EFFECT OF HARVESTING PERIOD ON THE QUALITY OF AERIAL YAM (*DIOSCOREA BULBIFERA*) BULBILS

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Adetunji I. Lawal[1]*, Rahman Akinoso[2] Mayowa R. Olubiyi[3] and F. O. Afolabi[1]

[1]Department of Food Science and Technology, Faculty of Engineering and Technology, First Technical University Ibadan, Oyo State, Nigeria.

[2]Department of Food Technology, Faculty of Technology, University of Ibadan, Ibadan, Oyo State, Nigeria.

[3]National Centre for Genetic Resources and Biotechnology (NACGRAB), P.M.B. 5382, Moor Plantation, Ibadan, Oyo State, Nigeria.

*Corresponding author: tunjawal@gmail.com

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Abstract: Aerial yam is an underutilized food crop that has potential for reducing food insecurity in Sub-Saharan Africa. Two cultivars of aerial yam (Tob2857 and Tob3059) were evaluated for the impact of harvesting period on the on-farm energy, yield, selected engineering properties, and volatiles organic compounds of the bulbils. The average expended energy on the farm at the end of 6, 7 and 8 months harvesting period was found to be 5625.25, 5889.01 and 6162.85 MJ, respectively. The energy input for the three harvesting period depended on the forms of energy and followed the order; fuel energy > labour > yam setting>machine> chemical energies. The bulbils yield increases with increase in harvesting period and Tob2857 was 14.81, 12.70 and 44.56%, respectively higher at 6, 7 and 8 months harvesting period than Tob3059. The geometric mean diameter, sphericity, transverse and longitudinal force at break ranged from 56.88 - 71.78 mm, 0.69 - 0.75, 1125.16 - 1411.74 N and 588.66 - 869.37 N, respectively. Thirty-six different volatiles compounds were found in the yam bulbils, among which acetate derivatives (ethyl acetate, propyl acetate, 2- methyl butyl acetate, isobutyl acetate and isoamyl acetate) were abundant as the key odour-active. The principal components analysis reflected a significant relationship ($p<0.05$), and the first, second and third PCs elucidated 39.5, 22.4 and 10.8%, respectively of the total variation. Eight months harvesting period with highest geometric mean was related to lowest specific energy.

Key words: Aerial yam, volatiles organic compounds, mechanical properties, geometric mean, specific energy.

Introduction

Aerial yam (*Dioscorea bulbifera (DB))* is an underutilized and Sub-Sahara agricultural crop that deserves attention, in general, for being a food security crop, as direct source of carbohydrates, minerals and bioactive compounds with significant biological values due to beneficial effect on human health especially in Africa and in countries with high preference for yam and other tuberous crops such as Nigeria, Ghana and Central Africa countries. Economic wise, the recent exportation of yam species into the global market, especially in Europe and regions with increasing passion for tubers such as Asia, has aroused enormous interest by indigenous farmers (Achy *et al*., 2017). Aerial yam is known to be relatively low in free sugar and glycemic index which makes it a suitable food for the diabetic patient *(Ayoola et al.*, 2008). Its cultivation only requires low capital, labor and total overhead cost as a perennial crop compared to other yam species (Olatoye & Arueya, 2019). This yam species has potential to grow in the marginal areas (even in low rainfall environments) with aerial tuber formation and usually matured after six-month of planting (Libra et al., 2011). Despite the enormous potentials of aerial yam, it remains a traditional crop, less studied and has high rate of post-harvest losses (Lawal & Akinoso, 2019). To reduce post-harvest losses and promote utilization of aerial yam beyond traditional usage, it is important to ensure that bulbils harvest time coincide with, or exceed the minimum acceptable level to the consumers and agricultural processing industries. Suitability of such underutilized crop in processing industries usually involves appropriate determination of physical and engineering properties for easy adaptation to existing machine and design of new processing equipment. A holistic approach to appropriate harvest time must also balance the energy input for such crop since agriculture itself is regarded as an energy consumer in various forms, and supplier in the form of bio and renewable energies (Lawal *et al*., 2014). Energy input in agriculture has been heightened in a form of feedback to geometric growth in populations, competition for arable land, climate change and crops maturity, thus optimal use of energy in crop production is vital to sustainable agricultural production (Zangeneh et al., 2010). Akinoso et al. (2013) had also reported that inadequate attention to the agro-energy sector in developing countries put both the farmer and food processor at a disadvantage and also hurt the economy of the Country. The aim of this study was to characterize energy utilization, selected engineering properties and volatiles organic compounds of aerial yam bulbils during various stages of development to determine the ideal harvest time.

Materials and Methods

The aerial yam germplasms (Tob2857 and Tob3059) used in this study was obtained from International Institute for Tropical Agriculture, Ibadan. The planting of the two germplasms were done during the consecutives years 2020, 2021 and 2022 at the National Centre for Genetic Resources and Biotechnology (NACGRAB) farm, Ibadan (7º 24 ′N, 3º 55 ′E), Oyo State in derived savanna region of Nigeria. The average weather and environmental conditions during the period were, 76.44% for RH, 23.17 ºC for minimum temperature, 31.61 ºC for maximum temperature and 123.00 mm rainfall. Matured and healthy bulbils were harvested randomly at three different harvest regimes (6, 7 and 8 months after planting) and transported to the laboratory

(Department of Food Technology, University of Ibadan, Nigeria) in cool bag.

On-farm energy

The inputs (on-farm) energy used for DB production (human labor energy, machinery energy, diesel fuel energy, chemical fertilizers energy, seeds energy) and output (DB yield) were calculated per hectare and then converted to energy forms for the output-input analysis using standard equations 1-5 (Lawal et al., 2014).

$$Energy\ productivity = DB\ output/energy\ input \quad (1)$$

$$Specific\ energy = energy\ input//DB\ output \quad (2)$$

$$Net\ energy = energy\ output - energy\ input \quad (3)$$

$$Energy\ efficiency = energy\ output/\ energy\ input \quad (4)$$

$$Agrochemical\ energy\ ratio\ (\%) = \frac{input\ from\ chemical\ input\ \ (MJ/ha)}{total\ input\ energy\ (MJ/ha)} \quad (5)$$

Physical properties

The dimensional and gravimetric properties of freshly harvested bulbils were determined using 25 repetitions at their natural moisture contents. Polar (L), equatorial diameters (W) and thickness (T) were measured from pole to pole using location of cavity as a reference point (Digital calipers, Mitutoyo 500-196-30, Japan). Geometric mean (Dg) diameter, sphericity, surface area and aspect ratio were estimated using standard relationship in equations 6-9 (Akinoso & Lasisi, 2013). Coefficient of static friction (μ) was determined on five different surfaces (plywood, glass, medium density fibre board, rubber and galvanized steel).

Bulk density was obtained from the modified method (Aremu & Fadele, 2011). The bulbils were filled into a container of known volume and ratio of mass to volume (equation 10) was calculated as bulk density. True density was estimated from equation 11 using water displacement of a unit mass of the bulbils. Porosity is obtained from the equation 12. The bulbils were neither compressed nor deformed in any way.

Compressive force and deformation were determined at transverse and longitudinal orientations using a constant deformation rate (10.00 mm/min) on Instron 3369 series, Universal Testing Machine. The procedures were repeated in 10 replicates (Akinoso & Lasisi, 2013).

$$Dg = (LWT)^{\frac{1}{3}} \quad (6)$$

$$Sphericity = \frac{Dg}{L} \quad (7)$$

$$Surface\ area = \pi Dg^2 \quad (8)$$

$$Aspect\ ratio = \frac{W}{L} x\ 100 \quad (9)$$

$$Bulk\ density = \frac{Mass\ of\ the\ bulbils\ in\ the\ container}{Volume\ of\ the\ container}\ (g/cm^3) \quad (10)$$

$$True\ density = \frac{Mass\ of\ the\ bulbils\ in\ the\ submerged}{Volume\ of\ water\ container}\ (g/cm^3) \quad (11)$$

$$Porosity = \left(1 - \frac{Bulk\ density}{True\ density}\right) x100 \quad (12)$$

Volatile organic compound

For dynamic headspace sampling of volatile compounds, intact bulbils were enclosed in an air tight glass jar with lid. The glass jar was purged continuously with compressed air (purified form) at $1.67 mLS^{-1}$. The head space components from the outlet stream were adsorbed on to 50 mg (0.51 - 0.85 mm) Tenax TA packed in glass tubing (17.5 cm×0.4 cm i.d.). Tubes were desorbed at 250 °C for 3 min in helium and the analytes condensed on a cryofocusing module adjusted to -120 °C. The inlet was flash heated to 250 °C to free the focused compounds (Zhu et al., 2008).

Statistical analysis

The experimental design was a randomized factorial arrangement (2 cultivars in 3 harvesting period). Data obtained were statistically analyzed (ANOVA) and means were separated by Duncan's multiple range tests using SPSS software at $\alpha<0.05$. The principal component analysis (PCA) was used to visualize possible relationships between the various parameters and DB varieties. The data are reported as the mean values of the results of triplicate analyses.

Results and Discussion

On farm energy

The energy input and output of aerial yam production at three harvesting period were analyzed and compared (Table 1). As expected, the total energy input for producing DB at 8 (6162.85 MJ) was especially different from the 6 (5,625.35 MJ) and 7 (5889.01 MJ) months; it represented a significant ($p\leq0.05$) higher amount by 61.11 and 33.64% for 7 and 8 months, respectively. The energy inputs from fuel (28.68MJ) consumption, manual weeding (274.4 MJ) and chemical (190.06 MJ) utilizations accounted for the observed differences in the energy input of the delayed harvested DB. Generally, the energy input for the three production processes followed similar order with fuel energy > labour > yam setting > machine > chemical energies, which is an indication that the production processes expended much of human labor than machinery. These results are consistent with a previous study on energy utilization for producing root and tuber crops in tropical countries (Adekanye et al., 2020; Zangeneh et al., 2010). The result of energy indicator (Table 2) shows that a decrease in specific energy of Tob2857 (1.81 - 0.60 MJ/kg) and Tob3059 (2.08- 0.67 MJ/kg) were observed with delayed harvesting period, whereas energy productivity increased with increases in harvesting period. The minimum energy productivity of DB was 0.48 (6 months of Tob3059) and highest 1.67 kg/MJ (8 months of Tob2857). This means that 2.08 and 0.60 MJ of energy were used to produce 1 kg DB at 6 (Tob3059) and 8 (Tob2857) months, respectively. The energy productivity at 7 months (Tob3059) was similar to 0.79 kg/MJ reported for plantain production in Nigeria (Jekayinfa et al., 2012). Energy use efficiency is a pointer to the effectiveness of the agricultural system. The values observed at 6, 7 and 8 months production for Tob2857 were 3.53, 5.76 and 10.70%, and Tob3059 were 3.07, 5.11 and 9.55%, respectively. Increased value is an indication of efficiency use of energy in aerial yam production system .The results obtained at 6 months (3.07-3.53%) were similar to 3.53 reported for maize production system in Nigeria by Lawal et al. (2014) but lower than 4.9% reported by Adekanye et al. (2020) for cassava production system in North- Central Nigeria. The efficiency of energy in crop production in an index of energy ratio and the value can be increased either by raising the yield of aerial yam or by decreasing energy input on the farm. Thus, the higher the energy ratio, the more efficient the use of production energy obtained for the crop (Flores et al., 2016). The net (14214.65 - 59757.17 MJ/ha for Tob2857 and 11654.65 - 52717.15 MJ/ha for Tob3059) direct (3654.2- 4172.38 MJ/ha) and indirect (1971.15 - 1990.47 MJ/ha) energies increases with harvesting period and 8 months had the highest. The higher value of direct energy could be attributed to low utilization of inputs such as chemical fertilizers and machinery during the DB production. Similar study was reported for potato production in Philippines (Flores et al., 2016).

The forms of energy varied after different harvesting period. Six-month had the lowest biological (2544.2 MJ/ha) and industrial (3081.15 MJ/ha) energies. The estimated industrial energy shows that, this portion of energy increased with the harvesting period. Also a decreased ratio of biological to industrial energies was obtained between 6 and 8 months harvesting period, the ratio of which were 0.83, and 0.72 respectively. This result is consistent with the finding of Flores et al. (2016), who observed low ratio (0.66) of biological to industrial energy to be associated with intense use of fossil resources and chemical fertilizers on the farm. Higher biological energy ratio is a pointer to green energy, organic farming, and sustainable agricultural practice (Jekayinfa et al., 2012).

Yield

The effect of harvesting period on DB yield is shown in Table 2, and the values ranged from 2.7 to 10.3 tonnes per hectare. The bulbils yield increases with increase in harvesting period regardless of the cultivars. This means that there is an increase in the energy output (Table 1). Crop yields denote the quality of crop produces harvested per unit land area. It is also important in the estimation of land use efficiency for food and agricultural commodity production (Milanez et al., 2016). The Bulbils yield at 7 and 8 months increased by 70.79 and 232.26% (Tob2857); 74.07 and 240.74% (Tob2059), respectively when compared with the yield at 6 months harvesting period. Also, there was a noteworthy difference ($p < 0.05$) between the values obtained for different aerial yam cultivars. For instance, the bulbils yield of Tob2857 was 14.81, 12.70 and 44.56% higher at 6, 7 and 8 months, respectively when compared with the Tob3059. The observed differences could be attributed to the influence of genetics. High yield potential and early maturation is crucial for food security and also provides information to assess the agricultural health of the nation (Law-Ogbomo & Osaigbovo, 2014; Milanez et al., 2016).

Table 1. Energy equivalent of on-farm aerial yam bulbils.

		6		**7**		**8 months**	
Inputs/outputs (units)	**Energy equivalent (MJ)**	**Input**	**Utilized energy (MJ)**	**Input**	**Utilized energy (MJ)**	**Input**	**Utilized energy (MJ)**
Human labour (h ha^{-1})			1,264.20		1,283.80		1304.38
Land cleaning Harrowing	1.96	480	940.8	480	940.8	480	940.8
Planting	1.96	35	68.6	35	68.6	35	68.6
Weeding	1.96	122	235.2	130	254.8	140	274.4
Harvesting	1.96	10	19.6	10	19.6	10.5	20.58
Machinery (h ha^{-1})			520.41		520.41		520.41
Land preparation	62.7	3.8	238.26	3.8	238.26	3.8	238.26
Transportation	62.7	4.5	282.15	4.5	282.15	4.5	282.15
Fuel (L ha^{-1})	47.8	50	2390	55	2629	60	2868
Chemicals (kg ha^{-1})			170.74		175.8		190.06
Pesticides	101.2	0.3	30.36	0.35	35.42	0.4	40.48
Herbicides	92	1.5	138	1.5	138	1.6	147.2
Fungicides	238	0.01	2.38	0.01	2.38	0.01	2.38
Yam setting (kg ha^{-1})	6.4	200	1280	200	1280	200	1280

Dimensional and gravimetric properties

Dimensional and gravimetric properties of freshly harvested aerial yam bulbils varieties are shown in Table 3. The highest polar (101.74 mm) and equatorial (75.42 mm) diameters was found in Tob2857. The diameters of the bulbils harvested early, was lower than the bulbils

Table 2. Energy indicator of on-farm aerial yam bulbils.

		Tob2857			Tob3059		
Energy indicator	**Unit**	**6**	**7**	**8**	**6**	**7**	**8 months**
Specific energy	MJ/Kg	1.81	1.11	0.6	2.08	1.25	0.67
Energy productivity	Kg/MJ	0.55	0.9	1.67	0.48	0.8	1.49
Energy use efficiency		3.53	5.76	10.7	3.07	5.11	9.55
Net energy	MJ/ha	14,214.65	28,030.99	59,757.15	11,654.65	24,190.99	52,717.15
Agro chemical energy ratio		3.04	2.99	3.08	3.04	2.99	3.08
Direct energy	MJ/ha	3,654.2	3,912.8	4,172.38	3,654.2	3,912.8	4,172.38
Indirect energy	MJ/ha	1,971.15	1,976.21	1,990.47	1,971.15	1,976.21	1,990.47
Biological energy	MJ/ha	2,544.2	2,544.2	2,584.38	2,544.2	2,544.2	2,584.38
Industrial energy	MJ/ha	3,081.15	3,081.15	3,578.4	3,081.15	3,081.15	3,578.4
Total input energy	MJ	5,625.35	5,889.01	6,162.85	5,625.35	5,889.01	6,162.85
Total output energy	MJ	19,840	33,920	65,920	17,280	30,080	58,880
Bulbils yield	Kg/ha	3,100	5,300	10,300	2,700	4,700	9,200

Table 3. Dimensional, coefficient of friction and mechanical properties of aerial yam bulbils.

	Tob2857			Tob3059		
Parameter/Harvesting period	6	7	8	6	7	8 months
Moisture content (%)	71.76 ± 0.42^{d}	69.20 ± 0.17^{e}	68.39 ± 0.26^{e}	77.20 ± 0.40^{a}	75.48 ± 0.23^{b}	73.53 ± 0.52^{c}
DG						
Length(mm)	82.59 ± 2.30^{c}	90.72 ± 1.20^{b}	101.74 ± 3.50^{a}	76.82 ± 1.32^{d}	81.41 ± 2.16^{c}	90.51 ± 0.61^{b}
Width(mm)	67.18 ± 0.54^{c}	69.97 ± 0.50^{b}	75.42 ± 0.22^{a}	62.34 ± 0.41^{e}	65.34 ± 0.31^{d}	68.38 ± 0.42^{bc}
Thickness(mm)	43.37 ± 0.74^{c}	45.61 ± 0.50^{b}	48.18 ± 0.47^{a}	38.43 ± 0.63^{d}	42.11 ± 0.35^{c}	39.35 ± 0.58^{d}
Mass(g)	126.67 ± 3.40^{e}	236.11 ± 2.11^{a}	238.34 ± 4.76^{b}	130.52 ± 3.65^{e}	227.36 ± 2.21^{c}	228.79 ± 3.31^{d}
Mean(mm)	62.20 ± 0.31^{c}	66.04 ± 0.40^{b}	71.78 ± 0.22^{a}	56.88 ± 1.18^{e}	60.73 ± 0.83^{d}	62.45 ± 0.71^{c}
Sphericity	0.75 ± 0.52^{a}	0.73 ± 0.45^{ab}	0.71 ± 2.23^{b}	0.74 ± 0.43^{a}	$0.72\pm o.27^{b}$	0.69 ± 1.17^{c}
Surf. Area(cm^2)	121.56 ± 0.23^{c}	137.51 ± 0.29^{b}	161.85 ± 0.31^{a}	101.66 ± 0.71^{e}	115.89 ± 1.17^{d}	122.53 ± 2.30^{c}
BD(g/cm^3)	0.51 ± 0.03^{c}	0.60 ± 0.029a	0.57 ± 0.15^{b}	$0.53.03\pm0.83^{c}$	0.62 ± 0.029^{a}	0.58 ± 0.01^{b}
TD(g/cm^3)	1.14 ± 0.22^{b}	1.27 ± 0.20^{a}	1.11 ± 0.12^{c}	1.07 ± 0.21^{c}	1.10 ± 0.14^{c}	1.10 ± 0.11^{c}
Porosity (%)	55.26 ± 1.32^{a}	52.76 ± 0.41^{c}	48.65 ± 0.63^{c}	50.47 ± 1.18^{b}	43.64 ± 0.43^{d}	47.27 ± 2.16^{c}
AR (%)	81.34 ± 1.32^{a}	77.12 ± 0.41^{b}	74.13 ± 0.63^{c}	81.15 ± 1.18^{a}	80.26 ± 0.43^{a}	75.55 ± 0.16^{bc}
Friction coefficient						
Plywood	0.48 ± 0.01^{d}	0.56 ± 0.04^{ab}	0.53 ± 0.02^{c}	0.54 ± 0.00^{bc}	0.54 ± 0.02^{bc}	0.57 ± 0.00^{a}
Glass	0.39 ± 0.02^{d}	0.47 ± 0.00^{b}	0.40 ± 0.01^{d}	0.43 ± 0.00^{c}	0.47 ± 0.01^{b}	0.50 ± 0.01^{a}
MDF	0.43 ± 0.04^{c}	0.47 ± 0.02^{b}	0.50 ± 0.01^{a}	0.42 ± 0.02^{c}	0.46 ± 0.03^{b}	0.52 ± 0.02^{a}
Rubber	0.46 ± 0.01^{bc}	0.48 ± 0.00^{ab}	0.50 ± 0.03^{a}	0.45 ± 0.03^{c}	0.45 ± 0.03^{c}	0.48 ± 0.02^{ab}
Galvanized steel	0.32 ± 0.02^{b}	0.35 ± 0.01^{b}	0.43 ± 0.02^{a}	0.35 ± 0.02^{b}	0.40 ± 0.00^{a}	0.42 ± 0.01^{a}
Mechanical						
TFB(N)	1271.83 ± 7.61^{c}	1299.16 ± 12.42^{b}	1296.43 ± 11.18^{b}	1225.16 ± 9.00^{d}	1126.32 ± 8.36^{d}	1411.74 ± 10.09^{a}
Deformation (mm)	13.63 ± 0.20^{ab}	12.74 ± 0.10^{b}	14.27 ± 0.50^{ca}	13.38 ± 0.22^{ab}	14.01 ± 0.31^{cde}	14.64 ± 0.16^{a}
LFB (N)	588.66 ± 3.32^{f}	692.10 ± 4.41^{e}	857.34 ± 7.63^{b}	799.81 ± 6.01^{c}	744.08 ± 4.02^{d}	869.37 ± 3.19^{a}
Deformation	15.24 ± 0.05^{a}	13.39 ± 0.08^{b}	16.21 ± 0.26^{a}	12.94 ± 0.34^{bc}	11.56 ± 0.15^{c}	10.39 ± 0.21^{d}

Mean values in the same row which is not followed by the same letter are significantly different ($p<0.05$). DG, Dimensional and gravimetric properties; BD, bulk density; TD, True density; AR, aspect ratio; MDF, medium fibre board; TFB, transverse force at break; LFB, longitudinal force at break.

Table 4a. Volatiles organic compounds of aerial yam bulbils.

Organic compounds (%)	Tob2857 6	 7	 8	Tob3059 6	 7	 8 months
Alkanal/Aldehyde						
Acetaldehyde	12.53± 0.78^{a}	12.18± 0.88^{a}	11.96± 0.91^{a}	8.74± 0.90^{c}	10.69± 0.61^{b}	9.56± 0.48^{bc}
2-Propenal	2.81± 0.51^{a}	2.85± 0.80^{a}	2.95± 0.50^{a}	3.84± 0.10^{a}	3.15± 0.23^{ac}	2.62± 0.40^{ac}
Propanal	9.84± 0.31^{b}	9.93± 0.68^{b}	11.75± 0.47^{b}	16.36± 0.18^{a}	14.91± 0.14^{a}	16.60± 0.21^{a}
2-Methylpropanal	0.79± 0.15^{a}	0.73± 0.10^{a}	0.65± 0.02^{ab}	0.69± 0.11^{a}	0.87± 0.07^{a}	0.72± 0.13^{a}
2-Butenal	4.34± 0.18^{a}	3.85± 0.12^{ab}	3.91± 0.21^{ab}	4.12± 0.18^{a}	4.39± 0.04^{a}	3.92± 0.01^{ab}
Butanal	10.48± 0.24^{a}	11.26± 1.13^{a}	12.00± 0.90^{a}	8.90± 0.24^{b}	9.50± 0.40^{ab}	9.39± 0.31^{ab}
3-Methylbutanal	9.16± 0.32^{bc}	9.37± 0.71^{bc}	9.05± 0.30^{bc}	8.45± 0.46^{b}	7.81± 0.37^{b}	8.16± 0.51^{b}
Pentanal	4.71± 0.16^{b}	4.40± 0.28^{b}	3.82± 0.35^{b}	4.92± 0.16^{a}	4.19± 0.34^{a}	4.26± 0.40^{a}
Heptanal	4.44± 0.14^{a}	4.12± 0.18^{a}	3.85± 0.15^{a}	4.14± 0.20^{a}	4.79± 0.21^{a}	4.04± 0.28^{a}
Furfural	5.14± 0.26^{a}	4.96± 0.25^{a}	3.96± 0.24^{ab}	4.63± 0.25^{a}	4.60± 0.17^{a}	4.60± 0.20^{a}
Alkanol						
Ethanol	9.56± 0.37^{a}	8.49± 0.60^{a}	9.31± 0.58^{a}	8.37± 0.31^{a}	8.65± 0.28^{a}	8.52± 0.08^{a}
Propanol	6.47± 0.16^{b}	7.72± 0.34^{b}	7.12± 0.26^{b}	6.37± 0.23^{a}	5.94± 0.21^{a}	5.78± 0.30^{a}
2-Methylpropanol	1.74± 0.07^{ab}	2.43± 0.51^{a}	2.18± 0.47^{ab}	1.63± 0.06^{a}	1.67± 0.31^{a}	1.56± 0.16^{a}
3-Methylbutanol	4.22± 0.31^{ab}	4.15± 0.17^{ab}	4.10± 0.14^{ab}	3.40± 0.19^{a}	3.41± 0.24^{a}	3.73± 0.36^{a}
2-Methylbutanol	1.52± 0.13^{a}	1.54± 0.03^{a}	1.56± 0.08^{a}	1.36± 0.45^{a}	1.31± 0.35^{a}	1.38± 0.28^{a}
Heptanol	0.05± 0.00^{a}	0.05± 0.00^{a}	0.07± 0.00^{a}	0.06± 0.00^{a}	0.06± 0.00^{a}	0.04± 0.00^{a}
Carboxylic acid						
Acetic acid (ethanoic acid)	1.94± 0.03^{b}	1.98± 0.14^{b}	1.95± 0.09^{b}	1.78± 0.11^{c}	3.23± 0.13^{ab}	3.99± 0.10^{a}
Caproic acid (fat)	0.06± 0.00^{ab}	0.04± 0.00^{ab}	0.04± 0.00^{ab}	0.05± 0.00^{ab}	0.06± 0.00^{ab}	0.06± 0.00^{ab}
Caprylic acid	0.20± 0.05^{c}	0.19± 0.03^{c}	0.18± 0.02^{c}	0.26± 0.04^{c}	0.24± 0.12^{c}	0.21± 0.04^{c}

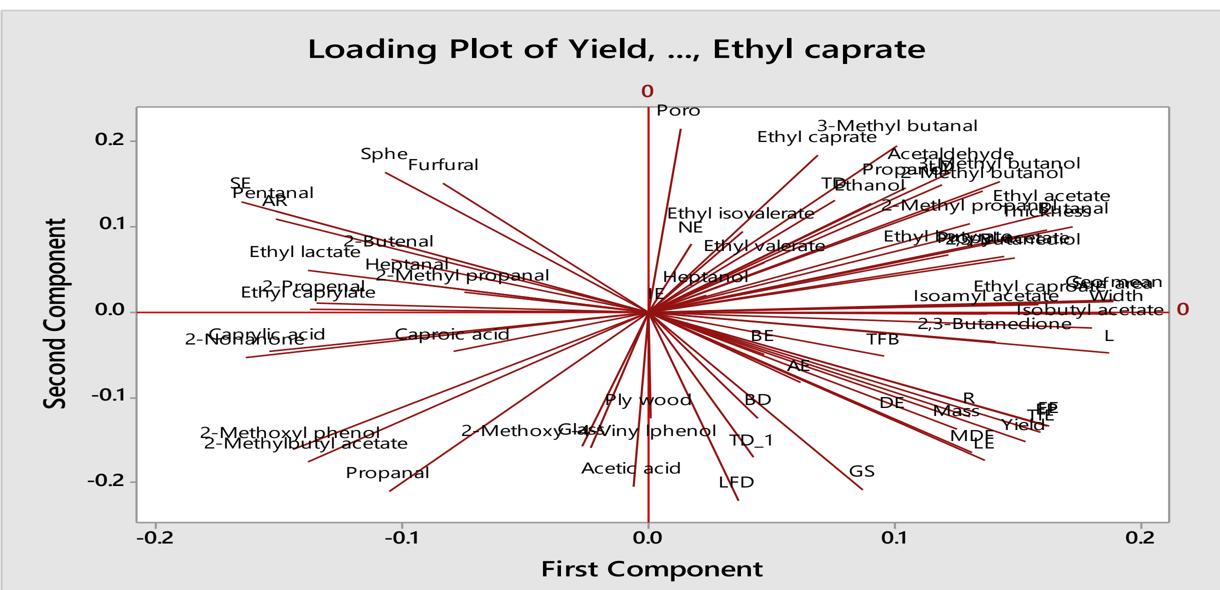

Figure .1. Biplot of the first two principal components of aerial yam bulbils describing the variation of on-farm energy, yield, selected engineering properties and volatile organic compounds at different harvesting period. DG, Dimensional and gravimetric properties; BD, bulk density; TD, True density; AR, aspect ratio; MDF, medium fibre board; GS, Galvanized steel; TFB, transverse force at break; LFB, longitudinal force at break.

Table 4b. Volatiles organic compounds of aerial yam bulbils (cont.)

Organic compounds (%)	Tob2857 6	 7	 8	Tob3059 6	 7	 8 months
Alkanone/Ketone						
2,3-Butanedione	0.03 ± 0.00^{b}	0.03 ± 0.00^{b}	0.05 ± 0.00^{ab}	0.01 ± 0.00^{a}	0.04 ± 0.00^{a}	0.03 ± 0.00^{a}
2,3-Butanediol	0.05 ± 0.00^{a}	0.04 ± 0.00^{a}	0.06 ± 0.00^{a}	0.04 ± 0.00^{a}	0.03 ± 0.00^{a}	0.04 ± 0.00^{a}
2-Nonanone	0.39 ± 0.07^{b}	0.30 ± 0.08^{b}	0.21 ± 0.08^{b}	1.11 ± 0.10^{a}	0.50 ± 0.12^{a}	0.57 ± 0.09^{a}
Phenol						
2-Methoxylphenol	1.52 ± 0.05^{b}	1.41 ± 0.21^{b}	1.34 ± 0.07^{b}	2.09 ± 0.10^{a}	2.11 ± 0.07^{a}	2.09 ± 0.10^{a}
2-Methoxy-4-vinylphenol	0.01 ± 0.00^{b}	0.01 ± 0.00^{b}	0.02 ± 0.00^{b}	0.02 ± 0.00^{b}	0.02 ± 0.00^{b}	0.02 ± 0.00^{b}
Ester						
Ethyl acetate	3.31 ± 0.15^{ab}	3.36 ± 0.24^{a}	3.34 ± 0.17^{ab}	2.46 ± 0.30^{a}	2.71 ± 0.21^{a}	2.96 ± 0.36^{a}
Propyl acetate	0.46 ± 0.07^{bc}	0.41 ± 0.19^{c}	0.46 ± 0.11^{bc}	0.29 ± 0.26^{b}	0.37 ± 0.20^{b}	0.41 ± 0.08^{b}
Isobutyl acetate	0.01 ± 0.00^{a}	0.01 ± 0.00^{a}	0.02 ± 0.00^{a}	0.00 ± 0.00	0.01 ± 0.00^{c}	0.01 ± 0.00^{c}
Ethyl butyrate	0.03 ± 0.00^{a}	0.02 ± 0.00^{a}	0.03 ± 0.00^{a}	0.01 ± 0.00^{b}	0.02 ± 0.00^{ab}	0.02 ± 0.00^{ab}
Ethyl lactate	2.05 ± 0.16^{c}	2.01 ± 0.13^{c}	1.93 ± 0.11^{c}	2.18 ± 0.20^{a}	1.96 ± 0.20^{a}	2.02 ± 0.14^{a}
Ethyl isovalerate	1.29 ± 0.14^{b}	1.18 ± 0.08^{b}	1.19 ± 0.12^{b}	1.13 ± 0.10^{b}	1.20 ± 0.13^{b}	1.19 ± 0.16^{b}
Isoamyl acetate	0.02 ± 0.00^{a}	0.02 ± 0.00^{a}	0.02 ± 0.00^{a}	0.01 ± 0.00^{b}	0.02 ± 0.00^{b}	0.02 ± 0.00^{b}
2-Methylbutyl acetate	0.30 ± 0.0^{d}	0.25 ± 0.05^{e}	0.23 ± 0.03^{e}	0.98 ± 0.12^{c}	1.07 ± 0.10^{c}	0.95 ± 0.12^{c}
Ethyl valerate	0.50 ± 0.12^{bc}	0.61 ± 0.13^{ab}	0.57 ± 0.14^{ab}	0.54 ± 0.20^{c}	0.51 ± 0.15^{c}	0.48 ± 0.14^{c}
Ethyl caproate	0.01 ± 0.00^{c}	0.03 ± 0.00^{bc}	0.06 ± 0.00^{a}	0.01 ± 0.00^{b}	0.01 ± 0.00^{b}	0.01 ± 0.00^{b}
Ethyl caprylate	0.01 ± 0.00^{b}	0.01 ± 0.00^{b}	0.01 ± 0.00^{b}	0.02 ± 0.00^{ab}	0.01 ± 0.00^{b}	0.01 ± 0.00^{b}
Ethyl caprate	0.05 ± 0.00^{b}	0.06 ± 0.00^{b}	0.05 ± 0.00^{b}	0.04 ± 0.00^{b}	0.03 ± 0.00^{b}	0.03 ± 0.00^{b}

Mean values in the same row which is not followed by the same letter are significantly different ($p<0.05$).

Delayed before harvest. Thus, the relationship between polar and equatorial diameters at all harvesting period provided a basis for bulbils characterization as ellipsoid oblate. This characterization is in agreement with the findings, of Milanez et al. (2016) on buriti crop. The sphericity of bulbils ranged from 0.69 to 0.75. The highest sphericity was determined for Tob2857 (6 months) while Tob3059 (8 months) had the lowest. The sphericity, which could be used to distinguish one crop from another, plays a major role in cleaning and bulk behaviour (Akinoso & Lasisi, 2013). Although the values obtained showed a decreased as the harvest time is delayed, nonetheless they were within the range (0.32-1.00) reported for agricultural crops (Raji & Ahemen, 2011). Generally, nearest value of sphericity to 1 (sphere) is an indication of smoothness in the design of hoppers, chutes and conveyors facilities (Aregbesola *et al*., 2016). The mass of yam bulbils varieties in harvest time varied from 126.67 to 236.11 g. Mass of Tob2857 and Tob3059 varieties with delayed harvesting were 236.11 and 227.36 g (7 months) 230.34 and 228.79 g (8 months), respectively. However, the values observed were higher than 108.03 and 97.55 g reported for cocoyam and tacca tuber, respectively (Balami et al., 2012; Raji & Ahemen, 2011). The result of geometric mean and surface area ranged from 56.88 to 71.78 mm and 101.66 to 161.85 cm^3, respectively. An increase was observed in the geometric means and surface area of the bulbils with delayed harvesting of the bulbils. The geometric mean diameter at varying harvesting period were higher than the values (36.92 46.47 mm) reported for two potato varieties of India (Singh et al., 2006). These size properties are necessary in the design of processing and handling equipment. The highest bulk and true densities, were observed for Tob3059 (0.62 g/cm^3) and Tob2857 (1.14 g/cm^3), respectively. Bulk densities of delayed harvest (7 and 8 months) were higher than bulbils harvested at 6 months by 17.64 and 11.76% (for Tob2857) and 16.98 and 9.43% (for Tob3059), respectively. Also, the true density of the bulbils increased when the harvest period was delayed to 7 months for Tob2857 (11.4%) and Tob3059 (2.80%), respectively. The range of values (1.07-1.27 g/cm^3) observed for true density is greater than the density of water which implies suitability of bulbils in separation and cleaning operation involving soaking. Porosity of yam bulbils varied from 43.64 (Tob3059) to 55.26 (Tob2857). The porosity of delayed harvest for Tob2857 and Tob3059 bulbils were 52.76 and 43.64% at 7; 44.65 and 47.27% at 8 months, respectively. Porosity indicates the volume fraction of void space or air space inside a material and volume determination is relative to the amount of internal (or closed) or external (or open) pores present in the food structure (Akinoso & Lasisi, 2013). The porosities results obtained are very useful for evaluating bulbils weight in standard containers and aeration during storage.

Statistic coefficient of friction and mechanical properties

The static coefficient of friction (SCF) for the fresh yam bulbils on plywood, glass, medium fibre board (MDF), rubber and galvanized steel ranged from 0.48 to 0.57; 0.39 to 0.50; 0.42 to 0.52; 0.46 to 0.50 and 0.32 to 0.43, respectively (Table 3). In general as the harvest is delayed, the coefficient of friction increased, and the highest values of static friction coefficient on plywood (0.57), glass (0.50) and MDF (0.52) were found for Tob3059 harvested at 8 months. Moreover, the smallest value (0.32) on all the five surfaces in this study was observed on galvanized steel (for Tob2857 harvested at 6 months). This is in agreement with the findings of Hacıseferogullari et al. (2007) who reported lowest SCF value (0.18) for apricot fruits on galvanized steel. Accurate value of SCF enables the engineers to design appropriate handling, metering and processing equipment that could minimize physical deterioration of the agricultural crops (Raji & Ahemen, 2011). The variation has also been observed to provide a guide for choosing maximum angle of inclination in the design and installation of conveyors (Balami *et al*., 2012).

Transverse and longitudinal compressive force at break varied between 1125.16 and 1411.74 N, 588.66 and 869.37 N, respectively (Table 3). Compressive force varied with the orientations (transverse greater than longitudinal) at all harvesting, and the value increased with delayed in harvesting of DB. The implication of lower value recorded for longitudinal orientation is that yam bulbils are stronger along equatorial than polar diameters and lower load will be required to cause rupture of bulbils positioned at the lowest layer during storage and transportation compared to the higher load that could be sustained by yam bulbils along the transverse orientation. Also, the transverse force value increased with delayed harvesting of Tob2857 and Tob3059 yam bulbils between 6 and 8 months and this may be due to reduction in moisture content from 71.76 to 68.39% and 77.20 to 73.53%, respectively. This corroborates the earlier findings who associated variation in mechanical properties of different agricultural materials to moisture differences, orientation and physiology of the crops (Akinoso & Lasisi, 2013; Bentini et al., 2006),. An increase was observed in deformation values (12.74 - 16.21 mm) of yam bulbils with delayed harvest, similar to compressive force at fracture. However, deformation of Tob3059 showed significant ($p<0.05$) reduction (12.94 - 10.39 mm) with harvesting period on longitudinal orientation. The higher resistance of Tob3059 to deformation on longitudinal orientation could be due to the cell wall rigidity. Brunnschweiler (2004) suggested that the reduction of deformation values for yam varieties compressed on transverse and longitudinal orientations were attributed to lignification or hardening of yam parenchyma. Therefore, effort must be made to prevent any alteration on the structure of fresh bulbils during postharvest handling so as to prevent irreversible physiological damages to the bulbils.

Effect of harvesting period on volatiles organic compounds

Alkanals, alkanols, carboxylic acid, alkanone, phenol and esters were the active volatiles compounds identified from the bulbils of aerial yam cultivars (Table 4a-b). Thirty-six components were identified in bulbils which were quantitatively different between cultivars. Esters had the highest occurrence with fourteen different compounds identified from yam bulbils at harvest. Also, the derivatives of acetate were abundant as the key odour-active compounds. The emission of other identified esters remained relatively low and their values did not follow even trend throughout the harvesting period. This could be attributed to crop genetics. The result was consistent with the findings of Zhu et al. (2008) who observed relatively low and insignificant difference in the value of esters observed from granny smith variety of apple over the 8-week sampling period. Defilippi et al. (2009) attributed such odour-active pattern to an event that was regulated by plant hormone. Fatty acids were identified in the bulbils volatile fraction being monomers of different organic compounds and could influence the aroma development. This is in agreement with the work of Zhu et al. (2008) that fatty acids and triglycerides have their peculiar aroma that may varied with the maturity of agricultural products. The dominant phenol compound was 2-methoxylphenol and varied with the cultivars. Generally, compounds of phenol are known to be potent antimicrobial and are utilized in crops as defensive mechanism (Soetan & Oyewole, 2009). The findings on volatile organic compounds revealed that, yam bulbils like other carbohydrates rich tubers do not emit higher volatile flavor compounds at harvest due to the stable thick, compact, well structure cuticle and lack of carotenoids compounds in the bulbils. These findings suggest that raw aerial yam bulbils have very subtle aromas, since flavor compounds are not necessary for attraction of pollinating agents during DB development. This corroborates the findings of Stegli ´nsk et al. (2022) who reported low level (11.98% of total variance) of odour-active compounds for potato.

Principal component analysis

Principal component analysis (PCA) was used to explain the relationship among on-farm energy, yield, selected engineering and volatile organic compounds of the yam bulbils at different harvesting period. The result of PCA showed that sixty- seven principal components (PC1-PC67) explained the variance among the data, and the first, second and third PCs elucidated 39.5, 22.4 and 10.8%, respectively of the total variation (Fig.1). The length of space between the locations of any two harvesting period on the score plot is directly proportional to their similarity or difference (Romano et al., 2018). The distribution of bulbils harvesting period along PC1 reflected that width, geometric mean, surface area, length, and isobutyl acetate for 8 months harvesting period of Tob2857 and Tob3059 had positive loading. Conversely, harvesting period of Tob3059 and Tob2857 at 6 months which had negative scores for PC1 had higher specific energy, 2-nonanone, caprylic acid, pentanal and aspect ratio. For bulbils harvesting period distribution along PC2; longitudinal force at break, coefficient of friction on galvanized steel, propanal, acetic acid and industrial energy while porosity, 3-methyl butanal, ethyl caprate, acetaldehyde and sphericity had positive loadings. The properties of the two cultivars of aerial yam showed similar patterns, which is an indication of strong relationship between the evaluated attributes. The PCA was sufficient to elucidate the relationship of on-farm energy and selected post-harvest properties on the harvesting period of aerial yam bulbils. However, the harvesting period (8 months) with higher length, geometric mean and yield were related to lower specific energy while, those (6 months) with lower longitudinal force at break and statistic coefficient of friction on galvanized steel were related to higher VOC such as 2-

nonanone, ethyl lactate and caprylic acid. Similar study on potato in which
fourth component accounted for 11.98% of the total variance and was related mainly to β-cedrene, 1-octen-3-ol, 2-nonen-1-ol, benzothiazole, and isobutylbenzene was reported (Stegli ´nsk et al., 2022). Thus, the PCA results proved that, there were significant relationship between the on-farm energy requirement and post-harvest properties of aerial yam bulbils at different harvesting period.

Conclusions

The outcome of the research provided comprehensive elucidation of the harvesting period of aerial yam bulbils in relations to on-farm energy, yield, selected engineering properties and volatile organic compounds of the bulbils. The total energy input and yield of DB increases with increase in harvesting period. Aerial yam bulbils of Tob3059 harvested at the end of 6 months had lowest energy productivity while 8 months of Tob2857 had the highest. The relationship between polar and equatorial diameters at all harvesting period characterized the DB as ellipsoid oblate. Yam bulbils are stronger along equatorial than polar diameters and lower load will be required to cause rupture of bulbils positioned at the lowest layer during handling. The yam bulbils have very subtle aromas, since flavor compounds are not necessary for attraction of pollinating agents during yam bulbils development. The PCA output displayed a significant relationship between on-farm energy and selected post-harvest properties on the harvesting period of aerial yam bulbils. Generally, eight months harvesting period with higher length, geometric mean and yield were related to lower specific energy

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