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Research Article

Physical parameters of some varieties of yam tubers relevant in the design of mechanical yam harvester

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Abstract: Yam harvesting had been identified as one of the crucial and labour-intensive operations in producing the root crop. It involves standing, bending, squatting, and even sitting on the ground sometimes, depending on the size of ridges and depth of penetration of harvested tubers. During the period of harvesting farmers still use simple tools such as hoes, cutlasses and other simple farm tools. An efficient yam harvester is therefore not only necessary but also important to regenerate the production of yam to meet up with ever-increasing demand for the yam exportation. Thus, the knowledge of the physical properties of yams becomes imperative in the design of suitable and appropriate yam harvesters. The properties investigated were length, diameter and weight of different yam species and the height of ridges, space between the ridges and space between the rows. The results revealed that the range of mean values of: (17.34 – 48.66 cm), (7.53 – 14.23 cm) and (9.7 – 27.6 N) for the length, diameter and weight of yam species, respectively, will be useful in the design of space between the blades and adjustment of blades while that of the length of the yam tuber will be useful in the design of depth of penetration and adjustment of the digging device. While the range of mean values of 30.0 – 85.1 cm, 108.9 – 216.0 cm and 106.0 – 195.6 cm for the height of ridges, space between ridges and space between the rows, respectively, this will be useful in the design of spacing between each set of the blade to accommodate two ridges at once.

Keywords: Yam tuber; engineering properties; yam harvester; ridges; shape/size of yam

1. Introduction

Yam (*Dioscorea spp*.) is a prevalent crop in many parts of the world. They are perennial herbaceous vines and are cultivated in places such as Africa, Asia, and Latin America (IITA, 2009). Yams are starchy staples in the form of sizably voluminous tubers engendered by annual and perennial vines grown in Africa, the Americas, the Caribbean, the South Pacific, and Asia. There are hundreds of wild and domesticated *Dioscorea* species. White Guinea yam, (*D. rotundata*) is the most paramount species, especially in the West and Central Africa zone. It is indigenous to West Africa, as is the Yellow yam (*D. cayenensis*), water yam, (*D. alata*), the second most cultivated species, originated from Asia and is the most widely distributed species in the world (IITA, 2009).

According to the Aliment Information Network in 2008, it was estimated that the world yam production in 1993 was at 28.1 million tons, in which 96% of this estimate emanated from the West Africa tropical regions and 71% from Nigeria (Uchenna et al*.,* 2015). This figure was later reviewed in 1998, accounting for about 72.4% of the total world production of 29.6 million tons. Also, according to the Federal Office of Statistics, Nigeria is the world's major producer of yams; water yam (*Dioscorea alata*) and the yellow yam (*Dioscorea rotundata*) as her most cultivated species of yam (Uchenna et al*.,* 2015). In addition, Odior and Oyawale (2012) reported that yam had remained one of the most highly regarded food

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produced in West Africa and categorically Nigeria as virtually all her ethnic groups feed on it; hence its close integration into the socio-cultural, economic and religious aspect of life such as marriage where some tubers of yam are presented to the bride family in accordance with the customs of the people. Also, there is a new yam festival which marks the harvest and eating of the newly harvested yams and is also used as sacrificial and appreciation items (Odior & Oyawale, 2012).

In many West African countries, mature yams are harvested at the peak of the rainy season or early part of the dry season, which coincides with the terminus of vegetative magnification. Yams for long storage, high marketing value, and seedling are conventionally harvested between December and early January in many parts of Southeastern Nigeria when the crop has procured maximum magnification and maturity. During this period, the soil is generally hard and harvesting becomes more stressful (Opara, 2003). Table 1 shows the periods of planting to maturity and yield for different yams species. Harvesting has been identified as one of the crucial and labour-intensive operations in the production of yam. It involves standing, bending, squatting, and even sitting on the ground sometimes, depending on the size of ridges, tuber sizes, or the depth of penetration of harvested tubers (Opara, 2003). Bosrotsi (2017) reported that physical damage during harvesting operations can be the primary cause of postharvest losses in roots and tubers. Care must be taken to avoid damage to the tuber because damaged tubers do not store well and spoil rapidly.

However, the use of existing implements for yam harvesting is customarily associated with high tuber damage, leading to substantial levels of post-harvest losses. According to Bosrotsi (2017), post-harvest losses for root and tuber crops can be as high as 40% of total production. Over the years, increases in yam production have been achieved mainly due to more or increasing in the area under cultivation, development, and relinquish of higher-yielding varieties through scientific research and adoption of some amended methods of cultivation (Ennin et al., 2009; Bergh et al., 2012).

The harvesting involves digging around the tuber to loosen it from the soil, lifting it, and cutting from the vine with the corm affixed to the tuber. Yams can be harvested once (single harvesting) or twice (double harvesting) during the season; the first harvest can be referred to as topping, beheading, or milking. In single harvesting, each plant is harvested once, which occurs at the cessation of the season when the crop is matured (Uchenna et al., 2015). Some farmers were engaged in mixed farming by the planting of maize or guinea corn on the same farm with the yam, although both maize and guinea corn were usually harvested before yam matured.

Table 1: Period of Planting to Maturity and Yield for Different Yam Species

S/N	Species (Common Name)	Period from planting to Maturity	Yield and Size of Tubers
1.	*D. alata* (Water yam)	220-300 days	20-25 t/ha 1-3 tubers per plant 5 – 10 kg per tuber
2.	*D. Bulbifera* (Potato yam)	140-180 days; 90-120 days	Aerial: 2-15 t/ha ; 3-5 t/ha Underground: 2-8 t/ha
3.	*D. Cayenensis* (Yellow yam)	280-350 days	30 t./ha 2 kg per tuber (mean) 7-10 kg per tuber (highest)
4	*D. Dumentorum* (Bitter yam)	240-300 days	--
5	*D. esculenta* (Lesser yam)	200-300 days	7-20 t/ha 25-35 t/ha (exceptional) 5-20 tubers per plant
6	*D. Opposita* (Chinese yam)	24 weeks	4-6 t/ha
7	*D. rotundata* (White yam)	200-330 days	16-20 t/ha
8	*D. trifida* (Cush-cush yam)	280-330 days	15-20 t/ha

Source: (Opara, 1999).

After harvesting the guinea corn, the residues (stem) were used to staking yam, which can impede the smooth operation of the machine. For this type of farming practice, such crop residue (stem) should be first removed by hand (Uchenna et al., 2015).

Despite all the various challenges, there is a need to develop an improved root crop harvester. The lack of suitable and appropriate mechanical harvester for yams tubers is due to a number of numerous reasons such as the geometry of tubers in the soil at maturity, soil conditions, difficulties associated with harvesting, high manpower requirement, lack of existing valuable data, and little or no knowledge of engineering properties of yam tubers relevant to the development of yam harvester. Therefore, the objective of this study is to evaluate some properties of

yam tubers relevant in the design of tractor-mounted yam harvester, and investigate some engineering pertinent properties in the design of tractor mounted yam harvester.

2. Materials and method

2.1. Study areas

The study areas comprise of Ogbomoso (8° 7' 00" N, 4° 14' 60.00" E), Osogbo (7° 46' 15.74" N, 4° 33' 25.13" E) and Iwo (7° 38' 6.97" N, 4° 10' 53.62" E) in South West, Nigeria. Yam tubers available in Adekunle Farm Ltd in Osogbo and Adeoye Farm in Iwo, Osun State, and Arada market in Ogbomoso South Local Government Area of Oyo State were accessed based on different species. In addition, some other farms were also visited to obtain useful information on land preparation and farming practices for yam cultivation. The major occupation of the study area are farming (crops and livestock production).

2.2. Sampling procedure and sample size

A total number of ten yam tubers, each from fifteen (15) different species (Table 2) that were selected from the study area using simple random sampling techniques. Different sizes and shapes of the yams were considered in the selection, and farmers were contacted and their farms were also visited.

2.3. Instrument for data collection

Data were obtained by direct contact with the yam farmers and yam marketers in major available markets. Fifteen different yam species were selected at random, and measurements were taken (Table 2). The data obtained were recorded. The following devices (tape rule, rope, ruler, stick, and weighing balance) were used for measuring the size, shape and width of the yams. The data collected include; methods used for harvesting the yam, time of harvesting, the growth parten of yam in the soil, mechanical damage/bruises which yam tuber may sustain during harvesting, size and shape of the yam tuber and size of heap/ridges used in planting yam, which is the information required for the design of the mechanical yam harvester.

2.4.Procedure for data collection

2.4.1. Size of the yam tuber

Different yam species were selected at random, and ten measurements were taken for each species of selected yams using rope to measure the length and diameters as reported by Bosrotsi et al. (2017). This was done because of the irregular shape possess by the yam tubers, and the length of the rope was placed on the ruler to obtain the actual length of the tuber and size (diameter). The shape of the yam tuber was classified into minor, intermediate and major diameter, in which major diameter was considered for the study. Also, a weighing scale was used to measure the mass of the selected yam tuber. The data collected were recorded. Figures 1 and 2 show the procedure for measuring the principal sizes of the chosen yam tubers for different species.

The diameter of the yam tuber was calculated as follows:

$$C = \pi D \tag{1}$$

where, C = Circumference (cm) and D = Diameter, cm

2.4.2. Lift force

Force applied during harvesting depends on the time of harvesting, size of the tuber, depth of tuber penetration, and stability of the soil, either loose or compacted. The force required to pull the yam tuber from the soil will be greater than the weight of the tuber neglecting the effect of the surrounding soil, the force needed to pull out the tuber can be obtained from the relationship below as given by Khurmi and Gupta (2006).

$$F = m\,g \tag{2}$$

where; F is lift force (N), m is the mass of the tuber in kg and g is the acceleration due to gravity (m/s^2).

The power required is expressed in equation 3.

$$Power\ \mathrm{Re}quired = \frac{FD}{t} \tag{3}$$

where; F is lift force (N), D is the maximum depth which digging device will reach to lift the tuber, which is the depth of penetration of the yam tuber plus clearance to avoid bruise of the yam in (m) and t is the time taken in (s).

2.4.3. Size of the ridge/mound

Farms were visited to obtain useful information about the land preparation (ridges) and type of farming practices engaged by the farmer, as reported by Nwachukwu and Simonyan (2015). In each farm visited, rows were selected at random, and the height, space between the ridges in the selected rows was measured and also space between rows was measured. The distance between ridges was measured from the center of one ridge to the center of another ridge with tape rule and recorded. The

Table 2: Measured dimensions of yam tuber species collected: Length (L), Diameter (D), and Weight (W) of yam tubers.

Name	S/N	1	2	3	4	5	**6**	**7**	**8**	**9**	**10**	**Mean**	**Standard Deviation**
Amula (Dioscorea rotundata)	L(cm)	44	32.5	30	35	46.5	32.5	28.5	44.2	29	33.5	33.57	6.71
	D (cm)	11.0	8.8	9.1	10.7	12.7	9.1	9.3	13.3	8.9	12.5	10.81	1.54
	W (N)	30.4	18.2	18.7	20.0	35.6	15.0	16.5	29.7	13.1	18.2	21.54	6.82
Ehuru (Dioscorea rotundataa)	L(cm)	66	52.5	48	34	25.3	50	29	27	35.1	40.2	40.71	12.17
	D (cm)	17.5	13.1	10.7	9.2	8.3	19.6	9.4	8.7	8.9	9.6	11.50	8.34
	W (N)	39.0	29.7	25.1	15.9	12.2	29.4	14.0	12.8	15.1	17.0	21.0	8.63
Ewura* (white yam) Red type *(Dioscorea alata)	L(cm)	26	23	32.5	42	54	46.5	33.4	32.2	26.2	31.7	34.75	3.55
	D (cm)	12.1	10.2	12.6	13.5	14.6	14.8	13.0	11.4	12.4	11.9	12.65	2.36
	W (N)	15.7	10.2	19.3	29.3	37.4	32.7	20.0	20.2	16.3	19.6	22.1	6.06
Ewura* (white yam) white type *(Dioscorea alata)	L(cm)	36	31.5	32.5	26	30	31.2	27.8	38	33.5	28.0	31.45	5.14
	D (cm)	14.8	16.9	10.5	9.1	10.1	11.2	11.4	13.1	14.2	15.2	12.6	1.27
	W (N)	25.4	19.4	20.4	12.8	18.7	19.6	17.3	34.5	29.5	17.7	21.6	4.22
Ookun (Dioscorea rotundata)	L(cm)	26.3	28.2	25.5	38.5	30.6	32.2	34.0	40.1	33.0	40.1	32.85	5.11
	D (cm)	10.7	10.2	8.7	12.8	10.0	11.1	9.0	10.2	9.3	12.1	10.4	1.25
	W (N)	18.6	19.1	11.8	20.6	19.4	19.4	19.8	21.9	20.2	21.9	21.6	2.23
Gbongi (Dioscorea rotundata)	L(cm)	34.4	27.4	39.2	25.2	44.1	40.2	46.5	22.7	30.1	53.3	36.31	9.46
	D (cm)	12.2	10.9	13.1	9.7	13.1	15.3	17.1	11.1	14.2	16.9	13.36	2.35
	W (N)	21.8	16.2	21.9	12.9	22.7	22.8	25.1	11.8	16.5	26.5	19.8	4.76
Dagidagi (Dioscorea rotundata	L(cm)	56.1	61.0	40.1	64.2	50.2	42.1	34.0	38.2	48.3	52.4	48.66	9.26
	D (cm)	18.2	20.3	12.6	22.5	17.5	14.1	11.2	11.8	12.1	13.8	14.23	3.92
	W (N)	29.5	38.4	24.9	39.9	27.1	25.1	17.0	19.4	25.7	28.5	27.6	6.92
Aroo (Dioscorea rotundata)	L(cm)	24.8	24.6	20.0	21.1	50.2	22.1	19.7	23.1	20.7	21.2	17.34	11.31
	D (cm)	12.6	13.7	12.8	12.1	11.8	12.0	10.9	11.1	9.9	11.6	11.86	1.02
	W (N)	15.7	15.9	7.0	8.9	20.6	9.9	5.9	10.2	3.9	6.0	10.4	5.08
Oolo (Dioscorea rotundata)	L(cm)	42.5	40.3	41.2	44.0	45.6	47.2	46.1	39.9	46.3	43.4	43.65	2.31
	D (cm)	11.8	11.2	11.7	10.2	10.7	11.5	11.9	10.3	10.9	10.5	11.07	0.62
	W (N)	23.1	21.9	22.6	23.6	24.1	24.4	24.0	21.1	25.1	22.7	23.3	1.15
Ifegi (Dioscoarea rotundata)	L(cm)	32.3	47.6	40.1	36.3	43.3	42.1	33.6	45.1	40.0	39.2	28.06	12.03
	D (cm)	8.8	6.7	8.9	7.3	6.8	7.2	6.3	7.9	8.6	6.8	7.53	0.88
	W (N)	7.4	22.8	10.6	7.6	15.2	15.1	7.8	19.4	14.9	10.4	13.1	4.98
Lasinrin (Dioscorea cayenesis)	L(cm)	39.2	47.3	40.1	48.1	24.1	23.2	30.5	23.2	30.1	33.6	33.94	8.20
	D (cm)	10.2	11.1	8.1	11.6	9.3	7.1	10.9	7.3	8.9	9.3	9.38	1.22
	W (N)	10.8	21.7	11.9	20.4	7.9	9.8	10.9	8.4	1.0	10.5	11.3	5.63
Oodo (Dioscorea rotundata)	L(cm)	22.3	25.6	19.5	18.3	12.6	20.1	26.1	24.2	27.0	20.1	21.58	4.62
	D (cm)	9.8	11.2	10.6	8.9	10.2	12.0	12.9	11.3	13.1	10.8	11.08	1.26
	W (N)	11.1	11.9	10.9	6.6	6.4	9.4	11.3	10.1	11.4	7.7	9.7	1.95
Iganganran (Dioscorea cayenesis)	L(cm)	56.1	61.0	40.1	64.2	50.2	42.1	34.0	38.2	48.3	52.4	48.66	9.26
	D (cm)	18.2	20.3	12.6	22.5	17.5	14.1	11.2	11.8	12.1	13.8	14.23	3.92
	W (N)	10.3	11.4	19.4	22.8	29.6	26.3	22.8	11.9	12.4	11.7	17.9	6.26
Tegunde (Dioscorea rotundata)	L(cm)	24.8	21.7	30.4	26.2	36.1	25.1	45.0	40.3	26.4	31.1	30.71	6.89
	D (cm)	9.6	10.2	10.3	9.9	14.2	12.8	15.5	15.4	11.3	18.7	12.79	2.91
	W (N)	11.4	6.6	13.2	11.8	13.1	11.7	24.0	19.6	11.0	15.3	13.8	4.56
Jigbo (Dioscorea rotundata)	L(cm)	33.1	26.5	29.4	19.2	34.1	30.1	26.1	19.8	30.0	29.3	28.76	4.85
	D (cm)	9.3	11.5	11.1	8.7	13.2	15.3	13.0	11.3	10.1	13.2	11.67	1.66
	W (N)	14.3	12.9	12.9	7.5	14.2	13.0	11.9	9.9	13.1	11.0	12.1	1.99

able 3: Measured Dimensions of the Different Yam Ridges; Height of ridges (H), Distance between ridges (L), and Distance between rows (B).

Farm	Row	1	2	3	4	5	6	7	8	9	10
Farm1	H (cm)	45.2	42.8	46.1	46.8	42.4	46.1	47.9	44.5	42.1	48.4
	L (cm)	129.0	117.8	121.4	127.3	125.6	121.4	122.8	117.5	117.3	125.0
	B (cm)	121.1	125.2	119.4	124.6	128.6	124.4	119.9	128.3	126.4	119.6
Farm 2	H (cm)	34.6	32.5	37.34	35.56	41.1	40.4	30.9	31.7	39.3	33.4
	L (cm)	113.7	113.3	115.1	123.4	112.6	121.2	119.5	109.1	116.0	118.1
	B (cm)	124.1	123.3	122.9	120.8	123.5	120.7	119.0	128.5	124.2	128.6
Farm 3	H (cm)	33.3	33.1	30.5	32.2	31.1	30.0	30.5	34.7	32.5	37.4
	L (cm)	134.3	133.9	116.5	119.1	143.2	117.7	143.9	135.1	125.1	127.0
	B (cm)	118.6	109.3	109.9	113.3	124.5	101.6	121.4	105.5	113.2	112.0
Farm 4	H (cm)	62.4	62.5	65.5	67.7	60.8	68.0	71.3	64.7	69.0	63.3
	L (cm)	183.5	194.4	156.7	188.6	158.9	180.5	161.5	182.7	191.1	179.0
	B (cm)	183.9	177.7	193.4	184.6	135.7	195.6	213.3	194.9	203.8	135.9
Farm 5	H (cm)	55.4	53.3	56.7	61.5	51.1	53.8	52.6	59.9	59.0	57.0
	L (cm)	126.3	115.9	117.7	131.9	116.8	112.4	114.5	120.9	108.9	126.5
	B (cm)	123.7	121.3	122.1	120.9	118.9	124.5	125.7	119.3	112.1	126.2
Farm 6	H (cm)	75.0	72.8	76.9	75.5	72.3	70.6	78.2	78.6	78.0	72.5
	L (cm)	188.0	183.3	154.3	155.5	177.8	141.4	158.9	143.6	142.6	134.1
	B (cm)	144.4	145.5	142.5	146.8	132.0	145.7	141.1	135.4	137.0	135.6
Farm 7	H (cm)	64.6	66.5	66.9	59.1	60.9	61.4	60.0	58.5	60.4	62.5
	L (cm)	136.4	132.1	148.9	132.2	142.5	150.9	160.6	142.0	150.4	139.1
	B (cm)	145.9	145.6	153.4	150.1	162.5	156.7	142.1	164.5	154.5	155.6
Farm 8	H (cm)	45.1	52.6	47.1	45.6	50.8	50.7	46.7	51.9	49.0	52.9
	L (cm)	174.8	193.2	168.8	196.7	185.6	188.9	201.6	212.9	216.0	172.6
	B (cm)	148.0	162.4	166.8	152.9	170.0	150.2	162.5	154.6	184.4	163.1
Farm 9	H (cm)	77.5	73.7	76.6	77.3	81.3	76.7	81.5	72.1	78.5	85.1
	L (cm)	165.0	166.8	177.7	186.4	168.9	177.2	180.0	190.8	170.3	193.4
	B (cm)	166.7	157.4	171.1	162.6	164.5	172.1	180.9	167.2	178.0	163.0
Farm 10	H (cm)	39.3	36.5	37.	46.1	40.9	44.9	41.4	37.2	39.9	44.1
	L(cm)	111.9	120.0	120.1	116.7	111.7	124.2	105.6	109.1	115.6	109.3
	B (cm)	106.1	105.3	108.8	106.9	112.4	120.7	124.0	109.1	108.1	116.4

same procedure was followed for the space between the rows. The height of the ridge/mound was measured with a stick and the stick was then measured with a tape rule. The average height of the ridge in each row selected was calculated and recorded. Figures 3 and 4 show the procedure for measuring the average height, the distance between ridges and distance between rows on the farm, and the weighing of yam tubers, respectively.

3. Results and discussions

The data collected for the yam tuber dimensions showing the length, diameter, and weight of the different yam tubers and the standard deviation is presented in Table 2. The mean length of yam tubers obtained ranged from 17.34 - 48.66 cm, with a maximum length of 66 cm and a minimum length of 12.6 cm measured for *ehuru* and *oodo* species, respectively.

For the diameter of tubers, the mean value ranged from 7.53 – 14.23 cm, with maximum and minimum diameters of 22.5 cm and 6.3 cm recorded in dagidagi/iganganran and ifegi species, respectively. The data obtained from measured yam tuber diameter will be helpful in the design of space between the blades and adjustment of blades while that of the length of the yam tuber will be useful in the design of depth of penetration and adjustment of the digging device. The average weight of the yam tubers for all the species varies from 9.7 to 27.6 N, with the maximum and minimum tuber weight of 39.93 N and 5.9 N recorded in dagidagi and *aroo* species, respectively. The weights of the yam tuber will be helpful in the design of lifting force and power requirements. With these known axial dimensions, the yam tuber can be effectively graded. In the design of machines for processing, the knowledge of different dimensions is very vital to minimize wastage while carrying out harvesting, peeling and other postharvest operations (Balami et al*.,* 2012).

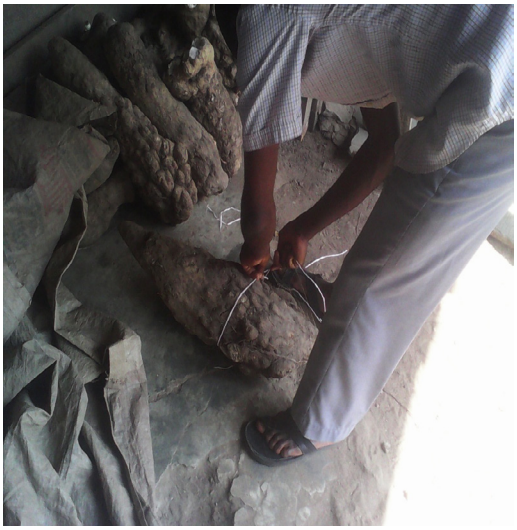

Fig. 1: Measurement of yam diameter

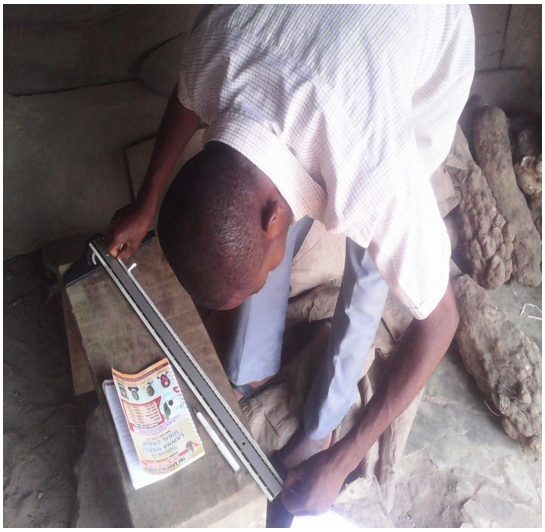

Fig. 2: Transfer of measured diameter to the ruler

Fig. 3: Measurement of height of ridge, distance between ridges and distance between rows on the farm

Fig. 4: Weighing of yam tubers

The data collected for the dimensions of yam ridge preparation from the ten different Farms showing the average height (H) of ridges, the distance between ridges (L) and distance between rows (B) is as presented in Table 3. The height of ridges, the distance between ridges and distance between rows ranged from 30.0 to 85.1 cm; 108.9 to 216.0 cm and 106.0 to 195.6 cm, respectively. The dimensions of the ridge will be helpful in the design of spacing between each set of the blade to accommodate two ridges at once. In addition, the forces of the soil surrounding the tubers were also considered. These properties were required as a first step in designing specific equipment for tuber processing and this will facilitate the design of a mechanical yam harvester. The moisture content of tubers greatly affects the mass of the yam tubers collected. The size and spacing of the ridges will be used in the design of spacing between each set of the blade to accommodate two ridges at once. Kachru et al. (1994) stated that it is essential to investigate the

engineering properties of tubers for the proper design of equipment for handling, conveying and harvesting. Orhevba et al. (2013) reported that the economic importance of crops has greatly increased with the modern technology for production, handling, storage and preservation. Evaluation in quality, distribution and marketing and their uses depends on and demands the knowledge of the engineering properties of crops. Engineering properties also reduce mechanical damage/ bruises to agricultural produce during harvesting, post-harvest handling, processing and storage, and the determination of design parameters for harvesting and postharvest systems (Anazodo, 1983). Thus, the knowledge of the engineering properties of the products is important in the design of agricultural machinery, equipment and facilities (Orhevba et al., 2013). The measured length, width, diameter and weight may be useful in estimating the size of machine components (Owolarafe et al., 2007).

4. Conclusions

From the study, the following conclusions were made: The physical parameters of different yam species have been evaluated and found helpful in the development of a mechanical yam harvester. The results revealed that the range of mean values of: (17.34 – 48.66 cm), (7.53 – 14.23 cm) and (9.7 – 27.6 N) for the length, diameter and weight of yam species, respectively. These will be helpful in the design of space between the harvester blades and design of depth of penetration.

The variation in the shapes, sizes and weights of different yam species will guide in the construction of adjustable blade and digging device.

The heights, size and spacing between ridges are useful in design and construction of two row mechanical yam harvester and further studies also recommended on the engineering properties of yam varieties..

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