Performance Evaluation of a Double Action Self-Fed Cassava Peeling Machine Adapted for Yam Peeling

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Abstract- In West Africa, yam is an important tuber crop owing to its enormous uses. Quite often, yam is manually peeled, thus leading to drudgery and time consumption. To this end, a Double Action Self-fed (DASF) Cassava Peeling Machine developed at the Federal University of Technology, Akure, Nigeria was adapted for yam peeling. The performance of the machine was evaluated using five different yam varieties: *Danisha, Loko, Aro, Shagari*, and *Egumo* under various crop and operational variables such as moisture content of the yam tuber, tuber size, time of peeling and three operating auger-brush speed ratios of the machine. Five replicates of the experimental results were tested using statistical analysis and multiple linear regression models were developed to predict the relationship between the variables and the machine performance parameters. The DASF peeler has a peeling capacity of 920 kg/hr. The performance evaluation showed that peeling efficiency, material recovery and tuber loss were significantly affected by the auger-brush speeds and tuber size.

Keywords Yam Peeling, auger-brush speed, tuber loss, material recovery, peeling efficiency.

1. Introduction

Yam belongs to the genus *Dioscorea*. It is a herbaceous vine generally cultivated in Africa, Asia and Latin America for the consumption of its ground tissue. There exist many cultivars of yam. According to FAOSTAT [1], the global production of yam was estimated to be 54.1 million metric tons as at the year 2009. In most West African countries, mystical importance is given to yam. Thus, it is usually utilized as prestige for marriage pride, ritual material for appealing to gods, and edible food during the festive celebration [2]. It is also used as royalty and for entertaining special guests, even on festive occasion [3].

Traditionally, it is often boiled, ground into flour or pounded into a paste for human consumption. Forms of processed yam include pounded yam, boiled yam, roasted/grilled yam, fried yam slices, yam balls and flakes. There are different species of yam and the top six include. *D. rotundata, D. cayenensis, D. dumetorum, D. alata, D. trifida, D. esculenta, D. bulbifera and D. villosa*. These six species constitute over 90 % of edible yam cultivated in tropical Africa [3] Regardless of the end-use of the yam tubers, whether for immediate consumption or, for further processing, peeling of the yam tuber's' pericarps is inevitable. Owing to the difficulty encountered with mechanized peeler due to varying tuber shapes and sizes, attempts were made at incorporating yam pericarps within its ground tissue especially for flour production. However, it was discovered to lead to a drastic increase in the dietary fibre content of the flour [4], which is recalcitrant to digestion [5]. Yam peeling, just like cassava peeling involves peeling off the tuber's outer skin or the removal of the thin layer (usually called the peel) from the tuber [6]. Most yam peeling operations in West Africa are done manually or semi-automatically.

Manual peeling is monotonous, time consuming and laborious, especially in large-scale production. Jimoh et al., [7] published that most abrasive and impact peelers developed in Brazil, China, Africa, are either manually operated, or possess low peel removal efficiency or high mechanical damage [8] Thus, developing low-cost peeling machines that will satisfactorily peel the tubers with reduced tuber loss, is still a big challenge [9]. The need for low-cost mechanized peeler cannot be over-emphasized. Ariavie and Ohowovoriole [10] worked on the improvement of a rotary cassava peeler. Some of the limitations observed in operating the modified rotary cassava peeler are reduced peeling efficiency and rusting of cutting blades.

[11] developed a yam peeler which consists of a hopper, a platform for in-feeding of yam, peeler disc and a power transmission source. The shortcomings of the peeler are its non-suitability for commercial use and a fixed thickness of peel removal without regard to the varying morphological properties of different yam varieties. An industrial yam peeler previously developed and evaluated by [12] has a fairly low peeling efficiency (60% to 80 %). Due to the high performance associated with cassava peeling and the similarity between yam physical properties and that of cassava, an insight toward the adaptation of cassava peelers for yam tubers was developed. According to Egbeocha, et al., [6], physical and mechanical characteristics such as weight of the tubers, peel thickness, the frictional resistance of the tuber, tuber shear strength, affects the mechanical peeling process.

The double-action self-fed (DASF) cassava peeling machine, evaluated for peeling yam, resulted from the improvement carried out on early models developed by Olukunle and Ademosun [13]. This machine has dual tuber path and it is provided with suitable adjustment of the peeling chamber for different tubers sizes. The tubers were fed into the two inlets simultaneously and their resident time is governed by the auger speed and the slippage caused by the combine action of the auger, the brush and the tuber monitor on the tuber. The rotary power for the auger and the peeling brush is obtained via a pulley system connected to a 5.25 kW Honda petrol engine. The flow of material within the peeling chamber was governed by the combined action of the auger and brush, approximated in Srivastava et al. [14] as:

$$Q_t = \pi/4(d^2_{sf} - d^2_{ss})\cdot L_p\cdot n \qquad (1)$$

The double-action/self-fed cassava peeling machine by Olukunle et al. [15] requires sizing the tubers to not less than 10cm before peeling. Machine capacity was reported to be 410 kg/h, peeling efficiency, 77 % and tuber loss, 8 %. Tubers less than 10 cm long would be poorly handled during the peeling process with this model, hence, it is advisable to ensure that the tuber length is beyond 10 cm during trimming. This research work focused on the use of the DASF cassava peeler for peeling five varieties of *Dioscorea rotundata* and to carry out its performance evaluation.

2. Materials and Methods

2.1 Experimentation Materials

A critical appraisal of the DASF peeling machine was performed using five different varieties of *Dioscorea rotundata* species. The varieties are *Danisha, Loko, Aro, Shagari and Egumo* which were selected because of their vast availability and nutritional values. The yam tubers used for the experiment were two months old after harvesting and were all procured from Akure, the southwestern region of Nigeria. The evaluation of the machine performance was based on the peeling efficiency, tuber loss and material recovery under different machine operational and plant morphological variables. These variables tested include auger: brush speed, moisture content, tuber size (diameter), and tuber length. The auger: brush speeds were carefully selected with step increase and a common ratio, based on equation 1.

2.2 Adaptation of the DASF peeling machine

A DASF peeling machine originally designed and constructed for cassava was adapted for peeling white yam (*D. rotundata*). The modifications were made possible due to the similarities and differences which exist between the physical properties of yam and that of cassava tubers. Preliminary testing of the DASF peeling machine using yam showed that most of the yams peeled were damaged in the flesh and that some yams were restrained by the inlet hopper. The damage observed on the yam flesh during the preliminary trial was because of the soft nature of yam periderm, cortex and cambium compared to that of cassava. Thus, the peeling brush used was changed to a less abrasive wire brush. The size of the inlet hopper was adjusted from 120 mm diameter to 150 mm in diameter. Also, the inlet and outlet tuber monitor clearance were increased to accommodate bigger yams up to the size of 150 mm tuber diameter.

2.3 Experimentation

Five different varieties of *Dioscorea rotundata: Danisha, Loko, Aro, Shagari and Egumo* were procured. Each variety was classified and sorted according to its size before feeding the tubers into the DASF peeling machine through the inlet hoppers. This was done to ensure even adjustment of the tuber monitor clearance. The weights of each yam tuber before and after the mechanized peeling, peeling duration, the mass of peel removed with a knife after the mechanized peeling, the mass of the tuber after manual peeling and mass of peel removed by the machine were all determined. The experiment was done in five replicates using five yam tubers for each variety tested under three different auger: brush speeds.

The moisture content, tuber length and, tuber size were measured, considering both the transverse and longitudinal sections, using standard procedures. The moisture content was determined using the oven-dried method. While the auger: brush speeds (machine operational variable) selected for the tests were 1000:1400; 1500:2100; and 2000:2800 rpms. The ratio of the auger speed to brush speed was selected based on the design of the machine in Olukunle and Ademosun [13].

2.3.1 Proportion of peel to yam tuber

The proportion of peel to whole yam tuber (*f*) was determined using the procedure described in Adetan et al. [16]. This procedure involves the measuring of the weight of tuber before and after careful hand-peeling of yam tuber. At least ten tubers were hand-peeled for each of the white yam varieties tested.

2.3.2 Determination of evaluation parameters

To develop a mathematical expression for each of the evaluation parameters: tuber loss, material recovery and peeling efficiency, the following assumptions were taken.

1. For a given variety of *Dioscorea rotundata*, the proportion of peel to whole yam tuber is relatively constant,
2. Yam flesh (ground tissues) lost due to adhesion with the machine parts or components is assumed to be negligible,
3. The quantity of ground tissue lost during secondary peeling (careful removal of unpeeled patches) is infinitesimal.

Based on the above assumptions and definitions;

$$M_{pg} + M_{pt} \leq M \quad (2)$$

$$f = {}^{M_e}/_{M} \quad (3)$$

$$M_p + M_{pe} \leq fM \quad (4)$$

$$M_{tr} + M_{pe} = M_{pt} \quad (5)$$

$$M_p + M_g = M_{pg} \quad (6)$$

$$M_{tr} + M_g = M - fM \quad (7)$$

$$\rho = \frac{M_{pt} - M_{tr}}{fM} \quad (8)$$

1. Tuber loss (η) was computed to determine the proportion of ground tissue in the peels produced by the machine to the overall ground tissue of the yam tuber tested.

$$\eta = 1 - \frac{M_{tr}}{M(1-f)} \quad (9)$$

2. Material recovery (λ) is the relative proportion of the ground tissue of yam tuber returned at the machine outlet after peeling. The material recovery was estimated using equation (10).

$$\lambda = {}^{M_{tr}}/_{M - M_e} \quad (10)$$

3. Peeling efficiency is a measure of ground tissue recovery and the extent to which the machine removes the tubers pericarps. It was determined using equation (11).

$$\varepsilon = \lambda \times \rho = \frac{M_{tr}(fM - M_{pt} + M_{tr})}{fM^2(1-f)} \quad (11)$$

2.4 Data analysis

The descriptive statistics of the evaluation parameters for the three different auger: brush speeds were computed. For standardization; the moisture content, tuber diameter and tuber length were subjected to analysis of variance. Each of the evaluation parameters under different treatments was compared using analysis of variance and post-hoc test: Turkey's procedure. The treatments involved are auger: brush speeds and the yam varieties. The evaluation parameters were also fitted to linear and multiple regression models.

3. Results and Discussions

3.1 Summary of the evaluation parameters

Table 1 presents the descriptive statistics of the evaluation parameters: peeling efficiency, tuber loss and material recovery. The least mean amounts of ground tissue lost to peeling were observed with *Aro* variety for the three auger brush speeds. These values are 8.79 %, 11.13 %, 14.69 % at auger: brush speeds 1000:1400, 1500:2100 and 2000:2800 respectively. This result can be attributed to the rough texture and the thickness of *Aro* variety compared to other varieties. Since there is a direct relationship between the abrasive force and the speed of the peeling brush, it can be argued that tuber loss increases with abrasive strength when the brush speed is up to 1400 rpm. Even with *Aro* variety, the lowest tuber loss was greater than 5percent.

Except for the auger: brush speed of 2000:2800 rpm; *Shagari* variety had the highest tuber loss, losing more ground tissue with the peel compared to other varieties. This is not unconnected with its pericarp adhesion to the ground tissue and the pericarp's thickness and texture. However, at auger: brush of 2000:2800 rpm; the order of performance of each variety concerning tuber loss varies drastically. This distortion was largely due to the turbulence which resulted from the application of excess auger speed of 2800 rpm. The peeling efficiency reduces as the auger: brush speed increases. The highest mean peeling efficiency was obtained with *Aro* variety having values of 83.16%, 71.38% and 62.27% at auger: brush speeds of 1000:1400 rpm, 1500:2100 rpm and 2000:2800 rpm respectively. A similar result was observed by Atere [17] when the same machine was adopted for peeling cassava. This implied that the DASF peeling machine is most suitable for *Aro* variety.

Table 1. Descriptive statistics of evaluation parameters.

	Tuber Varieties	Speed Ratios (rpm)								
		1000:1400			1500:2100			2000:2800		
		ε	η	λ	ε	η	λ	ε	η	λ
Min	*Danisha*	80.42	10.28	87.56	59.54	11.34	75.73	50.71	19.23	69.79
	Loko	81.10	9.63	88.51	66.20	11.79	78.97	53.83	17.14	74.99
	Aro	82.54	8.30	84.63	70.85	10.91	83.19	61.81	13.87	67.79
	Shagari	80.34	11.03	85.25	59.11	11.27	78.97	59.23	15.93	68.93
	Egumo	80.04	11.12	84.92	65.14	12.33	80.33	46.08	16.60	72.23
Max	*Danisha*	82.04	12.34	89.31	60.74	13.61	77.30	51.73	23.08	71.05
	Loko	81.96	10.02	90.58	66.90	13.10	80.08	54.41	17.83	77.00
	Aro	83.76	9.22	91.71	71.90	11.35	86.53	62.72	15.41	68.55
	Shagari	82.76	14.68	90.51	66.67	17.48	82.63	61.01	21.20	69.58
	Egumo	81.54	15.20	88.73	66.44	16.85	82.24	50.72	22.06	73.35

Mean	*Danisha*	81.23	11.23	88.42	60.14	12.39	76.77	51.22	20.93	70.49
	Loko	81.53	9.83	89.48	66.55	12.48	79.46	54.12	17.46	75.79
	Aro	83.16	8.79	90.01	71.38	11.13	85.13	62.27	14.69	68.12
	Shagari	81.55	13.10	87.26	61.43	14.84	81.62	60.12	18.92	69.28
	Egumo	80.78	12.83	86.93	65.76	14.23	81.29	49.46	19.03	72.75
SD	*Danisha*	0.58	0.98	0.83	0.43	1.08	0.60	0.37	1.73	0.49
	Loko	0.32	0.16	0.74	0.26	0.51	0.55	0.22	0.27	0.99
	Aro	0.51	0.36	3.01	0.43	0.18	1.27	0.38	0.61	0.30
	Shagari	0.92	1.42	2.02	3.01	2.43	1.51	0.68	2.06	0.24
	Egumo	0.56	1.78	1.49	0.48	1.97	0.76	1.93	2.45	0.45

[*] **ε**- Peeling Efficiency; **η**- Tuber Loss; and **λ**- Material Recovery

3.2 Effect of auger: brush speed on the machine performance

Figure 1 shows a remarkable increase in the loss of ground tissue as the auger: brush speed increases. This agrees with the findings of Jimoh and Olukunle [18] and Jimoh et al. [7], who observed an increase in mechanical damage with the increase in speed. Tuber losses in *Egumo* and *Shagari* varieties were analogous. Similarly, *Danisha* and *Loko* varieties were found to exhibit similar behaviour for tuber loss. Even though the tested auger: brush speeds were stepped up by a common ratio, the amounts of ground tissue lost in *Danisha, Loko, Shagari* and *Egumo* varieties between auger: brush speed 1500:2100 to 2000:2800 exceeded that which were lost between speed 1000:1400 to 1500:2100. This was not unexpected, since the abrasive force exerted by the brush is supposed to intensify with its speed.

The excessive abrasion provides enough momenta which are capable of causing more ground tissues to shear with its pericarps. On the contrary, the degree at which ground tissue was lost between higher speeds (1500:2100 to 2000:2800 rpm) in *Aro* variety is less compared to lower speeds (1000:1400 to 1500:2100 rpm). It may probably be due to stronger cohesive force toward the core of the ground tissue of *Aro* yam tubers. This depicts that the brush could not take up much yams flesh as did in other varieties when the auger: brush speed was increased to 2000:2800. According to Odigboh [19]; pericarp thickness, peel surface coarseness and strength of adhesion between the ground tissue and the pericarp affect the performance of a mechanized peeler. Generally, less amount of ground tissue was removed with the peel in *Aro* variety compared to the other yam varieties, even at a brush speed of 1400 rpm. It is well established from physical observation of the peeling texture that *Aro* variety has the thickest and roughest pericarp compared to other varieties. Hence, *Aro* peel texture and thickness are thought to be the main reasons why its ground tissue lost was least severe.

However, at an auger: brush speed of 1500:2100, tuber loss in *Loko* variety seems to be better than that of *Aro* variety. This tends to be disproved by Fig. 3 because there exists a relationship between material recovery and tuber loss. Comparing Figs. 1 and 2, *Danisha* and *Loko* varieties responded similarly to the mechanized peeling operation. Likewise, material recovery between *Shagari* and *Egumo* varieties are comparable. While *Aro* variety was found to have the least tuber loss at auger: brush speed of 2000:2800, the proportion of ground tissue recovered was the smallest of the five yam varieties tested. To explain this discrepancy, a mass balance carried out on *Aro* tubers showed the loss of the reasonable amount of its ground tissue within the machine. This variable was further assessed using ANOVA and Tukey's test. Another issue of paramount importance is the contact times between the peeling brush and the tuber pericarps, which were substantially reduced as the auger speed increases. The contact time, size and texture of the pericarps and brush speed affect the degree at which the pericarps are removed by abrasion.

The peeling efficiency was computed by considering both the quantity of ground tissue removed as peel and the proportion of pericarps found on the tuber after the mechanized peeling operation (equation 11). Invariably, the combined effect of material recovery and tuber loss of each variety is inherent in its peeling efficiency. On average, the DASF peeling machine is best suited for *Aro* variety and least for *Danisha* variety (Fig. 3). However, better performance can be obtained with the other varieties by changing the machine operational parameter as appropriate. Adetan et al. [16] reported that the age of tuber has a positive influence on the power requirement for peeling. For *Shagari* variety, the peeling efficiencies at auger: brush speeds 1500:2100 and 2000:2800 were very close. This uncertainty was checked for using statistical analysis and a more explicit discussion under machine performance section.

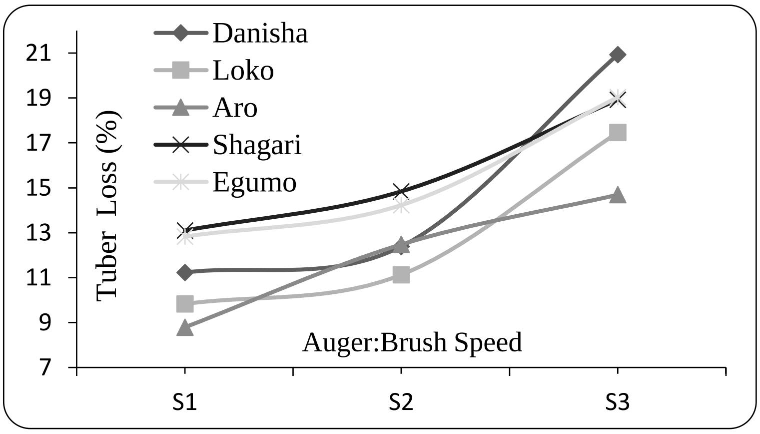

Fig. 1. Effects of auger-brush speed on tuber loss.

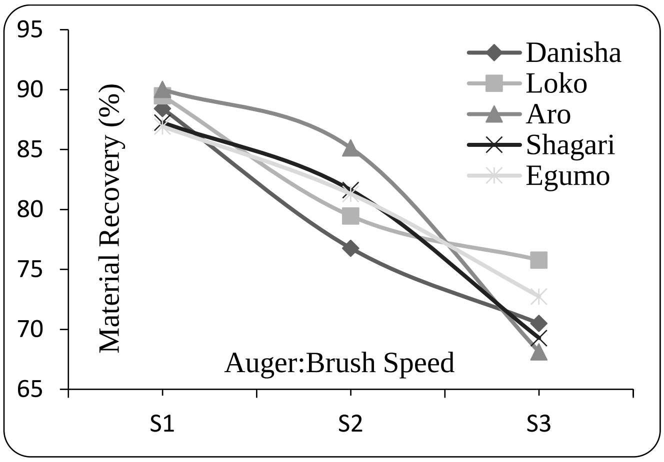

Fig. 2. Effects of auger-brush speed on material recovery.

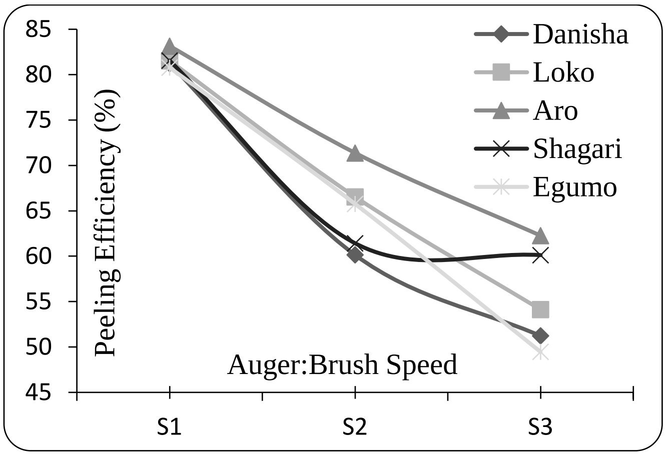

Fig. 3. Effects of auger-brush speed on peeling efficiency.

3.3 Machine performance

The evaluation parameters: tuber loss, material recovery and peeling efficiency were subjected to a two-factor analysis of variance. The factors are the five varieties (*Danisha, Loko, Aro, Shagari and Egumo)* and the three levels of speed (1000:1400, 1500:2100 and 2000:2800). There were five replicates for each pair of factors. For tuber loss, all single main effects were statistically significant at a 0.05 significance level. The main effect of variety yielded an F ratio of F (4, 60) = 2.64, $p < 0.05$, indicating that the ground tissue materials lost due to the DASF peeling operation vary with yam varieties. The mean and standard deviation for each of the varieties are presented in Table 3. The main effect of auger: brush speed was highly significant ($p < .01$), indicating that the tuber loss increases with the auger: brush speeds.

The tuber losses at auger:brush speed 1500:2100 rpm (M = 13.2%, S = 2.0) was greater than that of 1000:1500 rpm (M = 11.2%, S = 1.8) but less than that of 2000:2800 rpm (M = 18.1, S = 2.3). The interaction effect was not significant, F (8, 60) = 0.13, $p > 0.05$. As earlier discussed, the variation in tuber loss for each of the variety is related to the adhesion between the ground tissue and its pericarp. Cognizant of these different levels of adhesion of the pericarps to the ground tissue of yam, it is evident that precise removal of yam pericarps from its tuber largely depends on the selection of appropriate speed for each tuber variety.

For material recovery and the peeling efficiency, only the main effect of the auger: brush speed was significant (p<0.01). The main effect of auger: brush speed yielded F ratio of F (2, 60) = 222.84, $p < 0.01$ and F ratio of F (2, 60) = 241.93, $p < 0.01$ for material recovery and peeling efficiency respectively, indicating that both the material recovery and peeling efficiency decrease with the auger brush speed. This confirms the assertion of Olukunle and Akinnuli [13] and [9] that the peeling efficiency of the machine shows a decreasing trend with the increase in the speed of the machine. The mean value and standard deviation for the material recovery and peeling efficiency can be found in Table 2. However, the main effects of variety on material recovery and peeling efficiency and interactions were not significant (p>0.05) indicating that only the auger: brush speed had a significant effect on material recovery and peeling efficiency. Tuber loss and material recovery were computed from the samples received at the discharge ends. Since peeling efficiency is a function of the effects of both tuber loss and material recovery, this implied that a substantial proportion of the peel materials was lost within the peeling chamber. Besides, the F ratio (F (4, 60) = 2.64) of the main effect of varieties on tuber loss is slightly different from the F critical value (2.53) and there were no interaction effects (Table 3). To further investigate these significances, post-hoc analyses (Turkey's procedure) were carried out.

Table 2. ANOVA results for machine performance

*Parameter**	*Source of Variation*	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*	*Remark†*
η	Varieties	45.39	4	11.35	2.64	0.04	2.53	S
	Speeds	598.71	2	299.35	69.59	0.00	3.15	S
	Interaction	4.33	8	0.54	0.13	1.00	2.10	NS
	Error	258.12	60	4.30				
	Total	906.55	74					
λ	Varieties	4.19	4	1.05	0.13	0.97	2.53	NS
	Speeds	3686.24	2	1843.12	222.84	0.00	3.15	S
	Interaction	3.46	8	0.43	0.05	1.00	2.10	NS
	Error	496.27	60	8.27				
	Total	4190.16	74					
	Varieties	3.59	4	0.90	0.05	1.00	2.53	NS

ε	Speeds	8791.12	2	4395.56	241.93	0.00	3.15	S
	Interaction	6.70	8	0.84	0.05	1.00	2.10	NS
	Error	1090.10	60	18.17				
	Total	9891.51	74					

* **ε-** Peeling Efficiency; **η-** Tuber Loss; and **λ-** Material Recovery. NS- Not Significant; and S- Significant.

Post hoc analyses were carried out using Turkey's procedure had significant effects at p<0.05 and p<0.01 for tuber loss, material recovery and peeling efficiency, respectively. The tuber loss was found to vary with both the auger: brush speed and variety (Table 3). Hence the tuber loss was subjected to post-hoc along with two factors: yam variety and auger: brush speed. The post hoc result of auger: brush speed indicated that the tuber losses at 1000:1500 rpm and 1500:2100 rpm do not vary significantly (P<0.05) from each other. But both vary from the tuber loss at auger: brush speed of 2000:2800 rpm (**α** = .05 or .01). The effect of variety on tuber loss at 0.01 level of significance showed that the tuber loss for each variety does not differ from one another. However, at P<0.05 level of significance; Aro and Shagari varieties vary significantly from each other for tuber loss. As shown in Table 4, the post hoc results indicate that the material recovery and the peeling efficiency differ significantly (p<0.05) for the three augers: brush speeds. The highest values for material recovery (M = 88.4%, S = 2.1%) and peeling efficiency (M = 81.7%, S = 1.1%) were obtained at an auger:brush speed of 1000:1500 rpm. While the lowest values for material recovery (M = 71.3%, S = 2.8%) and peeling efficiency (M = 55.4%, S = 5.2%) were obtained at an auger:brush speed of 2000:2800 rpm. The material recovery and peeling efficiency decrease with auger: brush speeds. A higher auger: brush speed will culminate into poor performance due to increased turbulence within the chamber.

Table 3. Post-Hoc test results on the machine performance

*Evaluation Parameter**	*Variables†*	***α** =0.05*		***α** = 0.01*	
		Mean‡	*LSD Value*	*Mean‡*	*LSD Value*
ε (peeling efficiency)	S1(speeds)	81.65	5.72	81.65	7.66
	S2	65.05	5.72	65.05	7.66
	S3	55.44	5.72	55.44	7.66
η (tuber loss)	S1	11.16^{a}	2.12	11.16^{a}	2.84
	S2	13.21^{a}	2.12	13.01^{a}	2.84
	S3	18.11	2.12	18.21	2.84
	A (varieties)	14.85^{a,b}	3.38	14.85^{a}	4.47
	B	12.81^{a,b}	3.38	12.81^{a}	4.47
	C	11.99^{a}	3.38	11.99^{a}	4.47
	D	15.62^{b}	3.38	15.62^{a}	4.47
	E	15.36^{a,b}	3.38	15.36^{a}	4.47
λ (material recovery)	S1 (speeds)	88.42	4.76	88.42	6.38
	S2	80.85	4.76	80.85	6.38
	S3	71.29	4.76	71.29	6.38

* ε- Peeling Efficiency; η- Tuber Loss; and λ- Material Recovery.
† S1- 1000:1400; S2- 1500:2100; S3- 2000:2800; A- *Danisha;* B- *Loko;* C- *Aro;* D- *Shagari;* and E- *Egumo.*
‡Common letter indicates the evaluation variables that do not differ significantly from each other using Turkey's Procedure.

3.4.2 Regression analysis on the machine performance

Regression analyses were carried out to predict the performance of the DASF peeler at 0.05 level of significance. As shown in Table 1, the tuber size for each yam tuber does not differ with variety, likewise the moisture content. Tuber loss, material recovery and peeling efficiency varied with auger: brush speed. But contrary to material recovery and peeling efficiency, the tuber loss was also found to be variety dependent (Table 4). Subsequently, a linear regression model each was developed for material recovery and peeling efficiency, and for tuber loss, a multiple linear regression model was constructed for each variety. The magnitude of the force of abrasion is a function of the surface area in contact with the peeling brush, the thickness of peel and the pericarps' texture. Adetan et al. [16] claimed that for a cassava tuber, the thickness of peel increases with its diameter. A similar analogy is expected for yam tuber, though this may not necessarily be the case. Since the thickness of peel and the brush contact area could not be completely dislodged from the tuber diameter, both the auger: brush speed and the tuber size (diameter) were considered as variables in the regression model.

The coefficients of auger: brush speed in the models developed for tuber loss, material recovery and peeling efficiency differ significantly ($P < 0.05$). The coefficients of tuber size do not vary significantly ($P > 0.05$) except in the models developed for tuber loss in *Danisha* and *Aro* varieties (Table 4). Hence, excluding tuber losses in *Danisha* and *Aro* varieties; the null hypothesis that tuber size does not affect the machine performance was accepted. This implied that the effects of auger: brush speed on the three evaluation parameters are paramount while the influence of tuber size is dormant except when predicting tuber loss for *Danisha* or *Aro* variety. Auger: brush speed is a far more important factor when predicting the efficiency of a DASF peeler. The multiple linear regression model for *Aro* variety accounted for the highest proportion of variation in tuber loss (R^2 = 96.7 %) with a standard error of 0.5. On the other hand, that of *Shagari* variety explained the lowest proportion of variation in tuber loss (R^2 = 66.3 %) with a standard error of 2.0. This confirms the fact the DASF peeler is more appropriate for *Aro* variety.

Only the auger: brush speed was found to significantly (P < 0.05) affect tuber losses in *Loko*, *Egumo* and *Shagari* varieties, while both the auger: brush speed and the tuber size considerably affect the tuber loss in *Danisha* and *Aro* varieties. The models for predicting tuber loss in *Danisha* and *Aro* varieties have high R^2 values. Though auger: brush speed is more significant (P < 0.05) compared to tuber size(P < 0.05), it has a minimum effect; since tuber size accounted for the greater portion of the variation in tuber loss than auger: brush speed for *Danisha* and *Aro* varieties ($\boldsymbol{\alpha}_1 > \boldsymbol{\alpha}_2$). There are wide differences in the proportion of tuber loss predicted by the models across the yam variety; this further emphasizes the need for the selection of a precise auger: brush speed which should be variety-dependant. The models used for predicting material recovery and peeling efficiency have R^2 values of 89.6 % and 88.7 %. Indicating that, the models explained 89.6 % of the variation in material recovery with a standard error of 2.7 and also 88.7 % of the variation in peeling efficiency with a standard error of 4.3.

Table 4. Regression Models for the Machine Performance

Predicted Evaluation Parameter*	Variety†	Model coefficients‡,§			Model Variables‡ (*p*-value)			Overall Statistics	
		$\boldsymbol{\alpha}_0$	$\boldsymbol{\alpha}_1$	$\boldsymbol{\alpha}_2$	$\boldsymbol{\alpha}_0$	$\boldsymbol{\alpha}_1$	$\boldsymbol{\alpha}_2$	R^2	SE
η	A	63.84(11.03)	-10.952(1.89)	0.018(0.00)	0.000	0.000	0.000	0.942	1.203
	B	-1.173(3.26)	0.316(0.38)	0.008(0.00)	0.726	0.417	0.000	0.878	1.304
	C	10.121(2.60)	-1.168(0.43)	0.007(0.00)	0.002	0.018	0.000	0.967	0.501
	D	15.486(6.81)	-1.373(1.04)	0.007(0.00)	0.042	0.213	0.000	0.663	1.966
	E	23.941(9.72)	-2.281(0.00)	0.005(0.00)	0.030	0.085	0.002	0.697	1.997
λ		105.469(14.07)	0.064(2.12)	-0.017(0.00)	0.000	0.976	0.000	0.896	2.667
ε		132.855(22.71)	-4.005(3.42)	-0.024(0.00)	0.000	0.264	0.000	0.887	4.304

* ε- Peeling Efficiency; η- Tuber Loss; λ- Material Recovery
† *A- Danisha; B- Loko; C- Aro; D- Shagari; and E- Egumo*
‡ $\boldsymbol{\alpha}_1$and $\boldsymbol{\alpha}_2$ indicate the coefficients of tuber size and auger: brush speed respectively
§ Standard error in parenthesis

4. Conclusıon

A Double Action Self-fed (DASF) Cassava Peeling Machine developed at the Federal University of Technology, Akure, Nigeria was adapted for yam peeling. The performance of the machine was evaluated using five different yam varieties: Danisha, Loko, Aro, Shagari, and Egumo under various crop and operational variables. The highest mean peeling efficiency was obtained with *Aro* variety having values of 83.16 %, 71.38 % and 62.27 % at auger: brush speeds of 1000:1400 rpm, 1500:2100 rpm and 2000:2800 rpm respectively. The research has been able to establish that the DASF peeling machine is most suitable for *Aro* variety of yam.

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NOMENCLATURE

d_{sf} Screw flight diameter
d_{ss} Screw shaft diameter
f Proportion of the yam tuber that makes up the pericarp (*f varies according to the yam species*)
L_p Pitch length
M Mass of tuber before peeling operation
M_e Overall mass of pericarp in the tuber
M_g Mass of good tuber material in the peel after machine peeling
M_p Actual mass of pericarp in the peel after machine peeling
M_{pe} Mass of unpeeled patches of pericarp left by the machine
M_{pg} Mass of peel discharged by the machine
M_{pt} Mass of tuber after primary peeling operation (Machine peeling) (*M_{pt} includes both the tuber remain and unpeeled patches)*
M_{tr} Mass of tuber recovered after secondary peeling
n Rotational speed of auger
Q_t Volumetric capacity of the auger
ρ Proportion of pericarp unpeeled by the DASF machine
ε Peeling efficiency
η Tuber loss
λ Material recovery
S1 Auger:brush speed ratio- 1000:1400;
S2 Auger:brush speed ratio- 1500:2100;
S3 Auger:brush speed ratio- 2000:2800.
DASF Double Action Self-Fed