Journal of Experimental Research

December 2018, Vol 6 No 4

Email: editorinchief.erjournal@gmail.com
editorialsecretary.erjournal@gmail.com

Received: 28th June, 2018
Accepted for Publication: 22nd Nov., 2018

Effect of Drying on Rheological Properties of Yam Flours

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Abstract

The effect of drying on rheological properties of yam flours were studied. Five varieties of yam flours namely white yam (Dioscrea rotundata), Three leave yam (Dioscorea dumetorum), purple yam (Dioscore aalata) Water yam (Dioscorea alata), yellow yam (Dioscorea cayenensis) dried under three drying methods(oven, solar and sun drying methods) were used for the study. Results revealed that white yam, purple yam, three leave yam, water yam and yellow yam recorded viscosity ranges of 80 – 275kpa, 125 – 437kpa, 155 – 468kpa,89 – 563kpa and 113 – 471kpa respectively. In the same order, under sun, the yam varieties had viscosity range of 179 –349kpa,156 – 329kpa, 176 -416kpa, 83 – 233kpa, and 85 – 176kpa while under solar drying method white yam had viscosity range of 133 – 263kpa, purple yam, three leave yam, water yam and yellow recorded 184 – 442kpa, 204 -518kpa, 115 – 236kpa, and 95 – 274kpa respectively. The viscosity obtained for the yam varieties under different drying methods shows that their flours could be use as stabilizers or modifiers to enhance product in food industry. The analysis of variance on the effect of drying temperature and drying method on pasting behaviour of yam varieties showed no significant different at 5% level of probability for the drying temperature while there is significant difference in the drying methods of the yam varieties ($p > 0.05$).Five percent (5%) level of probability is a specified ? or p – value at which the significance of a given null hypothesis is adjudged after statistical analysis.

Key words: Drying method, properties, pasting behavior, rheology, yam flour,

INTRODUCTION

Yam is the common name for some species in the genus *Dioscorea* (family *Dioscoreaceae*). These are perennial herbaceous vines cultivated for the consumption of their starchy tubers in Africa, Asia, Latin America and Oceania (Wikipedia, 2009). There are many varieties of yam though only six are considered as staples in the tropics. Yams are high in vitamin C, dietary fiber, vitamin B6, potassium, and manganese; while being low in saturated fat and sodium (Agu et al. 2016). Worldwide yam production in 2007 amounted to 52 million tons, of which Africa produced 96%. Most of the world's production comes from West Africa representing 94%, with Nigeria alone producing 71%, equaling more than 37 million tons (FAO, 2008). Yam (*Dioscorea spp.*) is an important source of carbohydrate for many people of the sub-Sahara Africa, especially in the yam zone of West Africa (Akissoe et al. 2003). According to FAO (2008), yam is one of the important crops in the farming system of Nigeria with more than 2.8 million hectares of land under cultivation annually. Jimoh (2009) maintained that yam contributes significantly to dietary calories per capita daily and serves as a good source of income to the people. Yams are cultivated for the consumption of their starchy tubers in Africa, Asia, Latin America and Oceania. Some species of yam originated from Africa before spreading to other parts of the world while some originated from Asia and spread to Africa (Hahn *et al.* 1987). The global yam production was almost 48.7 million tonnes with 97% of this coming from sub-Saharan Africa (**Waziri et al 2016**).

FAO (2005) maintained that West and Central Africa accounted for 94%, Nigeria as the largest producer with 34% million tonnes, Cote d?voire 5 million tonnes and Ghana 3.9 million tonnes. Production of yam in Africa is largely confined to the “yam zones” comprising Cameroon, Nigeria, Benin, Togo, Ghana and Cote d?voire where approximately 90% of the world production takes place (Jimoh, 2009; Ibiyinka et al. 2011). Nigeria alone accounts for considerably more than half of the world total production (Ihekoronye and Ngoddy, 1995). Other countries where a significant production of yams occurs are Brazil, Venezuela, Papau New Guinea, China and Philippines. (Agronewsng, 2016) assert that **y**am production is a major source of employment to people both during planting and harvesting. However, its cost of production is relatively high compared with other root and tuber crops; this is attributed to costly inputs, especially labour and planting materials. The costs of obtaining seed yam constitute about 50% of the total cost of production. Conventionally, tuber is the only means of propagation for white yam and it is very expensive. Traditional yam production is faced with many constraints, including high cost and/or unavailability of seed yams for planting. Up to 33% of yams otherwise available for food are reserved for planting new crop (Adu-gynamfi and Blay, 2009). Yam is the second most important food crop after cassava in Africa (FAO, 2013). Yams are high in starch and contain the enzyme amylase which converts starch to sugars as the tuber matures in storage (Ibiyinka et al. 2011). It is the preferred stable crop that plays a predominant socio-cultural role in lives of the people of sub-Saharan Africa (FAO, 2003).

The science of rheology has many applications in fields of food acceptability, food-processing and food handling. According to (Gurstave et al. 1996), food rheology is the study of the rheological properties of food material, that is the flow of food consistency and deformation under specific conditions in this context food materials includes a wide range of biological materials with diverse rheological characters. They are mostly a mixture of different structures, Food consistency, degree of fluidity and other mechanical and functional properties are important in understanding and prediction of shelf life stability, and in storage and determining food texture. Food texture determines the acceptability of the food product by the consumer. Food rheology is important in quality control during food manufacture and processing. Knowledge of the rheological and mechanical properties of various food items are important in the design of flow process for quality control, in predicting storage and stability measurement. Rheological behavior is associated directly with texture qualities such as mouth feel, taste, rigidity which comes very close to being the classical elastic modulus. Every type of consumable food has some rheological characteristics; most readily consumable food products contain ingredients that have a major impact on the rheology of the final product. Food processors and raw materials manufacturers are aware of the importance of viscosity in food industry for many years and its effect in food industry. The objective of the study was to examine the effects of drying on the rheological characteristics of yam flour.

MATERIALS AND METHODS

Research Materials:

The research materials include five varieties of fresh yam namely; white yam (Dioscorea ro tundata), purple yam (Dioscorea alata), yellow yam (Dioscorea cayenensis), three leaves yam(Dioscorea bulbifera) and water yam (Dioscorea alata), which were obtained from Anambra State Agricultural Development Programme (ANADEP) at average storage moisture content of 57.94 % db. The yam tubers were washed, hand-peeled and sliced to range of 10 to 15mm thickness. Each variety of the yam tubers after slicing were divided into three sets according to the three different drying methods (oven dryer, sun dryer (open air) and solar dryer) in which the experiment was conducted; that of oven was further divided into three according to three drying temperatures used. The sliced yam tubers were generally dried in each case to a constant weight and milled accordingly using laboratory harmer mill. The yam flour was separately kept in moisture poof air tight container and was taken to the laboratory for rheological and functional test.

Yam drying process:

Drying experiment was conducted between November and December 2016 at Federal College of Education Ehamufu. Thin layer drying was employed in the experiment. The three drying methods used are oven, sun (open air) and solar drying methods. The drying temperatures are 50, 60 and 70^{0}C at air velocity of 1.35 to 2.3 m/s and Relative humidity of 21.1 – 35%, for oven method while the drying temperature in solar dryer is between 35 to 70^{0}C at 1.45 m/s air Velocity and sun (open air) is between 30 to 35^{0}C at air velocity of 1.25m/s, Relative humidity of 30.6%.

A dummy samples were used to achieve the stable drying condition in the oven, before loading the first set of yam samples. The yam samples at an average initial moisture content of 58% (wb) was loaded into the oven tray, the drying air temperature where determined. The samples were removed every 30 minutes and weighed to record moisture loss data; this was done for each temperature.

Figure 1: Rheometer set up for determination of rheological properties of yam flour

Determination of rheological Characteristics of yam flour:

The rheometer of model ATS instrument AB (Lund, Sweden) was used to determine the rheological behaviours of the yam flour. In the process, 3g of each yam flour sample was mixed in 25ml of distilled water in a sample canister. The samples were properly mixed and fitted into the STRESS-TECH rheometer canister as recommended in the operating manual. The corresponding values of shear stress, shear rate, viscosity, optimum pasting time and optimum pasting temperature were read from the computer connected to the Rheometer (Microsoft window based). The experiment was performed four times for each variety of yam flour and the average taken. The values of shear stress were plotted against shear rate and the corresponding relationship was used in classifying the yam flour fluid Rao et al (2005). Figure 1 shows the rheometer set up for determination of rheological properties of yam flour.

Determination of Flow consistency index (K) and flow behavioural index (N):

Two parameter model (power law fluid model) was used as suggested by Rao (2012) and Rao et al (2005).

$$\tau = K?^{n-1} \quad (1)$$

$$\ln(\tau) = \ln(k) + n \ln(?)$$

where

τ = shear stress, pa,

s?= shear rate,

k = flow consistency index,

n=flow behavioral index.

Ln shear stress and ln shear rate was determined and was used in plotting graph of ln shear stress against ln shear rate, the slope of the graph is the flow behavioral index while ln of the intercept (lnK) at shear stress axis is the flow consistency index (K).

RESULTS AND DISCUSSION:

Table 1. Pasting behaviour of five varieties of yam flour dried under oven drying methods at temperatures of 50, 60 and 70^{0}C.

Yam variety	50^{0}C Viscosity Kpa	Shear stress Pa	Shear rate s^{-1}	Shear strain	60^{0}C Viscosity KPa	Shear stress pa	Shear stress s^{-1}	Shear strain	70^{0}C Viscosity Kpa	Shear stress pa	Shear rate, s^{-1}	Shear strain
White	160	16	0.100	0.401	95	20	0.210	1.021	80	23	0.30	1.485
Yam	123	48	0.390	1.599	117	55	0.470	2.284	140	70	0.50	2.475
	208	146	0.700	2.807	150	105	0.720	3.992	174	120	0.69	3.416
	275	229	0.830	3.328	225	200	0.890	4.325	235	195	0.83	4.109
Mean	**192**	**110**	**0.505**	**2.034**	**187**	**95**	**0.572**	**2.904**	**157**	**102**	**0.580**	**2.871**
Purple	145	45	0.310	1.550	125	50	0.400	2.120	147	25	0.171	1.003
yam	210	120	0.570	2.85	177	85	0.481	2.549	200	70	0.352	2.065
	256	200	0.780	3.900	277	200	0.722	3.816	254	150	0.590	3.481
	276	240	0.870	4.350	437	350	0.801	4.245	407	285	0.710	4.189
Mean	**262**	**151**	**0.633**	**3.163**	**254**	**171**	**0.601**	**3.183**	**250**	**133**	**0.456**	**2.685**
Three	239	43	0.180	0.195	155	45	0.29	1.537	210	40	0.19	0.988
Leaves	321	90	0.280	1.478	175	100	0.57	3.021	240	125	0.52	2.704
Yam	366	150	0.410	2.165	276	210	0.76	4.028	346	235	0.68	3.536
	468	234	0.501	2.645	373	325	0.87	4.611	460	350	0.76	3.952
Mean	349	129	0.343	1.621	245	170	0.621	3.299	314	188	0.538	2.795
Water	89	25	0.280	1.209	192	65	0.339	1.397	251	60	0.239	1.076
Yam	103	50	0.481	2.078	250	135	0.540	2.225	278	120	0.431	1.940
	144	96	0.663	2.864	383	250	0.653	2.690	357	205	0.573	2.580
	202	150	0.742	3.205	563	400	0.741	3.053	500	325	0.650	2.925
Mean	**145**	**80**	**0.542**	**2.339**	**143**	**213**	**0.568**	**2.341**	**137**	**178**	**0.473**	**2.129**
Yellow	174	49	0.281	1.245	113	15	0.133	0.592	178	50	0.281	1.293
Yam	207	100	0.483	2.139	150	60	0.400	1.780	213	120	0.561	2.581
	293	200	0.682	3.021	223	170	0.761	3.386	316	225	0.711	3.271
	321	238	0.740	3.278	315	265	0.842	3.747	471	330	0.760	3.496
Mean	**249**	**587**	**0.547**	**2.421**	**220**	**128**	**0.534**	**2.376**	**205**	**181**	**0.578**	**2.660**

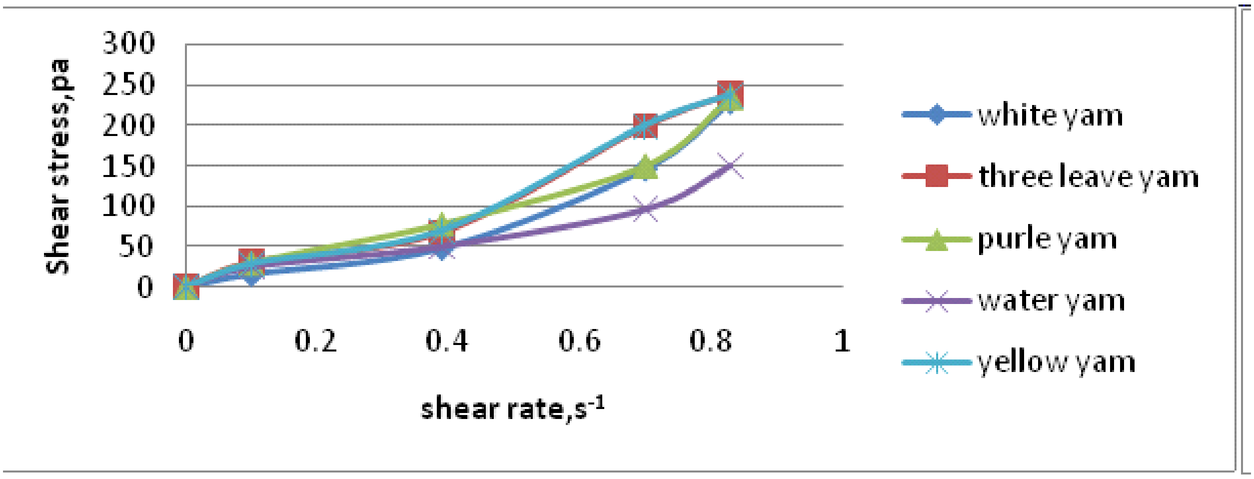

Figure 1. The relationship of shear stress and shear rate of five varieties of yam flour dried at temperature of 50^{0}C using oven dryer.

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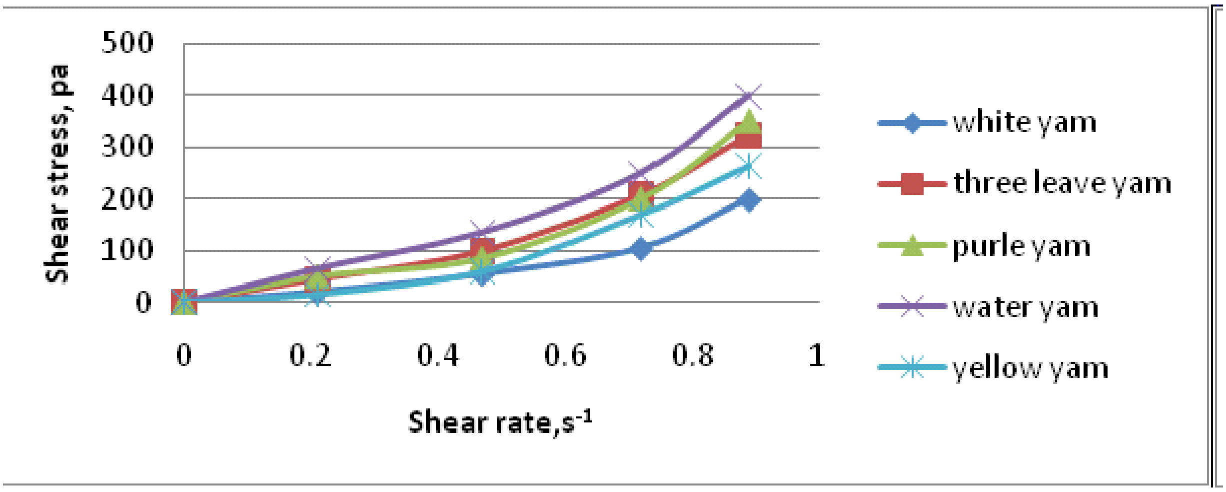

Figure 2: The relationship of shear stress and shear rate of five varieties of yam flour dried at temperature of 60°C using oven dryer.

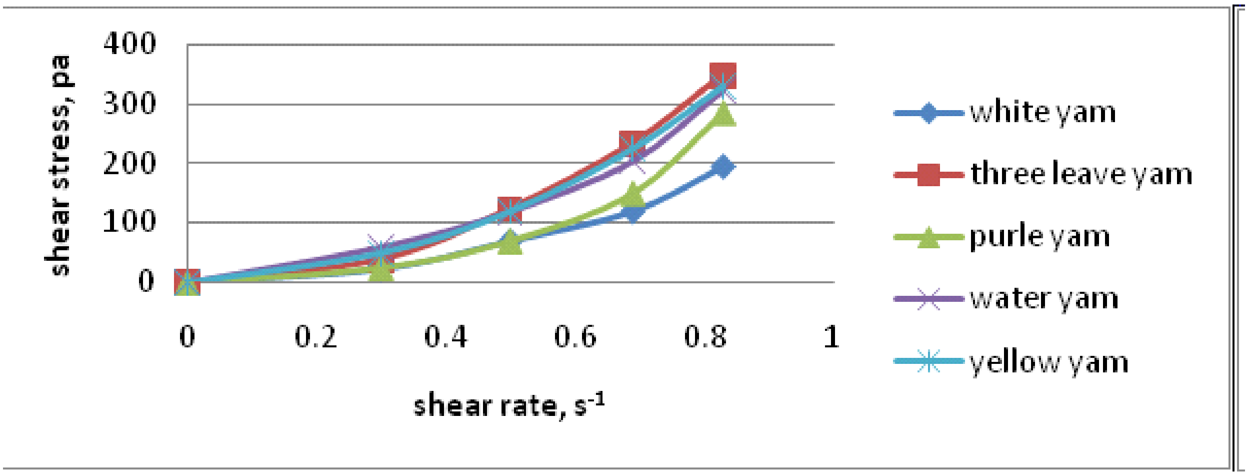

Figure 3: The relationship of shear stress and shear rate of five varieties of yam flour dried at temperature of 70°C using oven dryer.

Table 1 presents the pasting characteristics of yam flour varieties dried under oven drying methods at 50°C, 60°C and 70°C drying temperature. white yam record average viscosity, shear stress, shear rate and shear strain of 192kpa, 110pa, 0.505s^{-1} and 2.034, respectively, at 50°C; at 60°C it had 187kpa, 95pa, 0.572s-1 and 2.904 for viscosity, shear stress, shear rate and shear strain respectively. In same order at 70°C it had 187kpa, 102pa, 0.580s^{-1} and 2.871.Purple yam at 50°C in the same order recorded average of 222kpa, 151pa, 0.633s^{-1} and 3.163; at 60°C, it recorded average of 254kpa, 171pa, 0.601s-1 and 3.183 respectively for viscosity, shear stress, shear rate and shear strain. In that order, at 70°C purple yam recorded 252kpa, 133pa, 0.4565s^{-1} and 2.685 respectively. The three leave yam at 50°C had viscosity of 349kpa, shear stress of 129pa, 343s^{-1} for shear rate and shear strain of 1.621; at 60°C, it recorded 347kpa, 213pa, 0.568s^{-1} and 2.341 for viscosity, shear stress, shear rate and shear strain respectively. And in the same order it recorded 137kpa, 178pa, 0.473 and 2.129 respectively at 70°C. Water yam recorded 185kpa, 80pa, 0.542s^{-1} and 2.339 for viscosity, shear stress, shear rate and shear strain respectively at 50°C, while at 60°C in this arrangement had 143kpa, 213pa, 0.568s^{-1} and 2.341 respectively and at 70°C, the water yam had viscosity, shear stress, shear rate and shear strain of 137kpa, 178pa, 0.473s^{-1} and 2.129 respectively. The yellow yam recorded average viscosity of 249kpa, shear stress of 587pa, shear rate of 0.547s^{-1} and shear strain of 2.421 at 50^0C while at 60^0C it had 220kpa, 128pa, 0.534s^{-1} and 2.376 for viscosity, shear stress, shear rate and shear strain respectively. In the same order it recorded 205kpa, 181pa, 0.578s^{-1} and 2.66 respectively at 70^0C. The viscosity of the yam varieties at 50^0C were observed to be slightly higher followed by the values obtained at 60^0C and least viscosities value were recorded at 70^0C. This may be as a result of effect of high temperature, which is in agreement with the findings of Rao (2012) and Rao et al (2005).

Figures 1, 2 and 3 present the curve showing the relationship between shear stress and shear rate of five varieties of yam flour dried at 50^0C, 60^0C and 70^0C.The nature of the curves revealed that the flour is a time independent, non-Newtonian fluid. The curves are typical dilatants fluid curve as observed by Rao et al (2005).

Table 2. Pasting behaviour of yam flour under solar and sun (open air) drying methods

Yam variety	Sun drying method at 30^0C-35^0C				solar drying method 35^0C-70^0C			
	Viscosity kpa	Shear stress Pa	Shear rate s^{-1}	Shear strain	Viscosity kpa	Shear stress pa	Shear rate s^{-1}	Shear strain
White	179	50	0.280	1.193	133	48	0.360	1.732
Yam	245	103	0.420	1.789	217	150	0.691	3.324
	294	200	0.681	2.901	243	190	0.782	3.761
	349	290	0.832	3.544	263	250	0.952	4.579
Mean	**267**	**161**	**0.553**	**2.357**	**224**	**160**	**0.696**	**3.349**
Purple yam	156	30	0.192	0.845	184	46	0.250	1.205
	151	50	0.331	1.459	348	150	0.431	2.077
	237	135	0.570	2.514	417	230	0.552	2.661
	321	241	0.750	3.308	442	270	0.610	2.940
Mean	**226**	**114**	**0.461**	**2.032**	**210**	**174**	**0.461**	**2.220**
Three Leaves	176	30	0.170	0.741	204	45	0.221	1.179
Yam	237	100	0.421	1.836	339	129	0.380	2.037
	311	150	0.483	2.106	489	230	0.470	2.519
	416	233	0.560	2.442	518	270	0.521	2.792
Mean	**205**	**128**	**0.409**	**1.781**	**200**	**169**	**0.398**	**2.132**
Water Yam	83	30	0.361	1.744	115	35	0.303	1.463
	119	100	0.840	4.057	155	70	0.451	2.178
	205	235	1.141	5.506	208	150	0.722	3.487
	233	280	1.201	5.786	236	280	0.880	4.250
Mean	**160**	**161**	**0.886**	**4.276**	**149**	**134**	**0.589**	**2.845**
Yellow Yam	85	17	0.201	0.838	95	23	0.241	1.077
	65	22	0.342	1.426	163	100	0.615	2.749
	80	50	0.622	2.594	208	150	0.721	3.22
	176	150	0.851	3.549	274	241	0.881	3.938
Mean	**246**	**60**	**0.504**	**2.102**	**220**	**129**	**0.615**	**2.747**

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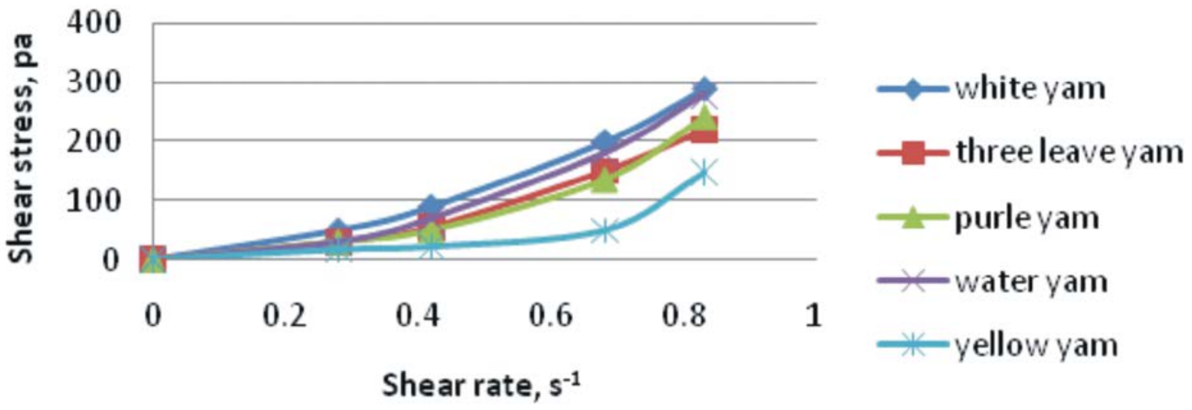

Figure 4. The relationship of shear stress and shear rate of five varieties of yam flour dried at temperature range of 30 - 35^{0}C using sun (open air) dryer.

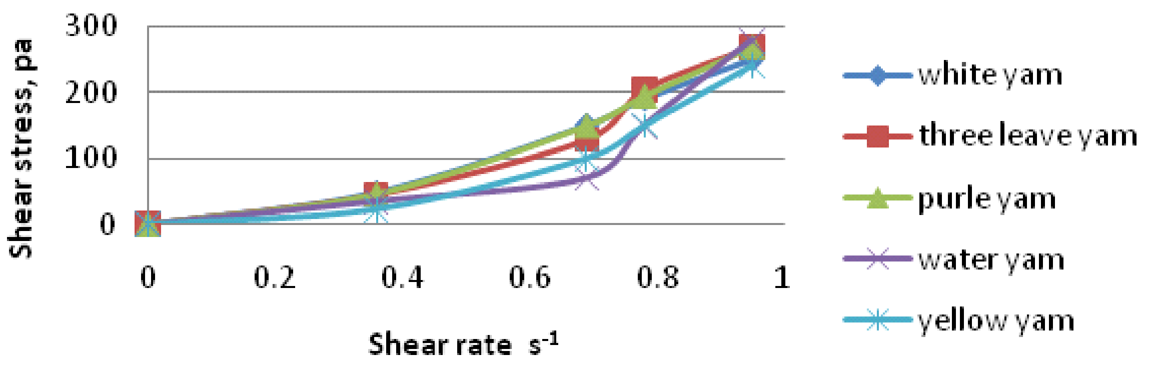

Figure 5. The relationship of shear stress and shear rate of five varieties of yam flour dried at temperature range of 35 – 70^{0}C using solar dryer.

Table 2 shows the pasting behavior of yam flour dried under solar and sun drying method. Under sum drying method at temperature of 30-35^{0}C, white yam recorded average viscosity of 267kpa, shear stress of 161pa, shear rate of 0.553s^{-1} and 3.349 for viscosity, shear stress, shear rate and shear strain respectively. The purple yam dried using sum drying method at temperature range of 30-35^{0}C recorded 226kpa, 114pa, 0.461s^{-1} and 2.032 respectively for viscosity, shear stress, shear rate and shear strain in the same order under solar drying method, it recorded 210kpa, 174pa, 0.461s^{-1} and 2.220 respectively. The three leaves yam had average viscosity, shear stress, shear rate and shear strain of 205kpa, 128pa, 0.409s^{-1} and 1.781 respectively under sum drying method while in solar drying method the three leaves yam in the same order recorded 200kpa, 169pa, 0.98s^{-1} and 2.132 respectively. Water yam dried under sun had average viscosity, shear stress, shear rate and strain of 160kpa, 161pa, 0.886s^{-1} and 4.276 respectively, while in solar drying method, in that order, it recorded 169kpa, 149pa, 0.589s-1 and 2.845 respectively. The yellow yam on the other hand, recorded average viscosity shear stress, shear rate and shear strain of 246kpa, 60pa, 0.504s^{-1} and 2.102 respectively, while in solar drying method, in the same arrangement it had 220kpa, 129pa, 0.615s^{-1} and 2.747 respectively.

Figure 4 and 5 show the relationship between the shear stress and shear rate of the yam varieties at different temperature ranges. The curve followed the same trend as the one plotted for oven drying method, indicating that the flour is a time independent non Newtonian fluid. Generally yam flour from sun drying method gave best rheological result that can give good result in food industry, followed by solar dryer; oven gave least result with oven dryer at 50^{0}C given best result among those dried with oven; though oven drying method gave the fastest drying/ shortest drying time I strongly recommend that commercial yam flour processors should use solar and oven at 50^{0}C it will give averagely good result at same time save both time and energy cost of drying. Sun drying method should be for subsistence production. Oven method is independent of climate condition but solar method will give good rheological result; Sun drying method is not hygienically acceptable because of pathogens in the air, climate change and lack of control over heat energy.

Table 3. Optimum pasting time and temperature of yam flour under three different drying methods.

Yam Varieties	Oven drying method Dried at 50,60 and 70^{0}C.						Sun drying Dried at 30 – 35^{0}C		Solar drying Dried at 35 – 70^{0}C	
	Optimum time(min)			Optimum temp(^{0}C)			Optimum pasting time(min)	Optimum pasting temp(^{0}C)	Optimum pasting time(min)	Optimum pasting temp(^{0}C)
	50^{0}C	60^{0}C	70^{0}C	50^{0}C	60^{0}C	70^{0}C	30 _ 35^{0}C	30 _ 35^{0}C	35 _ 70^{0}C	35 _ 70^{0}C
White yam	4.01	4.86	4.95	65.21	66.50	68.80	4.26	63.32	4.81	65.18
Purple yam	5.00	5.30	5.90	62.20	63.57	67.80	4.41	67.24	4.82	63.33
Three leaves yam	5.28	5.30	5.20	60.70	60.30	60.5	4.36	67.42	5.36	60.82
Water yam	4.32	4.12	4.50	68.32	62.00	60.00	4.83	64.28	4.83	62.61
Yellow yam	4.43	4.45	4.60	68.43	63.20	61.20	4.17	65.22	4.47	64.28

Table 3 presents the optimum pasting time and temperature of yam flour varieties under different drying methods. Results of this table revealed that while yam dried with 50^{0}C, 60^{0}C and 70^{0}C had optimum pasting time of 401mins, 4.86 mins and 4.95 mins at corresponding optimum temperature of 65.21^{0}C, 66.50^{0}C and 68.80^{0}C respectively. Under solar drying method at 35-70^{0}C, while yam had optimum pasting time and temperature of 4.8mins and 65.18^{0}C with sun drying method at temperature range of 30-35^{0}C the while yam recorded 4.26 mins and 63.32^{0}C for optimum time and temperature respectively. Purple yam dried using oven at the same temperature had optimum pasting time of 5.00, 5.30 and 5.90mins respectively with corresponding optimum temperatures of 62.20^{0}C, 63.57^{0}C and 67.80^{0}C. Under sun drying method at temperature range of 30^{0}C - 35^{0}C, the purple yam recorded optimum pasting time and temperature of 4.41mins and 67.24^{0}C respectively, and with solar drier at temperature range of 35-70^{0}C, the purple yam had optimum time had temperature of 4.82mins and 63.33^{0}C respectively. The three leaves yam dried with oven at 50, board 70^{0}C recorded optimum time of 5.28, 5.30 and 5.20 mins respectively and corresponding optimum temperature of 60.70, 60.30 and 60.50^{0}C. under sun drying method it recorded optimum time and temperature of 4.36mins and 67.42^{0}C, while with solar drier the three leaves yam recorded optimum time and temperature of 5.36mins and 60.82^{0}C respectively. Water yam under oven drying method had optimum time of 4.32mins, 4.12mins and 4.50mins respectively for the three drying temperatures with corresponding optimum temperatures of 68.32^{0}C, 62^{0}C and

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60^{0}C respectively; while under sun drier it recorded optimum pasting time and temperature of 4.83 and 64.28^{0}C; and under solar drier, the water yam recorded optimum pasting time and temperature of 4.83mins and 62.61^{0}C respectively. The yellow yam under oven drying method at 50^{0}C, 60^{0}C and 70^{0}C respectively recorded optimum pasting time and temperatures of 5.28min, 68.43^{0}C, 4.45mins, 63.20^{0}C and 4.60mins, 61.2^{0}C respectively Under sun drying method, the yellow yam had optimum pasting time and temperature of 4.17mins and 65.22^{0}C, while with solar drier it recorded optimum time and temperature of 4.47mins and 64.28^{0}C respectively.

Yam Varieties	**Oven drying method Dried at 50,60 and 70^{0}C.**						**Sun drying Dried at 30 – 35^{0}C**		**Solar drying Dried at 35 – 70^{0}C**	
	Optimum time(min)			**Optimum temp(^{0}C)**			**Optimum pasting time(min)**	**Optimum pasting temp(^{0}C)**	**Optimum pasting time(min)**	**Optimum pasting temp(^{0}C)**
	50^{0}C	**60^{0}C**	**70^{0}C**	**50^{0}C**	**60^{0}C**	**70^{0}C**	**30 – 35^{0}C**	**30 – 35^{0}C**	**35 – 70^{0}C**	**35 – 70^{0}C**
White yam	4.01	4.86	4.95	65.21	66.50	68.80	4.26	63.32	4.81	65.18
Purple yam	5.00	5.30	5.90	62.20	63.57	67.80	4.41	67.24	4.82	63.33
Three leaves yam	5.28	5.30	5.20	60.70	60.30	60.5	4.36	67.42	5.36	60.82
Water yam	4.32	4.12	4.50	68.32	62.00	60.00	4.83	64.28	4.83	62.61
Yellow yam	4.43	4.45	4.60	68.43	63.20	61.20	4.17	65.22	4.47	64.28

Table 3 presents the optimum pasting time and temperature of yam flour varieties under different drying methods. Results of this table revealed that while yam dried with 50^{0}C, 60^{0}C and 70^{0}C had optimum pasting time of 401mins, 4.86 mins and 4.95 mins at corresponding optimum temperature of 65.21^{0}C, 66.50^{0}C and 68.80^{0}C respectively. Under solar drying method at 35-70^{0}C, while yam had optimum pasting time and temperature of 4.8mins and 65.18^{0}C with sun drying method at temperature range of 30-35^{0}C the while yam recorded 4.26 mins and 63.32^{0}C for optimum time and temperature respectively. Purple yam dried using oven at the same temperature had optimum pasting time of 5.00, 5.30 and 5.90mins respectively with corresponding optimum temperatures of 62.20^{0}C, 63.57^{0}C and 67.80^{0}C. Under sun drying method at temperature range of 30^{0}C - 35^{0}C, the purple yam recorded optimum pasting time and temperature of 4.41mins and 67.24^{0}C respectively, and with solar drier at temperature range of 35-70^{0}C, the purple yam had optimum time had temperature of 4.82mins and 63.33^{0}C respectively. The three leaves yam dried with oven at 50, board 70^{0}C recorded optimum time of 5.28, 5.30 and 5.20 mins respectively and corresponding optimum temperature of 60.70, 60.30 and 60.50^{0}C. under sun drying method it recorded optimum time and temperature of 4.36mins and 67.42^{0}C, while with solar drier the three leaves yam recorded optimum time and temperature of 5.36mins and 60.82^{0}C respectively. Water yam under oven drying method had optimum time of 4.32mins, 4.12mins and 4.50mins respectively for the three drying temperatures with corresponding optimum temperatures of 68.32^{0}C, 62^{0}C and 60^{0}C respectively; while under sun drier it recorded optimum pasting time and temperature of 4.83 and 64.28^{0}C; and under solar drier, the water yam recorded optimum pasting time and temperature of 4.83mins and 62.61^{0}C respectively. The yellow yam under oven drying method at 50^{0}C, 60^{0}C and 70^{0}C respectively recorded optimum pasting time and temperatures of 5.28min, 68.43^{0}C, 4.45mins, 63.20^{0}C and 4.60mins, 61.2^{0}C respectively Under sun drying method, the yellow yam had optimum pasting time and temperature of 4.17mins and 65.22^{0}C, while with solar drier it recorded optimum time and temperature of 4.47mins and 64.28^{0}C respectively.

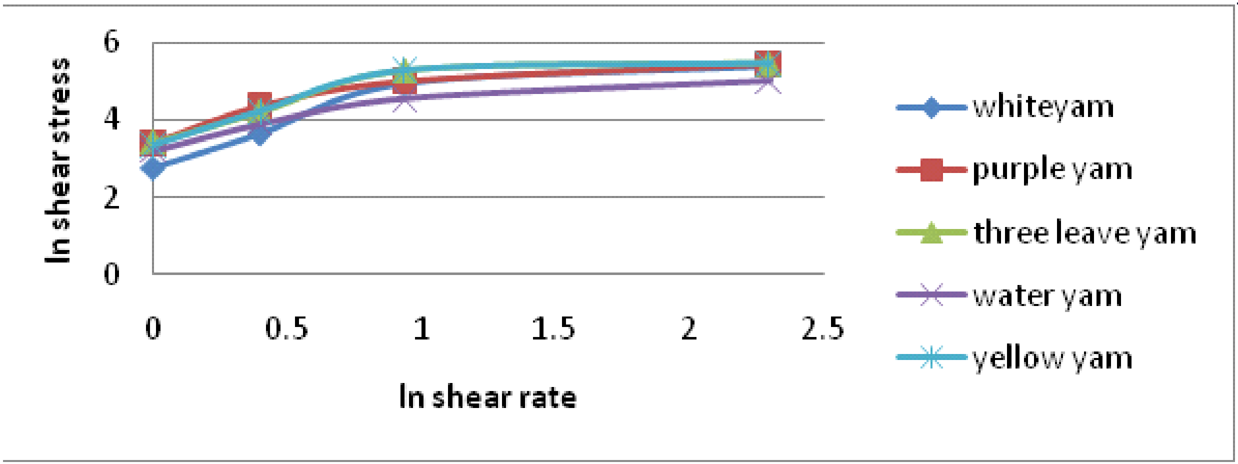

Figure 6: flow consistency index and flow behavior index of yam varieties dried at 50^{0}C temperature using oven.

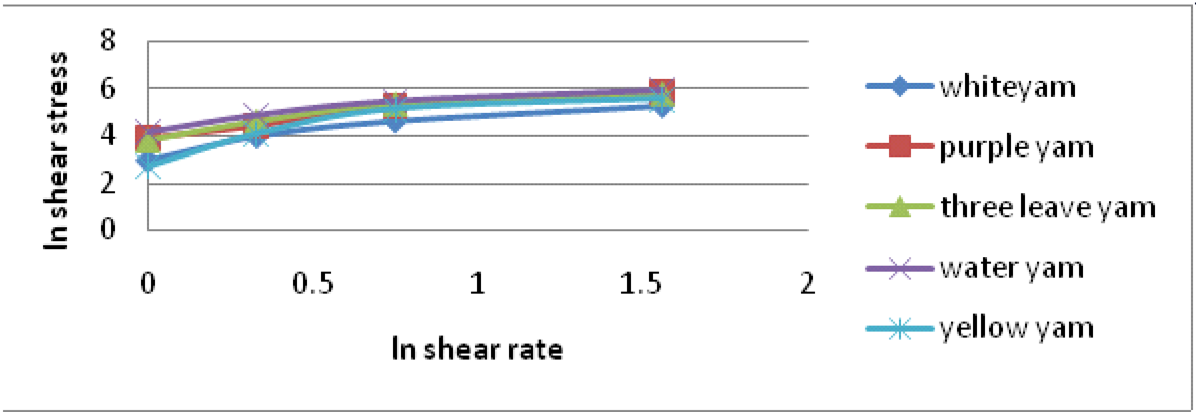

Figure 7: Flow consistency index and flow behavior index of five varieties of yam dried at 60^{0}C using oven dryer.

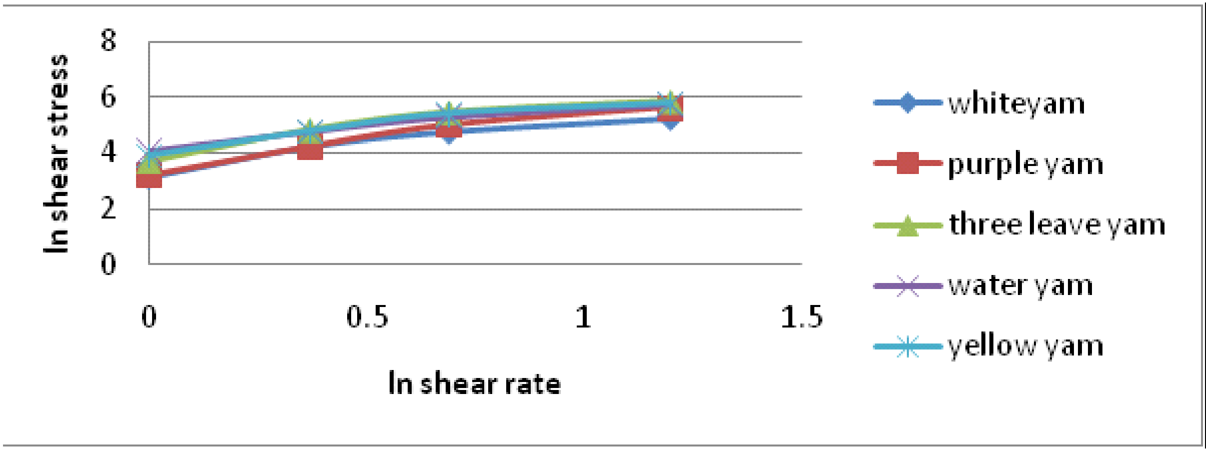

Figure 8: Flow consistency index and flow behavior index of five varieties of yam dried at 70^{0}C using oven drying method.

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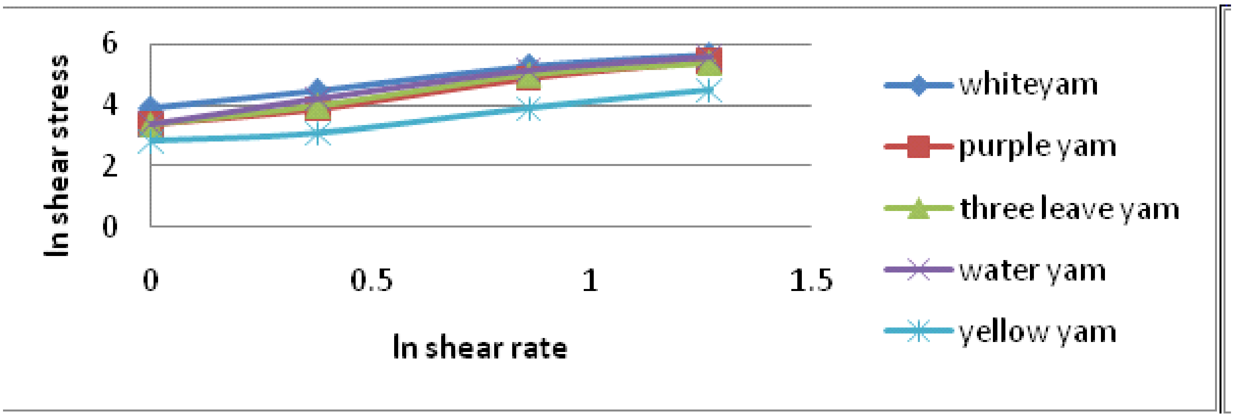

Figure 9: Flow consistency index and flow behaviour index of yam flour varieties dried at 30 - 35^{0}C using sun drying method.

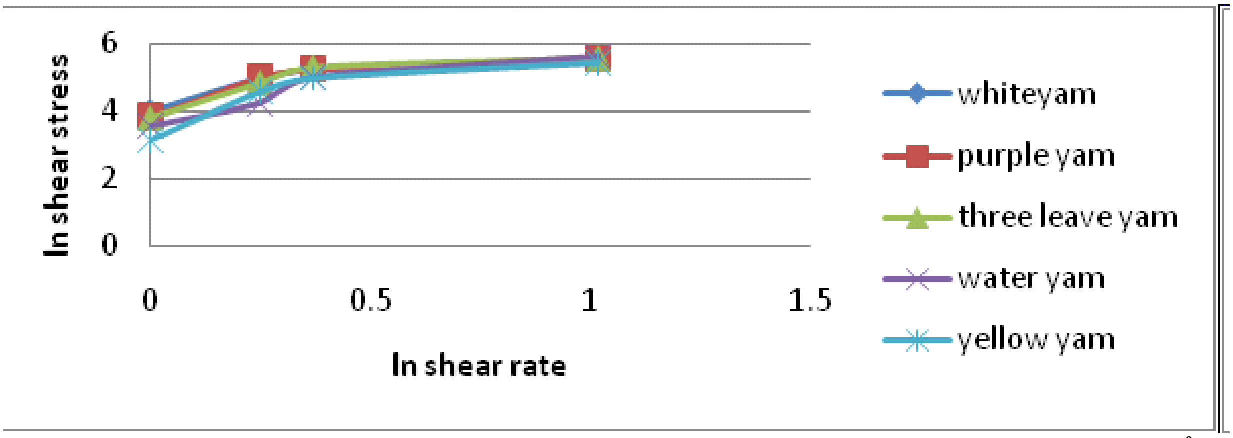

Figure 10: Flow consistency index and flow behavior index of yam flours dried at 35 - 70^{0}C using solar drying method.

Figure 10: Flow consistency index and flow behavior index of yam flours dried at 35 - 70^{0}C using solar drying method.

Yam varieties	50^{0}C			60^{0}C			70^{0}C		
	Intercept, C	In C = k(pas^n)	n	Intercept, C	In C = k	n	Intercept, C	In C = k	n
White Yam	2.8	1.03	2.20	3.00	1.09	2.0	3.20	1.16	2.5
Purple yam	3.41	1.23	1.60	4.01	1.39	1.9	3.0	1.09	2.7
Three leave yam	3.45	1.2	1.55	3.76	1.32	2.0	3.70	1.31	2.61
Water yam	3.20	1.16	1.78	4.20	1.44	1.87	4.0	1.38	1.7
Yellow yam	3.40	1.22	1.56	2.80	1.30	3.3	3.87	1.35	2.2

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Table 5: Flow behaviour index and flow consistency index of yam flour dried using sun and solar at temperature range of $30 - 35^0C$ and $35 - 70^0C$.

Yam variety	Sun dryer 30- 35^0C			Solar dryer 35 - 70^0C		
	Intercept, C	In C = k	n	Intercept, C	In C = k	n
White	4.00	1.39	1.56	4.00	1.39	3.25
Purple	3.35	1.21	2.32	3.81	1.34	3.5
Threeleave yam	3.30	1.19	2.28	3.70	1.31	3.75
Water	3.50	1.25	2.04	3.45	1.23	4.4
Yellow	2.80	1.01	2.3	3.20	1.16	4.5

Figure 6 to 10 show the flow consistency index and flow behavior index of the yam varieties dried using oven drying method at 50^0C, 60^0C and 70^0C from the figure, the slope which is the n (flow behavior index) of the yam varieties at the three drying temperatures (50^0C, 60^0C and 70^0C) range from 1.55 to 3.3 (table 4). These values are higher than 1; which indicates that the flour is dilatants fluid thus shear thickening fluid in line with Rao (2012).

Figure 6 and 10 presents the flour consistency index and flow behavior index of the yam varieties dried under sun and solar drying methods at temperature range of 30-35^0C and 35-70^0C respectively. The slope, n referred to 4.5 (Table 5) all the varieties showing that the flour is dilatants fluid (Shear thickening fluid).

Table 6: ANOVA of effect of drying temperature on pasting behaviour of yam flour varieties.

Source of variation	D.F	SS	MS	F.cab	F. Tab 5%
Yam flour variety	4	19.72	4.93	$9.2x10^{-7}$ NS	2.57
Temperature	4	44063.48	11015.87	0.002^{NS}	2.57
Error	41	217692057.02	5309562.37		
Total	49	217736140.22			

Table 7: ANOVA of effect of drying methods on pasting behaviour of yam flour varieties.

Source of variation	D.F	SS	MS	F.cab	F. Tab 5%
Yam flour variety	4	-20903.4	5225.85	2.05^{NS}	3.84
Drying method	2	45191	22595.5	8.88**	4.46
Error	8	-20364.6	2545.58		
Total	14	3923			

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Table 6 and 7 showed Analysis of variance (ANOVA) of the effect of drying temperature and drying methods on the pasting behaviour of yam flour varieties respectively. Results of the analysis showed that there is no significant different at 5% level of probability on the effect of drying temperature on the pasting behaviour of yam flours, while there is significant different on the effect of drying method of the yam varieties ($p > 0.05$).

CONCLUSION AND RECOMMENDATION

From the observations from the study, the following conclusions were arrived at:

1. At any giving temperature the drying rate and moisture content decreases as drying time progresses after the initial constant drying rate and the yam varieties showed different behaviours under diverse temperature and dying methods; a notable point in yam drying and in design of yam drying equipments.
2. The yam varieties recorded drying rate of 0.001 – 0.95kg/min, this can be useful in design of yam drying equipment. The viscosity obtained for the yam varieties under different drying methods showed that their flours can be used as modifier/stabilizer to enhance products in food industry.
3. The flow behaviour of the yam varieties indicated that they are non-Newtonian time independent fluids while their functional properties showed they can make good composite flour in bakery industry.
4. Sun drying method gave best rheological result that can give good result in food industry, followed by solar dryer; oven gave least result with oven dryer at 50^{0}C given best result among those dried with oven; though oven drying method gave the fastest drying/ shortest drying time I strongly recommend that commercial yam flour processors should use solar and oven at 50^{0}C it will give averagely good result at same time save both time and energy cost of drying. Sun drying method should be for subsistence production.
5. There exist some differences among yam flour varieties dried under different methods. Researchers are recommended make in-depth study on the rheological and drying characteristics of yam varieties not covered in this work to obtain vital information that may guide yam flour processors in improving in their processing, preservation or storage techniques.

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