



## EFFECT OF OPEN AIR DRYING DURATION ON SEED MOISTURE AND THE THRESHING QUALITY OF COWPEA

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### Abstract

To improve on the quality of threshed cowpea (*Vigna unguiculata* L.) produce by rural farmers in Ghana, variation in the duration of drying was employed. The cowpea was divided into five units and open air dried to 16.52, 14.69, 11.38, 9.69, and 8.36 % seed moisture contents (SMC) for three (3) days, five (5) days, eight (8) days, eleven (11) days and fourteen (14) days respectively after harvesting. The SMC effect on threshing and seed quality was assessed with a developed cowpea thresher using 334, 435, 533, 634 and 735 rpm rotor speeds. The results showed that the throughput and efficiency increase with the speed and decreasing SMC. The percentage seed damage increases as the speed and SMC increase. The cowpea at 16.52 % SMC after drying produced the highest average seed damage of 3.05 % while 8.36 % SMC yielded 1.39% average seed damage. Analysis of variance (ANOVA) performed showed that there were significant differences ( $P < 0.01$ ) among the throughput capacities, seed damage and threshing efficiencies. However, there was no significant difference ( $P > 0.05$ ) between the seed loss control of 9.69% and 8.36% SMC. The minimum seed loss of 11.38%, 9.69% and 8.36% were less than the overall mean by 7.4, 20.6, and 29.4 % respectively. Therefore, the best machine-crop parameter combination for optimal grain quality is 8–10 % SMC and rotor speeds of 388–550 rpm. To achieve these SMC, the crop must be dried in the open air for a minimum of eleven (11) days at 7 hour/day.

**Keywords:** Machine-crop parameter; Seed damage; seed moisture content; physical properties,

### INTRODUCTION

Cowpea (*Vigna unguiculata* L. Walp) has high economic value which makes it the most important legume in Africa (Langyintuo *et al.*, 2003; Murdock and Baoua, 2014) and in many parts of the world (Langyintuo *et al.* 2003). It can be used as green pods for fresh market or dry seeds. The grain contains about 24.8 % protein and improves soil properties especially in sandy and light soils (Morad *et al.*, 2007). Nowadays it is a legume widely adapted and grown throughout the world (Aveling, 1999; Gomez, 2004). Many people in some areas of Africa, especially the northern part of Ghana, earn their living directly or indirectly through the cultivation of cowpea (Irtwange, 2009). Once the crop has been harvested, the seeds must be dislodged from the pod, and the process is called threshing. The difficulty in separating the unwanted inedible parts such as straw and husk from the seed existed at the early stages when man started using cowpea seeds as food (Irtwange, 2009). Meanwhile, threshing is the most important practice in the grain production chain. Threshing loss, grain damage, and cleaning efficiency are the most qualitative key parameters for evaluating thresher operation performance (Salari *et al.*, 2013). The threshing can be done either mechanically or manually (Adekanye and Olaoye, 2013). Both methods of threshing inflict a lot of breakages to the seeds. Mechanical threshing is the use of engine or electric motor in driving the rotor of the machine for the threshing of the crop and the seeds are then separated by winnowing (Fulani *et al.*, 2013). The method involves high technology which is very expensive but helps to maintain the quality of the finished product. It eliminates drudgery associated with traditional system of threshing and reduces threshing losses (Olaoye, 2011). To reduce the incidence of stone in the product, a tarpaulin or similar materials are spread before threshing (Phillips *et al.*, 2000; Maunde, 2011).

Some factors affecting the efficiency of mechanical threshing of cowpea are identified as feeding method, cylinder speed, concave-to-cylinder clearance and moisture content (Kepner *et al.*, 1978). A study on the threshing of cowpea was carried out by Sharma and Devnani (1980), and reported an increase in the threshing efficiency with the increase of cylinder speed. The results however, reported a decrease in the threshing efficiency with the increase of feed rate and concave clearance. The authors further reported 5 % visible grain damage at higher speeds with low germination percentage. In another study Herbek and Bitzer (2004) reported that cylinder speeds ranging from 400 to 800 rpm were generally sufficient and that greater seed damages are caused by higher cylinder speeds ranging from 700 to 800 rpm. The authors therefore suggested that it may be necessary to use cylinder speeds lower than 500 rpm under the condition of excessive seed damage. Sudajan *et al.*, (2002) applied different threshing units for sunflower seeds and reported that visible grain damage increased with increasing drum speed and feed rate. Ajav and Adejumo (2005) evaluated an okra thresher with variable parameters. The results showed that germination of threshed seeds was significantly influenced by moisture content, cylinder speed, and concave clearance. In order to determine machine-crop parameters, Vejasit and Salokhe (2004) evaluated the effectiveness of an axial flow thresher on soybean. The results indicated that moisture content, feed rate, and threshing drum speed significantly affected the throughput capacity, threshing efficiency, and grain damage.

A review of the literature has revealed that there is inadequate data on the effects of machine-crop parameter combination on the performance of cowpea threshers. The appropriate rotor speeds for optimal machine performance is considerably related to the seed moisture content (SMC). The sum of seed damage and unthreshed seed as influenced by SMC is also



necessary information in the selection of drum speeds so as to meet the acceptable level of seed damage of 1.1 % (Ukatu, 2006). Majority of farmers in the rural areas do not have access to mechanical dryers and consequently, resort to open air drying before threshing. The required seed moisture content (SMC) for effective threshing can also not be determined by majority of rural farmers and thresher operators due to lack of moisture meters. However, the duration of the open air drying to reduce the SMC to the reliable level is not known. Meanwhile, it is an important parameter in determining the qualitative and quantitative loss of the threshed grains. Therefore, the objectives of this paper seek to: Firstly, determine the minimum duration of open air drying of cowpea that would keep the SMC at the optimum for effective threshing. Secondly, determine the best rotor speed at which the seed loss is at the minimum, for various cowpea SMC. Finally, provide the best machine-crop parameters combination for optimum machine performance in order to maintain the final product at high quality.

## MATERIALS AND METHODS

### Design Process and Principle of Operation

The cowpea thresher was designed based on the data collected on the physical properties of cowpea from literature. The availability of the physical properties of cowpea is critical for the threshing and handling equipment design (Altuntas *et al.*, 2005; Baryeh and Mangope, 2002; Srivastava *et al.*, 1990). Such information was useful in sizing prime mover requirements, determining the hole size of separating sieve, and selecting the appropriate material for the equipment components that handle grain and crop material flow (Al-Mahasneh and Rababah, 2007; Ogunjimi, 2002). Other factors that are also essential for effective threshing operations are the mechanical properties of the grains which are profoundly influenced by the grain moisture content (Razavi *et al.*, 2007; Yalcin, 2007; Baryeh and Mangope, 2002). Subsequently, the physical and the mechanical properties determine the behaviour of the crop when subjected to mechanical loading during threshing.

The thresher consists of a main frame, feeding hopper, main shaft carrying the threshing drum, cleaner shaft carrying the blower, threshing unit, chaff discharge chute, threshed grain collecting unit, motor for power transmission, pulleys and transmission belts. A height of 1.28 m for the machine was considered for easy feeding because the ergonomic height of a man is 1 m. The machine components were fabricated and assembled as shown in Figure 1. The threshing drum, threshed grain cleaner and other driven parts are powered by a three phase 3.73 kW electric motor. The power transmission is made possible by the use of a set of V-belt and pulley arrangement. An inverter (EDS1000-2S0037, 3.7 kW, 17 A, China) was used to control the speed of the motor.

### Design of The Main and Cleaner Shafts

The shafts are made of steel material because of the load that would be imposed on them. Steel is desired because it has high strength, resistance to shock and can withstand repeated loading (Olaoye, 2011). The selection of materials for the machine parts and structural members were based on the strength, stiffness, and cost (Khurmi and Gupta, 2005). Other factors include: strength in tension, the ability to support applied loads without distortion, availability and suitability for in-service working conditions. The diameter of a solid shaft is obtained by the equation:

$$\tau = \frac{T}{\left(\frac{\pi d^3}{16}\right)} \leq \tau_{dt} \Rightarrow d \geq \sqrt[3]{\frac{16T}{\pi\tau_{dt}}} \quad 1$$

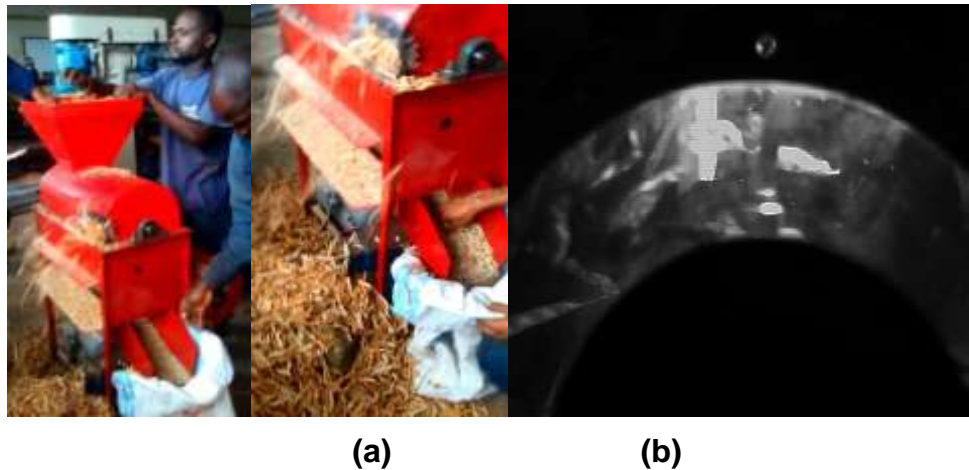
Where T [Nm] is the torque;  $\tau$  is allowable torsional shearing stress. For mild steel material the allowable torsional shearing stress is:  $\tau_{dt} = 28 \text{ N/mm}^2$ .

The torque is given by:

$$T = \frac{P}{\omega} = \frac{P}{2\pi n} = \frac{60P}{2\pi n} = \frac{30 \times 10^3 \cdot P}{\pi n} \text{ Nmm} \quad 2$$

Where P (kW) in the power; n (rev/min) is rotational speed.

Based on calculations the minimum diameters for the main and cleaner shafts should not be less than 21 and 16 mm respectively; therefore, 25 mm and 18 mm were chosen for the main and cleaner shafts respectively.



**Fig. 1: Pictorial view of the developed cowpea thresher in action (a), and an image from high speed camera showing how grains are removed from the pod.**

### Experimental Setup and Evaluation Procedure

The seed sample was obtained from Crops Research Institute, Ghana and cultivated at the Koforidua Technical University research farm from September 11, 2015 to November 20, 2015 at 60 x 20 planting distance. Black eye variety with white seeds which are smaller than the California Black-eye cultivar were used (Addo-Quaye *et al.*, 2011). The average moisture content of the cowpea at harvesting is 17.19 %. The harvested cowpea was separated into five (5) units and labeled A, B, C, D, and E. The units were dried for a number of days in an open air (24–35 °C Ambient temperature) for a sun shine duration of 7 hours from 8:30 am to 3:30 pm each day as follows: Unit 'A' was dried for three (3) days, unit 'B' for five (5) days, unit 'C' for eight (8) days, unit 'D' for eleven (11) days and unit 'E' for fourteen (14) days starting on the third day after harvesting. Three samples from each unit were taken after drying to the laboratory to determine the average seed moisture. The seed moisture contents (SMC) obtained after drying is 16.62 % for 'A', 14.23 % for 'B', 12.41% for 'C', 9.69 % for 'D', and 8.36 % for 'E'. After the SMC has been determined, machine feeding was carried out continuously in three replicates for 1 hour and the average taken using rotor speeds shown in table 1. The yield percentage recovery, grain damage, threshing efficiency, and unthreshed grain percent were then determined for each machine speed and SMC. This process was repeated for the other cowpea units. Analysis of variance was performed on the data to determine if there were any significant differences between the responses of the treatments using IBM SPSS statistics 20 software. The sum of the percentage seed damage and unthreshed seed for the various cowpea units as well as the average of the sum were computed and plotted against the rotor speeds as shown in figure 3a. The overall average and average of the sums obtained from the three reliable SMC were also plotted against the rotor speeds as shown in figure 3b. This was done to determine the speed at which the sum of seed damage and unthreshed seeds obtained from each SMC is lowest so as to provide the best machine–crop parameter combination for optimal performance. SigmaPlot software was used to generate 3D mesh for the combine effect of throughput and rotor speed; throughput and moisture content on threshing efficiency and percentage seed damage as shown in figure 2.

**Table 1. Inverter frequency and rotor speed used for the evaluation**

S/N	Inverter frequency, Hz	Rotor speed, rpm
1	25.29	334
2	32.94	435
3	40.36	533
4	48.01	634
5	55.66	735

## Results and Discussion

### Influence of SMC on machine performance

The machine performance data collected from the tests under the influence of rotor speed averaged for all SMCs are presented in Table 2. The speed range of 334–735 rpm used for the performance test resulted in an average throughput capacity ranging from 185.04 to 288.93 kg/h. The seed damage increased from 1.63 to 3.08 % with increase in rotor speed and decreased from 3.05 to 1.39 % with decrease in SMC. This means that the influence of rotor speed on seed damage is higher than SMC which has been confirmed by the trend of the threshing efficiency data obtained in tables 2



and 3. The range of the efficiency is commendable and indicates that the higher the rotor speed and the lower the SMC, the optimum the performance.

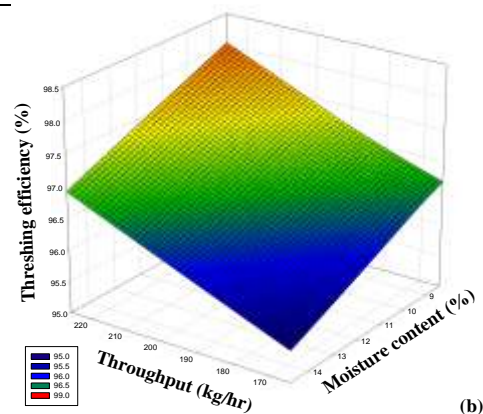
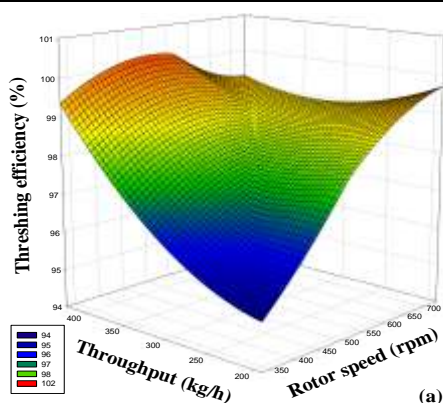
**Table 2. Influence of Rotor Speed on Machine Performance (Averaged for all Moisture Content)**

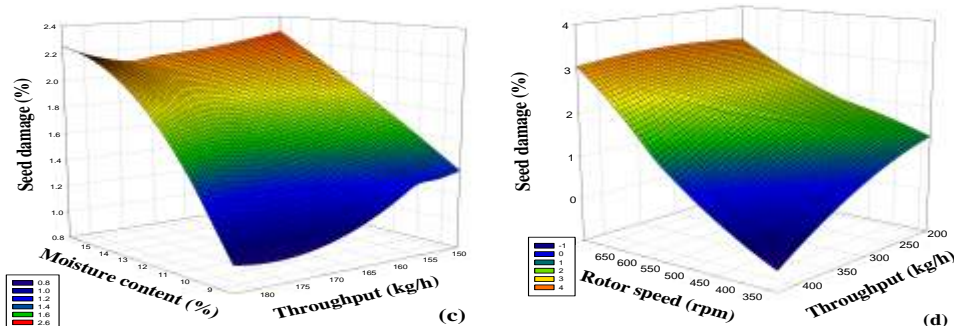
Rotor speed, rpm	Throughput Kg/h	Damaged seeds, kg	Damaged seed, %	Undamaged seed, kg	Unthreshrd seeds, %	Threshing efficiency, %
334	185.04	2.03	1.63	128.74	3.05	96.42
435	213.92	2.42	1.64	150.87	2.53	97.66
533	227.20	2.82	1.78	160.82	2.07	98.35
634	260.16	4.64	2.69	273.49	1.79	98.78
735	288.93	5.90	3.08	192.67	1.39	99.16

The data presented in table 2 is obtained from the effect of SMC on machine performance averaged for all rotor speeds. The SMC of 8.36 % for unit E obtained the lowest percentage seed damage range of 0.99–1.96 % with unit A of 16.52 % SMC obtaining the highest range of 2.28–4.67 % over 334–735 rpm rotor speeds. The cowpea unit E with 8.36 % SMC as a result of 14 days of drying produced the least percentage of seed damage. The unthreshed seed quantity decreases with decreasing SMC. Consequently, the threshing efficiency increases with decreasing seed moisture.

**Table 3. Influence of moisture content on machine performance (Averaged for all rotor speed).**

Moisture content, %	Throughput Kg/hr	Damaged seeds, kg	Undamaged seed, kg	Damaged seed, %	Unthreshed seeds, %	Threshing efficiency, %
16.52	187.46	4.26	129.88	3.05	3.58	97.07
14.69	208.70	3.87	144.33	2.53	2.34	97.64
11.38	232.36	3.47	158.81	2.07	1.65	98.21
9.69	258.70	3.35	176.29	1.79	1.22	98.58
8.36	288.03	2.85	197.27	1.39	0.84	98.88

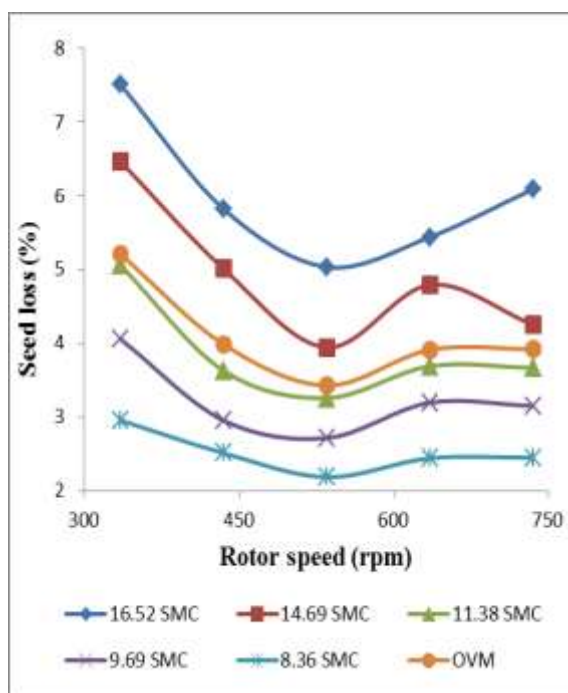




**Fig. 2:** Effect of (a) throughput and rotor speed, and (b) throughput and moisture content on threshing efficiency; the effect of (c) moisture content and throughput and (d) rotor speed and throughput on percentage seed damage.

### Machine–crop parameter combination for effective threshing

The sum of the percentage seed damage and unthreshed seed for the various cowpea units as well as the average of the sum were computed and plotted against the rotor speeds as shown in figure 3a. The minimum turning point of the overall average curve indicated that the 14.69 and 16.52 % SMCs were not reliable for effective cowpea threshing. This is because their minimum turning points are above the lowest value of the average. However, speeds of 535 and 544 rpm respectively obtained as indicated on figure 3a could be considered for threshing cowpea in such range of SMC. In the case of the other units, rotor speeds ranging from 458–524 rpm for unit C (11.38%), 388 – 514 rpm for unit D (9.69%) and 334 – 550 rpm for unit E (8.36%) are the best machine–crop parameter combinations for optimal performance. Furthermore, an overall average sum of the percentage seed damage and unthreshed seed as well as the data obtained from the best three performing SMC range (8.36–11.38%) were computed and plotted as shown in figure 3b. A horizontal line drawn through the lowest turning point of the overall average indicated that the speed range of 380–534 rpm and SMC range of 8.36–11.38% are the required machine–crop parameter combination for optimal cowpea threshing.



**Fig 3:** Effect of rotor speed on seed loss (sum of the percentage damage and unthreshed seeds)

The minimum seed loss of the units; C (11.38 % SMC), D (9.69 % SMC), and E (8.36 % SMC), were less than the overall mean loss by 7.4, 20.6, and 29.4 % respectively. Therefore, the best machine–crop parameter combination for optimal cowpea quality is SMC from 8–10 % and rotor speed ranging from 388–550 rpm. To achieve these SMC, the crop must be dried in the open air for a minimum of eleven (11) days at 7 hours/day after harvesting.



## Statistical comparison of rotor speeds and SMC

### Throughput capacity

Analysis of variance performed on the data for the best three SMC in Tables 2 and 3 showed that, at 1% level of significance the throughput capacities are not the same ( $P < 0.01$ ) with a  $p$ -value of 0.000178 for the SMC and 0.000149 for the speeds. Therefore, the rotor speed has higher influence on the throughput than the SMC.

### Seed damage

Analysis of the data from seed damage at 5 % significant level resulted in a  $p$ -value of 0.042335 for SMC and 0.006677 for the speed. These indicate that the SMC had lesser influence on the seed damage as compared to the rotor speed. However, a comparative analysis between 8.36 and 9.69 % SMC for all the speeds generated  $p$ -values of 0.122903 for the SMC and 0.050833 for the speed which implies no significant difference in both cases. Therefore, 8.36 and 9.69 % SMC in combination with the recommended speeds could provide the best quality grain.

### Threshing efficiency

The data analysed showed that the threshing efficiencies were not the same for the best three SMCs ( $P < 0.01$ ). However, a comparative analysis between 8.36 and 9.69 % SMC for all the speeds showed no significant difference ( $P > 0.05$ ) between 8.36 and 9.69 % SMC. This once again confirms the findings from the analysis of seed damage.

## CONCLUSION

In conclusion, a portable splitter in sieve threshing unit that would handle cowpea threshing at acceptable seed damage was developed. Open air drying was considered because of its versatility to the local farmers who may not have access to mechanical dryers as well as seed moisture meters. The areas employed were the duration of drying before threshing and the rotor speed. The performance of the different SMC which is due to variations in drying duration was compared in with that of the rotor speeds. Analyses done at 1% and 5% level of significance indicated a significant difference ( $P < 0.01$ ) in the control of seed damage among the SMCs. However, there was no significant difference ( $P > 0.05$ ) between the seed loss control of 9.69 and 8.36 SMCs. The cowpea at 16.52, % SMC after three (3) days of drying produced the highest average seed damage of 3.58 % and 8.36 % SMC after fourteen (14) days of drying, yielded the lowest seed damage of 0.99 %. The minimum seed loss of the overall mean was reduced by 29.4 % for unit E of 8.36 % SMC, 20.6% for unit D of 9.69 % SMC and 7.4 % for unit C of 11.38 % SMC. Therefore, the best machine–crop parameter combination for optimal cowpea quality is SMC from 8–10 % and rotor speed ranging from 388–550 rpm. To achieve these SMC, the crop must be dried in the open air for a minimum of eleven (11) days at 7 hour/day after harvesting. It is recommended that further work should be done on comparing the threshing quality of cowpea dried by the open air method to the quality from mechanical dryers. The study should focus on comparing visible and nonvisible seed damage as well as seed viability. Different drying duration, different cowpea varieties and different threshing speeds could also be employed to either confirm the reliability or improve on the quality of the grain.

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## REFERENCES

- 1 Langyintuo, A. S., Lowenberg-DeBoer, J., Faye, M., Lambert, D., Ibro, G., Moussa, B., Kergna, A., Musa, S., Kushwaha, S., Ntougam, G. 2003. Cowpea supply and demand in West and Central Africa. *Field crops research*. 82, 215– 231.
- 2 Murdock, L. L., Baoua, I. B. 2014. On Purdue Improved Cowpea Storage (PICS) technology: 402 Background, mode of action, future prospects. *Journal of Stored Products Research*. 58, 3 – 11
- 3 Morad, M. M., El-Kot, A. S., Ali, M. M., Salem, H. M. 2007. Study on the Mechanization of Cowpea Crop Production under Egyptian Conditions. *Misr J. Ag. Eng. Farm Machinery and Power* 24(3):450 – 468.
- 4 Gomez, C. 2004. Cowpea Post-Harvest Operations, Food and Agricultural Organization of the United Nations (FAO) Rome. 2 – 4.
- 5 Irtwange, S. V. 2009. Design, Fabrication and Performance of a Motorized Cowpea Thresher for Nigerian Small-Scale Farmers. *African Journal of Agricultural Research* 4(12):1383 – 1391.
- 6 Salari, K., Amiri Chayjan, R., Khazaei, J., Amiri Parian, J. 2013. Optimization of Independent Parameters for Chickpea Threshing Using Response Surface Method (RSM). *J. Agr. Sci. Tech.* 15, 467 – 477.
- 7 Adekanye, T. A., Olaoye, J. O. 2013. Performance evaluation of motorized and treadle cowpea threshers. *Agric Eng Int: CIGR Journal* 15(4): 300–306.
- 8 Maunde, F.A. 2011. Performance Evaluation of Manual Cowpea Thresher, *African Journal of Agricultural Research* 6 (30): 6412.
- 9 Fulani, A. U., Kuje J. Y., Mohammed, B. I. 2013. Effect of Moisture Content on Performance of a Locally Fabricated



Cowpea Thresher. Department of Agricultural Engineering. College of Agriculture. Lafia, Nigeria 2(5):1 – 2.

- 10 Olaoye JO (2011) Development of a Treadle Operated Abrasive-Cylinder for Threshing Cowpea. International Journal of Engineering Science and Technology, (IJEST) 3(12):8548 – 8549.
- 11 Kepner RA, Bainer R, Barger EL (1978) Principles of Farm Machinery, (3rd Edition). AVI Publishing
- 12 Sharma, K. D., Devnani, R. S. 1980. Threshing studies on soybean and cowpea. A.M.A. 65 – 68.
- 13 Herbek, J. H., Bitzer, M. J. 2004. Soybean production in Kentucky: part V- Harvesting, drying, storage, and marketing. Lexington, Ky.: Cooperative Extension Service Bulletin AGR 132.
- 14 Sudajan, S., Salokhea, V. M., Triratanasirichai, K. 2002. Effect of Type of Drum, Drum Speed and Feed Rate on Sunflower Threshing. Biosystems. Eng. 83(4):413 – 421.
- 15 Ajav, E. A., Adejumo, B. A. 2005. Performance Evaluation of an Okra Thresher. Agric. Eng. Int. 7, 1 – 8.
- 16 Vejasit, A., Salokhe, V. M. 2004. Studies on Machine-Crop Parameters of an Axial Flow Thresher for Threshing Soybean. Agric. Eng. Int. Paper No. 04 004. 12.
- 17 Ukatu, A. C. 2006. A Modified Threshing Unit for Soya Beans, Biosystems Engineering, 95 (3): 371–377.
- 18 Altuntas, E., Yıldız, M. 2007. Effect of moisture content on some physical and mechanical properties of faba bean (*Vicia faba* L.) grains Journal of Food Engineering. 78, 174–183. doi.org/10.1016/j.jfoodeng.2005.09.013
- 19 Baryeh, E. A., Mangope, B. K. 2002. Some physical properties of QP-38 variety pigeon pea. Journal of Food Engineering 56; 59–65.
- 20 Srivastava, A. K., Mahoney, W.T., West, N. L. 1990. The effect of crop properties on combine performance ASAE Paper. 63–67
- 21 Al-Mahasneh, M. A., Rababah, T. M. 2007. Effect of moisture content on some physical properties of green wheat. Journal of Food Engineering 79, 1467–1473. doi:10.1016/j.jfoodeng.2006.04.045.
- 22 Ogunjimi, L. A. O., Aviara, N. A., Aregbesola, O. A. 2002. Some engineering properties of locust bean seed. Journal of Food Engineering 55 (2): 95–99.
- 23 Razavi, S. M. A., Amini, A. M., Rafe, A., Emadzadeh, B. 2007. The physical properties of pistachio nut and its kernel as a function of moisture content and variety. Part III: Frictional properties. Journal of Food Engineering, 81, 226–235. doi:10.1016/j.jfoodeng.2006.10.025.
- 24 Yalcın, I. 2007. Physical properties of cowpea, (*Vigna sinensis* L.) seed. Journal of Food Engineering 79, 57–62. doi:10.1016/j.jfoodeng.2006.01.026.
- 25 Addo-Quaye, A. A., Darkwa, A. A., Ampiah, M. K. P. 2011. Performance of three cowpea (*vigna unguiculata* (l) walp) varieties in two agro-ecological zones of the central region of Ghana I: Dry matter production and growth analysis. ARPN Journal of Agricultural and Biological Science 6(2): 1 – 9.