	5.12	82.23
			LDPE	270.21	226.50	73.83	277.58	68.87	5.27	82.18
		75	PP container	277.63	241.67	66.08	286.74	62.87	5.19	82.18
			HDPE	243.88	211.25	62.76	252.41	58.95	5.26	83.13
			LDPE	225.63	198.50	57.24	235.41	54.70	5.25	82.98
		96	PP container	242.79	699.67	68.25	251.33	69.45	5.19	82.23
			HDPE	222.21	189.83	62.50	234.49	62.45	5.32	83.08
			LDPE	200.54	179.17	46.50	223.99	62.62	5.46	82.33
	35	36	PP container	262.13	162.10	53.00	236.91	59.45	5.19	82.33
			HDPE	271.63	191.00	58.75	274.16	67.95	5.12	82.28
			LDPE	266.63	176.93	67.83	268.41	76.28	5.19	83.08
		56	PP container	245.54	162.50	61.19	253.58	75.87	5.12	83.03
			HDPE	207.92	153.88	32.42	221.33	52.20	5.19	83.08
			LDPE	175.58	123.50	30.50	191.24	52.53	5.32	82.28
		75	PP container	175.33	121.58	32.17	174.65	51.12	5.32	82.18
			HDPE	201.58	148.33	31.67	201.57	51.28	5.12	83.08
			LDPE	237.25	163.50	52.26	230.40	64.95	5.19	83.03
		96	PP container	197.42	136.42	39.42	199.58	61.20	5.33	83.98
			HDPE	159.17	118.58	22.50	171.23	50.70	5.32	81.48
			LDPE	154.13	112.17	33.92	276.98	44.08	5.12	83.13
	45	36	PP container	303.00	201.67	79.75	287.40	77.08	5.06	82.23
			HDPE	299.17	221.83	55.75	297.15	66.67	5.07	81.38
			LDPE	277.25	195.83	59.83	268.65	64.17	4.92	81.43
		56	PP container	260.33	179.42	59.33	251.83	63.75	5.19	83.08
			HDPE	264.67	175.33	67.75	253.73	69.75	5.12	82.23
			LDPE	236.42	160.83	54.00	230.65	61.17	5.06	82.18
		75	PP container	191.42	130.67	39.18	197.48	58.17	5.12	82.93
			HDPE	164.08	115.07	27.44	176.31	52.58	5.46	84.78
			LDPE	166.08	118.50	28.50	175.32	48.17	5.52	84.78
		96	PP container	106.83	84.88	11.82	113.32	24.75	6.06	86.33
			HDPE	104.17	76.65	13.54	104.57	19.42	5.92	83.93
			LDPE	230.58	187.50	26.11	240.57	44.42	5.39	84.73

(Continued)

Table 3. (*Continued*)

Storage time (Weeks)	Temperature (°C)	Relative humidity (%)	Packaging material	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown viscosity (RVU)	Final viscosity (RVU)	Setback viscosity (RVU)	Peak time (Min)	Pasting temperature (°C)
8	25	36	PP container	282.17	228.73	50.56	288.75	59.47	5.29	83.83
			HDPE	290.17	222.32	64.98	286.50	63.64	5.35	84.68
			LDPE	291.75	234.98	53.90	298.34	62.80	5.29	83.03
		56	PP container	271.67	199.82	68.98	268.17	67.80	5.35	83.83
			HDPE	280.08	220.15	57.06	281.59	60.89	5.29	83.68
			LDPE	269.25	206.15	60.23	269.09	62.39	5.29	82.98
		75	PP container	270.33	211.48	55.98	273.59	61.55	5.29	82.98
			HDPE	240.17	187.90	49.40	240.84	52.39	5.29	83.83
			LDPE	220.17	170.73	46.56	222.92	51.64	5.29	83.78
		96	PP container	238.92	182.82	53.23	241.50	58.14	5.15	82.88
			HDPE	213.67	163.90	46.90	220.17	55.72	5.29	83.83
			LDPE	192.25	166.32	23.06	226.67	59.80	6.02	83.78
	35	36	PP container	287.92	214.07	70.98	278.50	63.89	5.29	84.68
			HDPE	291.75	208.23	80.65	278.59	69.80	5.22	82.93
			LDPE	281.75	208.15	70.73	273.75	65.05	5.15	83.78
		56	PP container	254.25	184.73	66.65	253.09	67.80	5.15	83.78
			HDPE	214.17	160.98	50.31	217.25	55.72	5.29	85.38
			LDPE	192.50	153.98	35.65	200.50	45.97	5.22	83.08
		75	PP container	235.83	176.48	56.48	238.34	61.30	5.15	83.88
			HDPE	185.42	151.57	30.98	192.50	40.39	5.35	83.83
			LDPE	155.33	131.82	20.65	165.17	32.80	5.75	82.98
		96	PP container	194.33	147.48	43.98	202.59	54.55	5.35	85.48
			HDPE	125.75	111.32	11.56	136.17	24.30	6.29	83.68
			LDPE	122.58	107.23	12.48	135.17	27.39	6.02	83.68
	45	36	PP container	307.50	222.40	82.23	292.75	69.80	5.15	82.78
			HDPE	286.17	201.48	81.81	273.17	71.14	5.22	83.73
			LDPE	307.58	237.82	66.90	305.59	67.20	5.09	82.18
		56	PP container	286.00	214.65	68.48	279.50	64.30	5.09	83.83
			HDPE	276.17	197.73	75.56	267.50	69.22	5.22	83.73
			LDPE	266.83	201.07	62.90	263.09	61.47	5.22	83.78
		75	PP container	228.75	168.32	57.56	224.50	55.64	5.22	83.78
			HDPE	182.25	139.40	39.98	192.84	52.89	5.29	83.88
			LDPE	154.67	121.65	30.15	175.42	53.22	5.42	85.53
		96	PP container	157.42	128.07	26.48	175.59	46.97	5.75	85.13
			HDPE	104.42	92.15	9.40	116.50	23.80	6.22	86.33
			LDPE	100.08	92.98	4.23	108.92	15.39	6.55	82.98

(Continued)

Table 3. (*Continued*)

Storage time (Weeks)	Temperature (°C)	Relative humidity (%)	Packaging material	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown viscosity (RVU)	Final viscosity (RVU)	Setback viscosity (RVU)	Peak time (Min)	Pasting temperature (°C)
12	25	36	PP container	277.61	226.39	49.63	284.43	57.60	5.31	83.84
			HDPE	285.61	219.98	64.05	282.18	61.77	5.37	84.69
			LDPE	287.19	232.64	52.97	294.02	60.93	5.31	83.04
		56	PP container	267.11	197.48	68.05	263.85	65.93	5.37	83.84
			HDPE	275.52	217.81	56.13	277.27	59.02	5.31	83.69
			LDPE	264.69	203.81	59.30	264.77	60.52	5.31	82.99
		75	PP container	265.77	209.14	55.05	269.27	59.68	5.31	82.99
			HDPE	235.61	185.56	48.47	236.52	50.52	5.31	83.84
			LDPE	215.61	168.39	45.63	218.60	49.77	5.31	83.79
		96	PP container	234.36	180.48	52.30	237.18	56.27	5.17	82.89
			HDPE	209.11	161.56	45.97	215.85	53.85	5.31	83.84
			LDPE	187.69	163.98	22.13	222.35	57.93	6.04	83.79
	35	36	PP container	283.36	211.73	70.05	274.18	62.02	5.31	84.69
			HDPE	287.19	205.89	79.72	274.27	67.93	5.24	82.94
			LDPE	277.19	205.81	69.80	269.43	63.18	5.17	83.79
		56	PP container	249.69	182.39	65.72	248.77	65.93	5.17	83.79
			HDPE	209.61	158.64	49.38	212.93	53.85	5.31	85.39
			LDPE	187.94	151.64	34.72	196.18	44.10	5.24	83.09
		75	PP container	231.27	174.14	55.55	234.02	59.43	5.17	83.89
			HDPE	180.86	149.23	30.05	188.18	38.52	5.37	83.84
			LDPE	150.77	129.48	19.72	160.85	30.93	5.77	82.99
		96	PP container	189.77	145.14	43.05	198.27	52.68	5.37	85.49
			HDPE	121.19	108.98	10.63	131.85	22.43	6.31	83.69
			LDPE	118.02	104.89	11.55	130.85	25.52	6.04	83.69
	45	36	PP container	302.94	220.06	81.30	288.43	67.93	5.17	82.79
			HDPE	281.61	199.14	80.88	268.85	69.27	5.24	83.74
			LDPE	303.02	235.48	65.97	301.27	65.33	5.11	82.19
		56	PP container	281.44	212.31	67.55	275.18	62.43	5.11	83.84
			HDPE	271.61	195.39	74.63	263.18	67.35	5.24	83.74
			LDPE	262.27	198.73	61.97	258.77	59.60	5.24	83.79
		75	PP container	224.19	165.98	56.63	220.18	53.77	5.24	83.79
			HDPE	177.69	137.06	39.05	188.52	51.02	5.31	83.89
			LDPE	150.11	119.31	29.22	171.10	51.35	5.44	85.54
		96	PP container	152.86	125.73	25.55	171.27	45.10	5.77	85.14
			HDPE	99.86	89.81	8.47	112.18	21.93	6.24	86.34
			LDPE	95.52	90.64	3.30	104.60	13.52	6.57	82.99

(*Continued*)

Table 3. (*Continued*)

Storage time (Weeks)	Temperature (°C)	Relative humidity (%)	Packaging material	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown viscosity (RVU)	Final viscosity (RVU)	Setback viscosity (RVU)	Peak time (Min)	Pasting temperature (°C)
16	25	36	PP container	276.59	231.64	50.49	288.49	61.36	5.32	83.19
			HDPE	284.59	225.23	64.91	286.24	65.53	5.38	84.04
			LDPE	286.17	237.89	53.83	298.08	64.69	5.32	82.39
		56	PP container	266.09	202.73	68.91	267.91	69.69	5.38	83.19
			HDPE	274.50	223.06	56.99	281.33	62.78	5.32	83.04
			LDPE	263.67	209.06	60.16	268.83	64.28	5.32	82.34
		75	PP container	264.75	214.39	55.91	273.33	63.44	5.32	82.34
			HDPE	234.59	190.81	49.33	240.58	54.28	5.32	83.19
			LDPE	214.59	173.64	46.49	222.66	53.53	5.32	83.14
		96	PP container	233.34	185.73	53.16	241.24	60.03	5.18	82.24
			HDPE	208.09	166.81	46.83	219.91	57.61	5.32	83.19
			LDPE	186.67	169.23	22.99	226.41	61.69	6.05	83.13
	35	36	PP container	282.34	216.98	70.86	278.24	65.78	5.32	84.04
			HDPE	286.17	215.08	80.53	277.18	71.69	5.25	82.28
			LDPE	276.17	215.00	70.61	272.34	66.94	5.18	83.13
		56	PP container	248.67	191.58	66.53	251.68	69.81	5.18	83.13
			HDPE	208.59	167.83	50.19	215.84	57.73	5.32	84.73
			LDPE	186.92	160.83	35.53	199.09	47.98	5.25	82.43
		75	PP container	230.25	183.33	56.36	236.93	63.31	5.18	83.23
			HDPE	179.84	158.42	30.86	191.09	42.40	5.38	83.18
			LDPE	149.75	138.67	20.53	163.76	34.81	5.78	82.33
		96	PP container	188.75	154.33	43.86	201.18	56.56	5.38	84.83
			HDPE	120.17	118.17	11.44	134.76	26.31	6.32	83.03
			LDPE	117.00	114.08	12.36	133.76	29.40	6.05	83.03
	45	36	PP container	301.92	229.25	82.23	291.34	71.81	5.17	82.13
			HDPE	280.53	208.33	81.81	272.37	73.15	5.24	83.08
			LDPE	301.94	242.06	66.90	304.79	69.23	5.11	81.53
		56	PP container	280.36	218.89	68.48	278.70	66.31	5.11	83.18
			HDPE	270.53	201.97	75.56	266.70	71.23	5.24	83.08
			LDPE	261.19	205.31	62.90	262.29	63.48	5.24	83.13
		75	PP container	223.11	172.56	57.56	223.70	57.65	5.24	83.13
			HDPE	176.61	143.64	39.98	192.04	54.90	5.31	83.23
			LDPE	149.03	125.89	30.15	174.62	55.23	5.44	84.88
		96	PP container	151.78	132.31	26.48	174.79	48.98	5.77	84.48
			HDPE	98.78	96.39	9.40	115.70	25.81	6.24	85.68
			LDPE	94.44	97.22	4.23	108.12	17.40	6.57	82.33

(Continued)

Table 3. (*Continued*)

Storage time (Weeks)	Temperature (°C)	Relative humidity (%)	Packaging material	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown viscosity (RVU)	Final viscosity (RVU)	Setback viscosity (RVU)	Peak time (Min)	Pasting temperature (°C)
20	25	36	PP container	292.86	236.51	55.76	300.59	64.09	5.30	83.02
			HDPE	284.78	215.43	68.76	283.01	67.59	5.36	83.17
			LDPE	298.11	236.18	61.34	305.93	69.76	5.30	82.27
		56	PP container	265.36	215.43	49.34	272.51	57.09	5.23	82.32
			HDPE	280.19	217.93	61.68	282.76	64.84	5.23	83.07
			LDPE	281.03	221.01	59.43	289.18	68.18	5.16	82.32
		75	PP container	246.94	190.18	56.18	252.26	62.09	5.23	82.27
			HDPE	228.78	177.84	50.34	235.43	57.59	5.36	83.22
			LDPE	214.94	168.68	45.68	229.51	60.84	5.43	83.12
		96	PP container	217.19	186.01	30.59	226.26	40.26	5.36	82.32
			HDPE	199.53	159.59	39.34	205.68	46.09	5.43	83.17
			LDPE	164.61	142.26	21.76	187.27	45.01	5.63	81.42
	35	36	PP container	290.53	214.01	75.93	284.93	70.92	5.23	82.27
			HDPE	267.33	203.13	63.88	263.13	60.13	5.21	82.41
			LDPE	287.66	203.96	83.38	285.13	81.30	5.15	82.46
		56	PP container	242.83	179.80	62.71	246.96	67.30	5.28	83.16
			HDPE	220.83	174.55	45.96	229.88	55.46	5.41	84.06
			LDPE	170.75	151.71	18.71	208.13	56.55	5.28	82.31
		75	PP container	193.49	148.46	44.71	206.46	58.13	5.41	84.16
			HDPE	147.41	128.63	18.46	162.05	33.21	5.94	82.51
			LDPE	150.58	105.71	44.55	162.46	56.88	5.28	82.36
		96	PP container	139.98	130.71	8.96	159.71	29.13	5.94	83.21
			HDPE	58.99	53.80	4.88	70.21	16.55	7.08	84.81
			LDPE	75.25	69.80	5.13	89.88	20.21	6.83	86.41
	45	36	PP container	298.08	208.55	89.21	285.73	77.46	5.28	82.41
			HDPE	306.33	221.71	84.20	302.65	81.21	5.13	81.59
			LDPE	285.64	200.88	85.36	276.31	75.71	5.26	82.29
		56	PP container	278.48	201.30	77.78	272.56	71.40	5.03	82.39
			HDPE	266.48	192.08	75.03	269.90	77.98	5.23	83.99
			LDPE	267.56	206.08	62.11	270.06	64.15	5.23	83.19
		75	PP container	185.14	144.99	40.78	193.48	48.65	5.23	82.49
			HDPE	158.48	129.74	29.36	182.15	52.56	5.43	84.89
			LDPE	139.06	117.41	22.28	165.06	47.81	5.56	84.84
		96	PP container	103.14	97.58	6.20	115.98	18.56	6.96	84.81
			HDPE	122.73	113.74	9.61	141.98	28.40	6.83	54.49
			LDPE	124.39	116.83	8.20	164.65	47.98	6.63	53.54

(Continued)

Table 3. (*Continued*)

Storage time (Weeks)	Temperature (°C)	Relative humidity (%)	Packaging material	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown viscosity (RVU)	Final viscosity (RVU)	Setback viscosity (RVU)	Peak time (Min)	Pasting temperature (°C)
24	25	36	PP container	274.12	198.96	75.37	261.71	63.51	5.09	80.73
			HDPE	265.04	190.54	74.71	244.37	54.59	5.15	83.08
			LDPE	279.87	200.04	80.04	265.79	66.51	5.09	81.53
		56	PP container	262.20	198.46	63.96	249.12	51.43	5.15	82.13
			HDPE	260.29	188.62	71.87	248.88	61.01	5.02	81.23
			LDPE	259.04	181.46	77.79	246.12	65.43	5.09	81.03
		75	PP container	216.37	168.54	48.04	216.87	49.09	5.29	82.18
			HDPE	204.45	159.12	45.54	227.04	68.68	5.35	81.43
			LDPE	188.04	157.46	30.79	216.96	60.26	5.42	80.68
		96	PP container	173.95	161.96	12.21	201.21	40.01	5.95	82.38
			HDPE	160.07	145.71	14.87	181.37	36.43	5.95	81.43
			LDPE	110.74	84.41	26.62	117.62	33.76	6.89	79.93
	35	36	PP container	282.82	202.49	80.65	270.21	68.26	5.12	83.18
			HDPE	279.07	203.32	76.07	269.48	66.88	4.95	80.78
			LDPE	264.32	184.49	80.15	256.89	73.13	4.95	80.78
		56	PP container	193.24	144.07	49.49	204.39	61.04	5.35	84.13
			HDPE	98.40	142.15	35.07	199.39	57.96	5.49	84.88
			LDPE	106.49	93.74	13.07	133.23	40.21	5.69	82.38
		75	PP container	102.74	97.90	5.15	113.31	16.13	7.02	86.53
			HDPE	88.15	83.40	5.07	114.06	31.38	7.02	84.88
			LDPE	78.07	76.24	2.15	105.48	29.96	6.89	80.73
		96	PP container	100.65	94.18	6.99	123.98	30.71	7.02	84.03
			HDPE	68.73	63.26	6.74	83.81	21.46	7.02	86.43
			LDPE	71.23	67.34	5.15	87.06	20.63	6.62	86.53
	45	36	PP container	286.31	203.26	84.32	267.14	64.79	5.15	83.23
			HDPE	297.56	183.43	115.40	274.14	91.59	4.90	80.83
			LDPE	300.73	202.09	99.59	282.39	81.17	4.96	80.77
		56	PP container	276.23	203.84	73.34	263.46	60.59	4.96	81.52
			HDPE	261.98	190.68	72.26	258.79	69.09	5.16	83.97
			LDPE	271.81	197.51	75.26	271.21	74.67	5.03	81.57
		75	PP container	166.14	139.01	28.09	179.38	41.34	5.30	81.57
			HDPE	135.89	111.18	25.68	155.96	45.75	5.50	84.82
			LDPE	123.56	101.43	23.09	149.54	49.09	5.43	83.17
		96	PP container	47.31	41.50	6.76	65.71	25.17	7.03	60.92
			HDPE	87.56	83.01	5.51	107.29	25.25	6.70	83.07
			LDPE	82.56	75.26	8.26	112.13	37.83	7.03	58.17
Range				47.31–429.42	41.50–699.67	2.15–115.40	65.71–488.92	13.52–160.92	4.90–7.08	53.54–86.53

(Continued)

Table 3. (*Continued*)

Storage time (Weeks)	Temperature (°C)	Relative humidity (%)	Packaging material	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown viscosity (RVU)	Final viscosity (RVU)	Setback viscosity (RVU)	Peak time (Min)	Pasting temperature (°C)
Mean				219.17	173.10	48.46	225.74	55.59	5.46	82.74
SD				68.30	59.31	24.33	61.19	17.11	0.50	3.79
SE				4.64	4.03	1.65	4.15	1.16	0.03	0.26
P of ST				*	*	*	*	*	*	*
P of Temp				*	*	*	*	*	*	*
P of RH				*	*	*	*	*	*	*
P of Pkg				*	*	*	*	*	*	*
P of ST × T				*	*	*	*	*	*	*
P of StxRH				*	*	*	*	*	*	*
P of ST × Pkg				*	ns	*	*	*	*	*
P of T × RH				*	*	*	*	*	*	*
P of T × Pkg				*	ns	*	*	*	*	*
P of RH × Pkg				*	ns	*	*	*	*	*
P of ST × T × RH				*	ns	*	*	*	*	*
P of ST × T × Pkg				*	ns	*	*	*	*	*
P of ST × RH × Pkg				*	ns	*	*	*	*	*
P of T × Pkg × RH				*	ns	*	*	*	*	*
P of ST × T × RH × Pkg				*	ns	*	*	*	*	*

*Significant ($p < 0.01$); ns = not significant ($p > 0.01$).

time, a measure of cooking time and time required to attain peak viscosity, increased with storage, indicating longer time is required to attain peak viscosity. The values obtained at the end of storage are comparable to those reported by Wireko-Manu et al. (2011) for water yam flour. The pasting temperature is the temperature at which the first detectable increase in viscosity is measured and it is an index characterized by the initial change due to the swelling of the starch granules. Lower pasting temperature observed for samples stored at 98% relative humidity indicates lower WBC and lower degree of association between starch granules (Adebowale et al., 2005; Numfor, Walter, & Schwartz, 1996).

3.4. Microbiological stability of water yam flour during storage

The effect of storage conditions and packaging material on microbial stability of high quality water yam flour is represented in Figures 10–12 and Table 4, which are plots of counts (bacteria and fungi) against storage time at different temperature and relative humidity. In each Figure, the plots are represented in four relative humidity 36, 56, 75 and 96% at constant temperature.

The mean values of total viable bacterial and total viable fungal count ranged between 0.10 and 2.15×10^6 cfu/g, and 0.00 and 0.65×10^6 cfu/g, respectively. An increase in both bacterial and fungal load was observed for the samples during storage. The increase in microbial load could be due to increasing moisture content level in the samples and storage conditions (storage temperature and relative humidity) conducive for their growth. The largest increase was observed in samples stored at higher relative humidity (75 and 96%). Length of storage time led to an appreciable increase in bacteria and mould growth. Low storage temperature and relative humidity resulted in lower microbial counts during storage; therefore, the storage of the flour at 35 and 45°C under high relative humidity (75 and 96%) makes them vulnerable to microbial contamination as more colonies were

Figure 10. Effect of storage conditions and packaging materials on total aerobic bacterial and fungal count of water yam flour at 25°C.

Notes: TBC—total bacterial count; TFC—total fungal count.

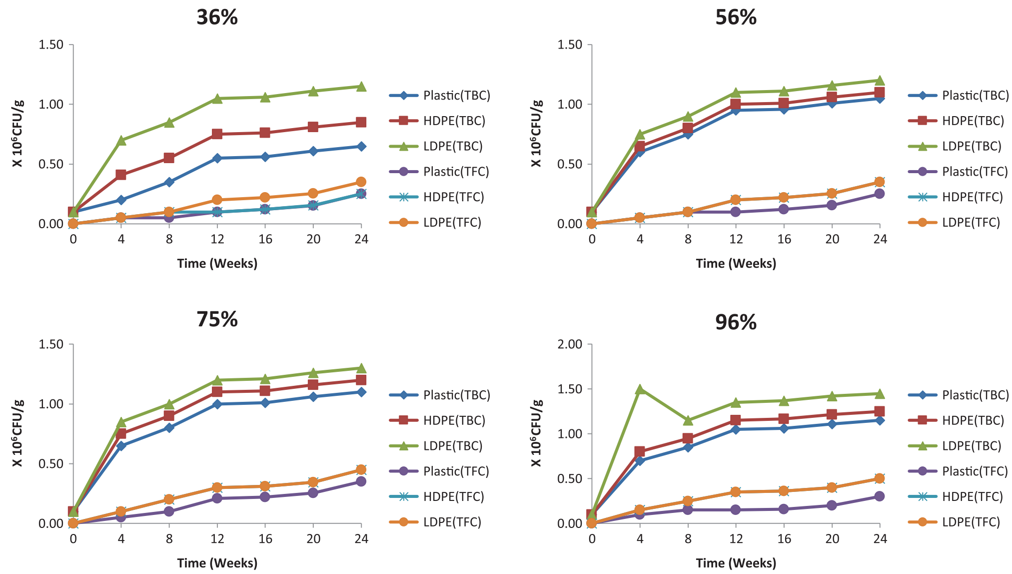
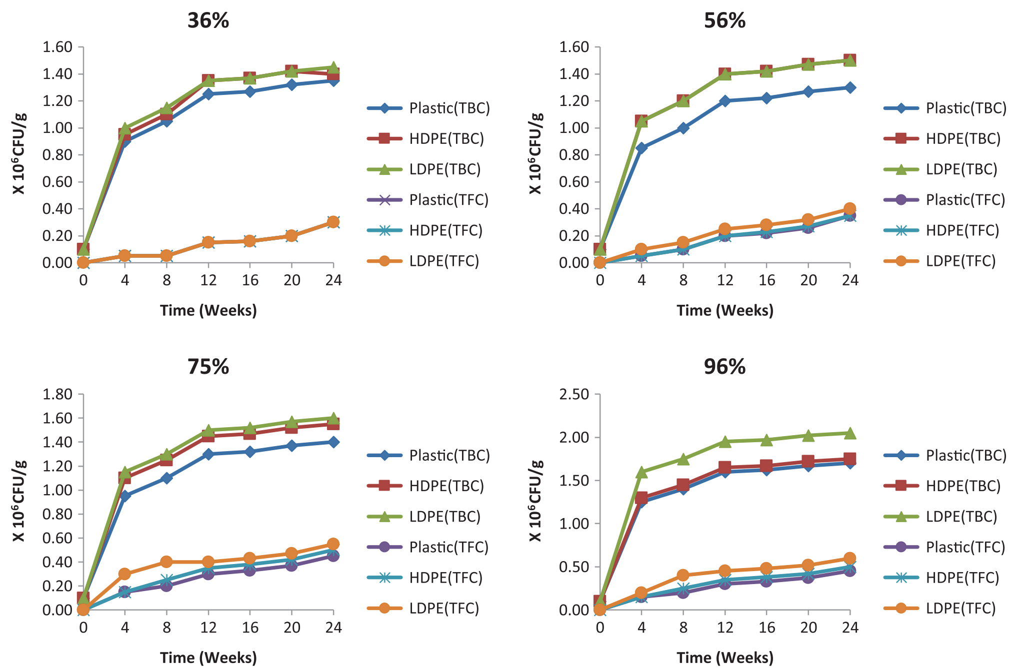


Figure 11. Effect of storage conditions and packaging materials on total aerobic bacterial and fungal count of water yam flour at 35°C.

Notes: TBC—total bacterial count; TFC—total fungi count.



observed in samples stored at these storage conditions irrespective of the packaging materials. Similar trends have been reported for storage temperature and relative humidity effect on mould growth in corn flour by Samapundo et al. (2007). Relative humidity in this study had a profound influence than storage temperature for microbial growth. Microbial load in all packaging materials increased at the end of 24 weeks of storage. This could be associated with the relative permeability of the packaging materials to atmospheric gases such as oxygen, carbon dioxide and water vapour and also probably due to storage conditions employed in this study which are favourable for microbial growth and availability of nutrients (Akhtar, Anjum, Rehman, Sheikh, & Farzana, 2008). Plastic containers exhibited a better protection against bacteria and mould attack, acting as an effective barrier to moisture as it recorded the least bacteria and fungi load of 1.95×10^6 and 0.50×10^6 cfu/g,

Figure 12. Effect of storage conditions and packaging materials on total bacterial and fungal counts of water yam flour at 45°C.

Notes: TBC—total bacterial count; TFC—total fungi count.

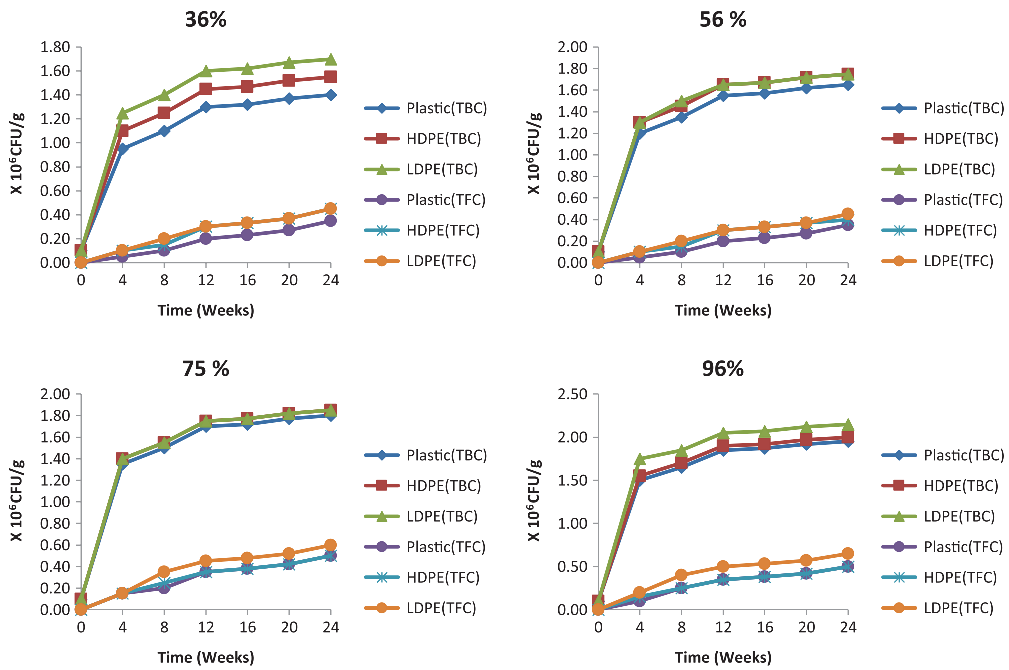


Table 4. Effect of storage conditions and packaging materials on microbiological load of water yam flour

Statistical parameter	Total bacteria count (×10⁶ cfu/g)	Total fungi count (×10⁶ cfu/g)
Range	0.10–2.15	0.00–0.65
Mean	1.32	0.27
Standard deviation	0.38	0.14
Standard error	0.03	0.009
P of storage time (ST)	*	*
P of temperature (T)	*	*
P of relative humidity (RH)	*	*
P of packaging material (P)	*	*
P of ST × T	ns	ns
P of St × RH	ns	ns
P of ST × P	ns	ns
P of T × RH	ns	ns
P of T × P	ns	ns
P of RH × P	ns	ns
P of ST × T × RH	ns	ns
P of ST × T × P	ns	ns
P of ST × RH × P	ns	ns
P of T × P × RH	ns	ns
P of ST × T × RH × P	ns	ns

*Significant ($p < 0.01$); ns = not significant ($p > 0.01$)

respectively at the end of storage. The microbial contamination of foods requires sufficient moisture and mould generally portends to thrive at lower moisture content (Akhtar et al., 2008).

4. Conclusion

Storage temperature and relative humidity significantly affected the quality attributes of the flour. Minimal loss of quality during storage was recorded at temperature of 25°C and 36% relative humidity. The packaging material with the best barrier properties and hence less losses in quality of water yam flour during storage was plastic container.

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Competing Interest
The authors declare no competing interest.

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References

Abiodun, O. A., Adegbite, J. A., & Oladipo, T. S. (2010). Effect of cassava starch substitution on the functional and sensory properties of trifoliate yam (*Dioscorea dumetorum*) flours. *African Journal of Food, Agriculture, Nutrition and Development, 10*(7), 2837–2849.

Achi, O. K., & Akubor, P. I. (2000). Microbiological characterization of yam fermentation for 'Elubo' (yam flour) production. *World Journal of Microbiology and Biotechnology, 16*(1), 3–7. https://doi.org/10.1023/A:1008980912708

Adebowale, A. A., Adegoke, M. T., Sanni, S. A., Adegunwa, M. O., & Fetuga, G. O. (2012). Functional properties and biscuit making potentials of sorghum-wheat flour composite. *American Journal of Food Technology, 7*(6), 372–379. https://doi.org/10.3923/ajft.2012.372.379

Adebowale, A. A., Sanni, L. O., & Awonorin, S. O. (2005). Effect of texture modifiers on the physicochemical and sensory properties of dried fufu. *Food Science and Technology International, 11*(5), 323–395.

Adebowale, A. A., Sanni, L. O., & Onitilo, M. O. (2008). Chemical composition and pasting properties of tapioca grits from different cassava varieties and roasting methods. *African Journal of Food Science, 2*, 77–82.

Adegunwa, M. O., Alamu, E. O., & Omitogun, L. A. (2011). Effect of processing on the nutritional contents of yam and cocoyam tubers. *Journal of Applied Biosciences, 46*, 3086–3092.

Adejumo, B. A. (2013). Some quality attributes of locally produced wheat flour in storage. *IOSR Journal of Environmental Science, Toxicology and Food Technology, 5*(2), 47–49.

Adeleke, R. O., & Odedeji, J. O. (2010). Functional properties of wheat and sweet potato flour blends. *Pakistan Journal of Nutrition, 9*(6), 535–538.

Akhtar, S., Anjum, F. M., Rehman, S. U., Sheikh, M. A., & Farzana, K. (2008). Effect of fortification on physico-chemical and microbiological stability of whole wheat flour. *Food Chemistry, 110*(1), 113–119. https://doi.org/10.1016/j.foodchem.2008.01.065

Ansah, I. G. K., Tetteh, B. K. D., & Donkoh, S. A. (2017). Determinants and income effect of yam postharvest loss management: Evidence from the Zabzugu District of Northern Ghana. *Food Security, 9*(3), 611–620. https://doi.org/10.1007/s12571-017-0675-1

AOAC. (2000). *Official methods of analysis of the Association of Official Analytical Chemists* (Vol. II, 15th ed., Sec. 985.29). Arlington, VA: The Association.

Awoyale, W., Maziya-Dixon, B., & Menkir, A. (2013). Effect of packaging materials and storage conditions on the physicochemical and chemical properties of *ogi* powder. *Journal of Food, Agriculture & Environment, 11*(3–4), 2–4.

Baah, F. D. (2009). *Characterization of water yam (Dioscorea alata) for existing and potential food products* (Unpublished PhD thesis). Kwame Nkrumah University of Science and Technology, Ghana.

Daramola, O. A., Idowu, M. A., Atanda, O. O., & Oguntona, C. R. B. (2010). Effects of packaging material on the quality of "pupuru" flour during storage. *African Journal of Food Science, 4*(5), 258–263.

Djeri, B., Tchobo, P. F., Adjrah, Y., Karou, D. S., Ameyapoh, Y., Soumanou, M. M., & Souza, C. (2015). Nutritional potential of yam chips (*Dioscorea cayenensis* and *Dioscorea rotundata* Poir) obtained using two methods of production in Togo. *African Journal of Food Science, 9*(5), 278–284.

Ekwu, F. C., Ozo, N. O., & Ikegwu, O. J. (2005). Quality of fufu flour from white yam varieties (*Dioscorea* spp). *Nigerian Food Journal, 23*, 107–113.

Fasasi, O. S. (2003). Effect of different packaging materials on the chemical composition of African breadfruit seed (*Treculia africana*) Flour during storage at room temperature. In *Proceedings of 27th Annual Conference of Nigerian Institute of Food Science and Technology* (pp. 153–154).

ICMSF. (1988). *Microorganisms in foods 1; their significance and methods of enumeration represents a major step in establishing a common understanding of, and developing standard methods for, important foodborne microorganisms* (2nd ed.). Toronto: University of Toronto Press.

Ilouno, B. E. L., Ndimele, E. C., Adikwu, O., & Obiekezie, S. O. (2016). Bacteriological quality of some fermented food products in Keffi, Nasarawa state. *FULafia Journal of Science & Technology, 2*(1), 4–10.

Karim, O. R., Kayode, R. M. O., Oyeyinka, S. A., & Oyeyinka, A. T. (2013). Proximate, mineral and sensory qualities of “Amala” prepared from Yam flour fortified with Moringa leaf powder. *Food Science and Quality Management, 12*, 10–22.

Maziya-Dixon, B., Adebowale, A. A., Onabanjo, O. O., & Dixon, A. G. O. (2005). Effect of variety and drying methods on physicochemical properties of high quality cassava flour from yellow cassava roots. *African Crop Science Conference Proceedings, 7*, 635–641.

Medcalf, D. G., & Gillies, K. A. (1965). Wheat starches 1: Comparison of physicochemical properties. *Journal of Cereal Chemistry, 42*, 558–562.

Nasir, M., Butt, M. S., Anjum, F. M., Sharif, K., & Minhas, R. (2003). Effect of moisture on the shelf life of wheat flour. *International Journal of Agriculture & Biology, 5*(4), 458–459.

Newport Scientific. (1998). *Applications manual for the rapid ViscoTM analyzer using thermocline for windows* (pp. 2–26). Warriewood: Author.

Numfor, F. A., Walter, W. M., & Schwartz, S. J. (1996). Effect of emulsifiers on the physical properties of native and fermented cassava starches. *Journal of Agricultural and Food Chemistry, 44*, 2595–2599. https://doi.org/10.1021/jf950610w

Nwosu, J. N., Onuegbu, N. C., Kabuo, N. O., & Okeke, M. O. (2010). The effect of steeping with chemicals (Alum and Trona) on the proximate and functional properties of pigeon pea (*Cajanus cajan*) flour. *Pakistan Journal of Nutrition, 9*(8), 762–768.

Okigbo, R. N. (2003). Fungi association with peels of post harvest yams in storage. *Global Journal of Pure and Applied Sciences, 9*(1), 19–23.

Osunde, D. Z. (2008). Minimizing postharvest losses in yam (*Dioscorea spp.*): Treatments and Techniques. In G. L. Robertson & J. R. Lupien (Eds.), *Using food science and technology to improve nutrition and promote national development. International Union of Food Science & Technology, Oakvile, Ontario,* (chapter 12, pp. 1–12).

Samapundo, S., Devlieghere, F., Geeraerd, A. H., Demeulenaer, B., Vanimpe, J. F., & Debevere, J. (2007). Modelling of the individual and combined effect of water activity and temperature on the radial growth of *Aspergillus flavus* and *A. parasiticus* on corn. *Food Microbiology, 24*(5), 517–529. https://doi.org/10.1016/j.fm.2006.07.021

Sanni, L., Maziya-Dixon, B., Akanya, J., Okoro, C. I., Alaya, Y., Egwuonwu, C. V., ... Dixon, A. (2005). *Standards for cassava products and guidelines for export* (p. 93). Ibadan: IITA.

Sanni, L. O., Kosoko, S. B., Adebowale, A. A., & Adeoye, R. J. (2004). The influence of palm oil and chemical modification on the pasting and sensory properties of fufu flour. *International Journal of Food Properties, 7*(2), 229–237. https://doi.org/10.1081/JFP-120026059

Standard Organization of Nigeria. (2004). *Standard for edible cassava flour* (Standards No. 344). Lagos: Nigerian Industrial.

Sosulki, F. W. (1962). The centrifuge method for determining flour absorption in hard red spring wheat. *Cereal Chemistry, 39*, 344–348.

Udensi, E. A., Oselebe, H. O., & Iweala, O. O. (2008). The investigation of chemical composition and functional properties of water yam (*Dioscorea alata*): Effect of varietal differences. *Pakistan Journal of Nutrition, 7*(2), 342–344. https://doi.org/10.3923/pjn.2008.342.344

Wireko-Manu, F. D., Ellis, W. O., Oduro, I., Asiedu, R., & Maziya-Dixon, B. (2011). Physicochemical and pasting characteristics of water yam (*D. alata*) in comparison with pona (*D. rotundata*) from Ghana. *European Journal of Food Research & Review, 1*(3), 149–158.