

A Review of Shelling, Threshing, De-Hulling and Decorticating Machines

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Abstract

Postharvest operations are activities which improves the value and conditions of agricultural materials. Primary postharvest operations such as shelling, threshing, de-hulling and decortications are very important in pods, seeds and nuts processing. Modern machines for improvement in the condition of pod, seeds and nut have been developed in the recent time. The principle of operation for pods, seeds and nut processing depends significantly on their engineering properties and as such may require different types of mechanism. This is discussed and the missing link in knowledge elucidated, especially on principle of operations of shelling, threshing, de-hulling and decorticating machines as well as factors affecting their efficiencies. The management and routine maintenance of shelling, threshing, de-hulling and decorticating machines are very important for extended useful life as discussed in the present paper.

Keywords: Shelling; Threshing; De-hulling; Decortications

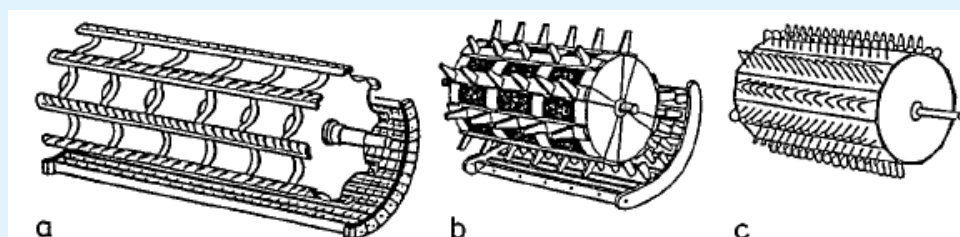
Introduction

In agricultural processing relevant activities include unit operations such as shelling, threshing, de-hulling and decortications. The major objective of shelling, threshing, de-hulling or decorticating of most farm products is to improve their value by detaching or dissociating their kernels or seeds from their enclosure. The principle of operation of a sheller usually involves application of impact force with partial shear force depending on the hardness of the shell of the seed while that of a thresher involves application of impact force only. Decorticators apply combination of impact with compressive force

while dehullers apply abrasive force to operate in most cases. Shelling, threshing, de-hulling and decorticating operations were done using manual methods like the use of sticks in hitting sacks loaded with pulses or cob with ears of corn, the use of mortar and pestle etc. before the advent of agricultural machines. Manual processing of agricultural material is time consuming and tedious; the conditions prevalent at this level of operation is generally unsanitary and inherently unhygienic, with little attention being paid to quality control, making the wholesomeness and quality of the products, below standard. The type of machine that is being used to work upon the agricultural materials depends on their engineering properties. For

instance a thresher is used for maize, decorticator for groundnut, de-huller for rice and shelling machine for moringa seed processing. Beside the crops mentioned above, these machines could be modified and used to process other crops. Maintenance of the processing machines listed above is similar to what is obtainable in

other agricultural processing machines. The working mechanisms in shelling and decorticating machines could be any of the following i.e. disc type, cylinder type, centrifugal type and roller type as shown in figure 1. This will be discussed later in the subsequent subtopics.

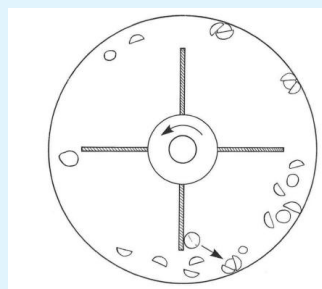


a Rasp bar cylinder

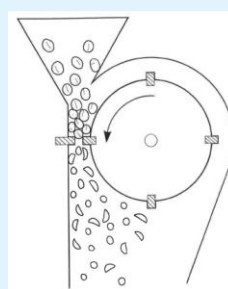
b Spike-tooth cylinder

c Wire-loop cylinder

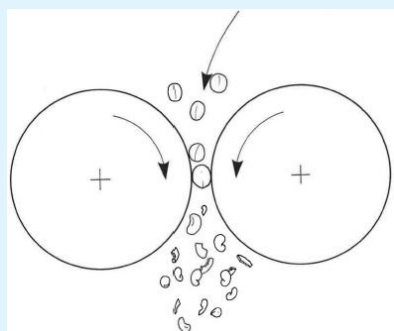
Source: CIGR (1999)



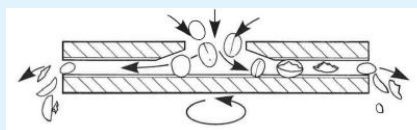
d. Centrifugal shelling device



e. Bars type shelling device



f. Roller type shelling device



g. Disc type shelling device

Source: Pinson et al. (1991)

Figure 1: Types of shelling and decorticating mechanisms

Shelling Machines

Shelling machines are mostly used for dry agricultural materials. Shelling machines are machines which apply mechanical force in removal of kernel from its casing (or enclosure) in order to free it from any attachment or confinement e.g. removal of palm kernel from its nuts,

removal of melon and moringa kernels from their shells. The principle of operation of shelling machines depends on the nature of the agricultural materials. For instance most motorized shellers use impact force in removing kernels from their encasement. This involves the application of mechanism such as flat bar or rasps bar

cylinder with concave screen. In this case the seeds are loaded into the hopper from where it moves into the shelling chamber. It is then beaten by the rotating cylinder to free the kernels from their casing. During this process, the kernels are being separated from their host and pass through the screen to be discharged at the chute. It should be noted that the principle of shelling depends relatively on the engineering properties of biomaterials to be shelled, as it varies from one type to another. Other shelling machines include melon sheller, palm nut cracker, bush mango seed shelling machine etc. These comprise of hopper- to hold the agricultural materials, spike-tooth cylinder or notched surface cylinder (depending on the nature of the seeds)- to shell the material, concave/screen- for separation and chute- to discharge the processed agricultural materials. Types of shelling machines include the following:

(a) Melon Sheller: A melon shelling machine is quite different from maize shelling machine. The working mechanism and the feeding unit in this machine are unique. The working mechanism consists of inclined flat bar cylinder. The feeding unit of this machine has a sliding gate which is used in controlling the feed rate. This machine applies centrifugal force in achieving shelling.

(b) Jatropha Seed Shelling Machine: A jatropha seed shelling machine is a new machine of research interest. The machine comprises of a hopper, shelling cylinder with a screen. In most cases, cleaners are usually incorporated into it. This machine also applies impact force in removing the jatropha kernel from its enclosure. This is shown below in figure 2.

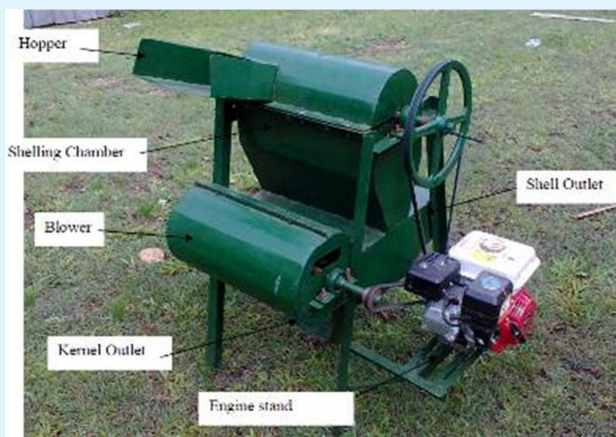


Figure 2: Jatropha seed shelling machine.
(Source: Aremu et al. 2015) [3]

(c) Moringa Seed Shelling Machine: The moringa seed machine is a machine which applies mechanical force in removing the endocarp of moringa seed to free the kernel moringa seeds from their enclosure. The moringa seed shelling machine comprises of hopper, shelling chamber, separation unit and chutes for both kernel and shell as shown in Figure 3.



Figure 3: *Moringa oleifera* seed shelling machine.
(Source: Fadele and Aremu, 2016) [4]

(d) Bush Mango Seed Cracker: A bush mango cracker is a device for removal of kernel of bush mango seed. This device applies only compressive force in cracking the seed when placed between flat plates as shown in figure 4.



Figure 4: Bush mango cracker.
(Source: Ogunsina et al. 2008) [5]

Thresher

This is also similar to a shelling machine. It uses the same principle as shelling machine to operate. Threshing means detachment of corn from their panicle. Threshing is accomplished by impact action in most conventional threshers. A rotating cylinder (spike-tooth cylinder) and a concave screen are utilized to accomplish threshing. As the cylinder rotate, the seed is detached by impact force from its panicle and drops on a reciprocating screen which separates the straws from the seed. Types of threshers include wheat, sorghum, millet guinea corn threshers and so on as shown in Figure 4. The components of most threshers comprises of the following:

- a. Hopper: to hold the agricultural materials before threshing
- b. Spike-tooth cylinder: to detach the seed from its panicle.
- c. Concave/Screen: to separate seeds from undesirable materials
- d. Chute: to discharge processed agric. materials

A conventional sunflower threshing machine is a machine which is used in detaching sunflower seed from its panicle. The major components of a motorized sunflower thresher are hopper, screen and spike-tooth cylinder. In some cases, a cleaner could be incorporated. The hopper is designed in such a way that it controls the rate at which the agric material is being fed into the threshing zone.

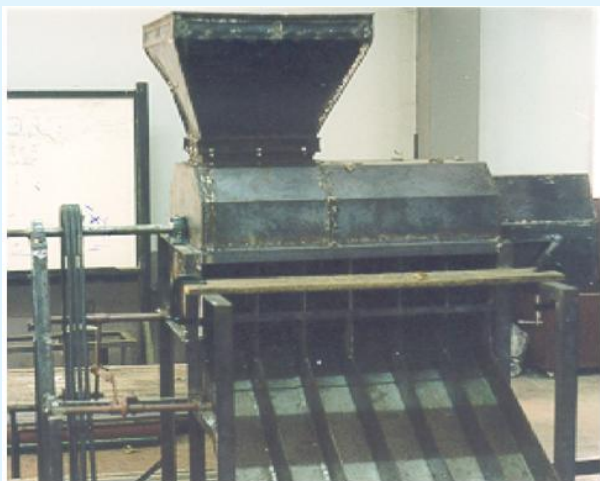


Figure 4: A sunflower thresher (Source: Sudajan et al., 2002) [6].

De-hullers

A de-huller is a machine used in removing outermost

thin-layer covering of a seed. De-hulling is a very important unit operation in food processing. De-hulling is the removal of the outer pericarp and testa (hull) during processing of cereal grains, grain legumes, nuts and oilseeds. Besides nutritional and aesthetic enhancement, de-hulling reduces the bulk density of the plant material, thereby facilitating better temperature management and control of other rate transfer processes in downstream processing. This unit operation is necessary in order to have products with desirable qualities. In the preparation of steamed bean cake, de-hulling of cowpea is very important in order to improve its appearance. Most de-hullers use frictional force in removing the outer thin layer of seed. This could be done using a serrated surface cylinder or grinding discs with a concave screen. The serrated cylinder rubs against the crop to remove its outer cover after which it is reduced to powdery form and passes through the screen to be removed while the de-hulled seed is discharged through the chute. The components of a de-huller are:

- a. Hopper- to hold the agricultural materials
- b. Serrated Cylinder or Grinding Disc- to de-hull the seeds
- c. Concave/Screen: for separation of grain from hulls.
- d. Chute: to discharge the processed agricultural materials

Decorticator

Decortication is the action of removing the seeds pod or casing in order to free the seed from any enclosure. This is usually done prior to milling and extraction of oil from oil bearing seeds. A decorticator is a machine that is used in the removal of outer coat of any agricultural materials usually pods. The process of decortication is synonymous to shelling. The word *decorticate* comes from the Latin verb *decorticare* derived by adding the prefix *de* (meaning to be rid off) to the noun *Cortex*. The cortex refers to the outer layer of a botanical or anatomical object, often specifically to a layer which lies just beneath the very outer surface, and to general features such as bark, husk, shell or rind. Conventionally, decortication encompasses dehulling, husking, cracking, splitting, popping and shelling. Decortication process is more generic than shelling process. In this case a decorticator could be used to remove the bark of a stem, seeds pod etc. A decorticating machine is a very versatile machine. Most decorticators apply shear and impact force to bring about decortications. This process is one of the most delicate operations in crop processing because the structure of the seed must not be tampered with or deformed. Types of decorticators include cowpea, groundnut and jatropha fruit decorticators as shown in Figure 5 to 7.

(a) Groundnut Decorticator: This machine is used in freeing groundnut seeds from their pods by cracking. Groundnut decortication may be achieved by means of different equipment varying in degree of complexity. A conventional groundnut decorticator perform the following functions:

- Control feeding of groundnut
- Crack the groundnut.
- Clean the seed from seed-pod mixture.

Therefore a groundnut decorticator consists of the following components:

1. Feeding Unit: The feeding unit comprises of a hopper, conveyor (usually belt conveyor). These components are very important in controlling the feed rate at which the material is being fed into the decortivating unit.

2. Decortivating Unit: The decortivating unit frees the seed from its enclosure. This is the working component of the machine. This mechanism is very important in the operation of the machine. The types of force in action are impact and shear force.

3. Cleaning Unit: The cleaning unit comprises of a fan which is driven by the prime mover. The fan blows in air through the separation tunnel to remove the pod from the groundnut seed. The principle of operation in this type of cleaner is dependent on the aerodynamic properties of the agricultural materials. Figures 5 and 6 show the diagram of a hand operated decorticator and a motorized decorticator.

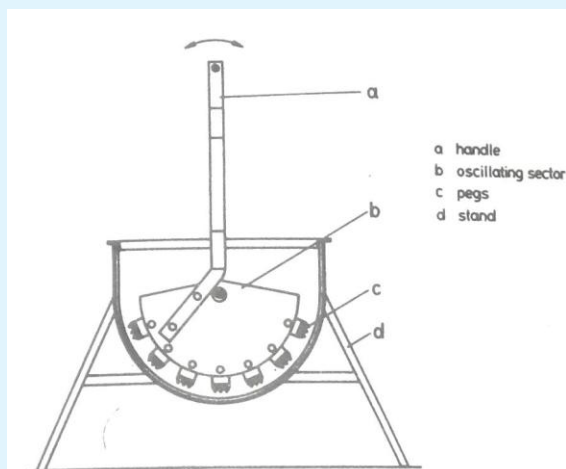


Figure 5: Hand operated groundnut decorticator.

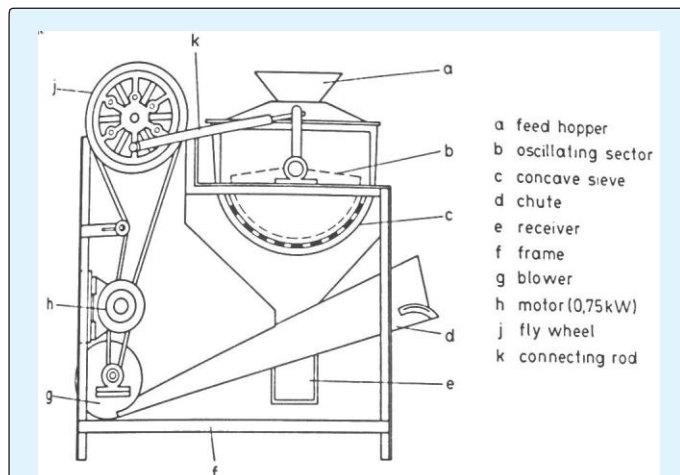


Figure 6: Motorized groundnut decorticator (Source: Asiedu, 1989) [7].

(b) Jatropha Fruit Decorticator: Ajatropha fruit decorticator is a machine which removes jatropha seed from its confinement. The jatropha fruit decorticator is a new machine of research interest. This machine comprises of a hopper, chute, seed/coat separator, and decortivating unit as shown in figure 7.

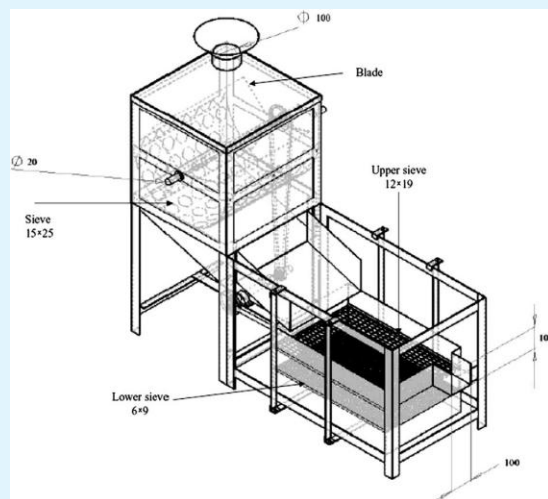


Figure 7: Hand-operated Jatropha fruit decorticator (Source: Pradhan et al. 2010) [8].

Factors Affecting Shelling, Threshing, De-hulling and Decortivating Processes

There are several factors that affect the performance of shelling, threshing, de-hulling and decortivating processes. These can be categorized into seed, operation

and design parameters. These factors determine the performance of shelling, threshing, de-hulling and decorticating machines in relation to kernel and seeds recovered [1,6,9,10].

Crop Factors Affecting Shelling threshing, de-hulling and Decorticating Processes

Crop factors are also known as crop conditions. Crop factors are the physical properties or characteristics of crop which affect machine performance. These include moisture content, crop maturity, sizes, shapes, species and cultivars. Many investigations have shown that the shelling, threshing, de-hulling and decorticating ability depends on different characteristics of the seeds, such as moisture content and seed sizes and shapes [1,11].

Makanjuola (1975) [12] investigated the impact of moisture content on shelling effectiveness of a melon shelling machine which revealed that the kernels could be separated more easily from the shells at low moisture contents. At low moisture content, the kernels do not fill completely the internal space of the shells and it is the little clearance between the kernels and the shells that facilitate the separation. It was established that the most appropriate moisture content for melon seed shelling is 8.6% moisture content (wet basis). Pradhan, et al. (2010) [8] studied the effects of moisture content on jatropha fruit decortications. The best moisture content was found to be 7.97% giving a maximum percentage whole kernel recovered to be $67.94 \pm 2.48\%$. It was established that this was due to the fact that at low moisture content the fruit become more brittle and susceptible to mechanical damage. Oluwole, et al. (2004) [13] developed and evaluated a shea nut cracker varying the moisture content of the nut. The best performance of the machine was discovered to be at moisture content of 23.1% with optimum cracking effectiveness, percentage of breakage, percentage partially cracked nut, percentage of uncracked nut and winnowing efficiency of 100.0, 0.0, 0.0, 0.0 and 97.9% respectively. Ogunsina and Bamgboye (2012) [14] identified moisture content as one of the seed factor having great influence on the whole kernel output of cashew nuts during shelling process. The best moisture content was found to be 8.34% giving 62.2 % percentage whole kernel. Prashant, et al. (2013) [15] worked on decortications of pretreated nutmeg varying the moisture content from 12% to 14%. A maximum value of 99.2% decorticating efficiency was obtained at a moisture content of 12% for the decortications of the nutmeg. Sharm, et al. (2013) [16] evaluated the performance of a tung fruit decorticator with the moisture content of the fruit varying from 8.65% to 15.61% (d.b). The best percentage whole kernel recovered of 52.24% was obtained with machine efficiency of 74.63% at fruit

moisture content of 8.65% (d.b.). Kumar, et al. (2016) [17] fabricated and tested a sal fruit decorticator varying moisture content of the fruit from 10.49% to 21.95% (d.b). The maximum percentage whole kernel recovered obtained was $62.71 \pm 1.73\%$ at 13.63% (d.b) moisture content.

Sizes of seeds or nuts are another factor that influence shelling and decorticating processes. Most researchers have worked on effects of variation in sizes of agricultural materials such as fruits and seeds on their decortications and shelling respectively. This is normally categorized into three viz. small, medium and large. It was reported that the sizes of the fruits depend mainly on the thickness of the shell for most seed [14,18-20]. The kernel sizes are not closely related to the external size of the nut. Irregularities in nuts or seed sizes can be dealt with by prior size grading, but it may be difficult to establish a workable machine setting for each size grade that will allow an acceptable balance to be achieved between the production of broken and whole kernels [2]. Ogunsina and Bamgboye (2014) [20] obtained the optimum percentage whole kernel of cashew nut to be 91.74, 90.94 and 87.98% for large, medium and small nut sizes; thus depicting increase of seed sizes with whole kernel recovery. This indicated that whole kernel recovery is dependent on seed sizes. Gupta and Das (1999) [18] reported best machine efficiency using sunflower medium seed size. Subramanian et al. (1990) [11] investigated the effect of seed characteristic on dehulling performance of a sunflower dehuller and it was established that shelling efficiency increased with increase in seed size, obtaining a maximum value of 76.7% using large sunflower seed. Large size seeds show greater shelling efficiency than the other seed sizes because the large seeds are more mature and the centrifugal force is greater, being proportional to the mass of the seed [11]. Romuli, et al. (2015) [21] also found that shelling efficiency of a jatropha seed shelling machine increased from 81.0% to 84.6% as the seed size increased.

Operation Parameters Affecting Shelling threshing, de-hulling and Decorticating Processes

Operation parameters are factors which affect the performance of a machine during a process or an activity. Some of these have been reported by researchers who worked on shelling, threshing, de-hulling and decorticating machines. Maduako, et al. (2006) [22] described operation parameters as operator based factors which include feed rate, operating speed, clearance, skill and experience.

Feed rate is the proportion of quantity of agricultural material being introduced into the machine to time taken.

Feed rate was reported to increase with losses during shelling while increase in the feed rate has a decreasing effect on the separation efficiency. Also, increasing the feed rate provides cushioning effect that may reduce grain damage [23]. Most researchers who worked on shelling and decorticating processes of seed or pods used feed rate ranging from 3 kg/h to 215.8 kg/h. Ranjeet and Sukhdev (2013) [24] reported feed rate values of 3, 4, 5, 6 and 7 kg/h. The maximum decorticating efficiency of 51.2% was obtained at feed rate of 6kg/h. Ranjeet and Sukhdev (2013) [24] reported that the decorticating efficiency increased with feed rate. Gupta and Das (1999) adopted a feed rate ranging from 20 to 200kg/h in dehulling sunflower seed. The feed rate was found to decrease with increase in dehulling efficiency, with the optimum feed rate being 100kg/h for sunflower seed dehulling. Oluwole, et al. (2004) [13] determined the effect of feed rate on shea nut shelling using feed rate values of 11.4, 15.5, 23.1 and 45.2 kg/h. The shea nut feed rate that gave the highest performance indices for the machine operation was found to be 11.4 kg/h. Subramanian, et al (1990) [11] investigated the effect of feed rate on dehulling performance of a sunflower dehuller and it was established that shelling efficiency increased with decrease in feed rate.

Operating speed is another operation factor that has been established to affect the performance of shelling or decorticating machines. Sudajan, et al. (2005) [10] reported that germination propensity of seed is inversely dependent on cylinder speed. The operating speed for seed/nut shelling or decortications ranges from 63 to 4750 rpm depending on the type of shelling device. In most cases it is usually high for centrifugal impaction devices [6,11,12,15,16,25-31]. Jain and Kumar (1997) [27] adopted discs speed of 160, 240, 320 and 400rpm in cashew nut shelling process and studied the effect of disc speed on shelling efficiency, capacity and percentage whole kernel recovered. It was established that with an increase in the disc speed, the capacity of the machine increased from 8 and 25 kg/h; shelling efficiency also increased from 60% at 160 rpm to 70% at 240 rpm but with further increase in the speed from 240 to 400 rpm the change in shelling efficiency was not significant at the 5% probability level; the whole kernel recovery varied between 50% and 53% when the speed ranged between 160 and 320 rpm. However, with further increase in speed (400 rpm), the whole kernel recovery reduced to 40-42%, which is significantly lower than the speed range of 160-320 rpm while the percentage broken increased with the increase in speed as a result of increase in shear force on the cashew nuts at the higher speed [27]. Sobowale, et al. (2015) [28] reported that the effect of shelling vane speed on melon, varying from 1500 to

2500rpm and obtained maximum percentage whole kernel and shelling efficiency of 61.22 % and 76.30% respectively at vane speed of 1500rpm. Balami, et al. (2012) [26] investigated the influence of cylinder speed on castor seed shelling process using the following values, 240, 320 and 400 rpm and established that shelling efficiency decreased with increase in the cylinder speed. The highest value obtained for the shelling efficiency was 99.5% at a cylinder speed of 240rpm. Chithra et al. (2008) [31] evaluated the performance of a black pepper decorticator varying the disc speed of the machine from 63 to 81rpm and obtained maximum decorticating efficiency of 69.52% at a speed of 71 rpm. There was an initial increase in decorticating efficiency with respect to speed, which may be attributed to the softening of the skin due to soaking, and the further decrease in efficiency may be due to crushing of berries at higher speed. Gupta and Das (1999) [18] optimized the dehulling process of sunflower seed varying the impeller speed from 34 to 54m/s, 28.3 - 41.9 m/s respectively and obtained optimum efficiency value between 69 and 77% and 74.15% at optimum impeller speed of 40.7 - 44.5m/s and 32.5 m/s respectively.

Moreover, operating clearance is another operation factor that affects the performance of shelling or decorticating machines. Operating clearance can be described as the gap or spacing between two different mechanisms which bring about a process. The operating clearance for seed/nut shelling or decortications ranges relatively depending on their sizes in terms of length, breadth, thickness, geometric and arithmetic mean diameter. Sudajan, et al. (2005) [10] showed that the germination percentage was directly proportional to the concave clearance. Many researchers who worked on shelling or decorticating process based operating clearance on the size and hardness of the agricultural materials [8,10,16,32]. Pradhan, et al. (2010) studied the effect of cylinder-concave clearance on the performance of a jatropha fruit decorticator using clearance values of 18 mm, 21 mm, 24 mm and 27 mm with best performance of 67.94% whole seeds and 90.96% machine efficiency at cylinder-concave clearance of 21mm. It was established that the decorticating efficiency of the jatropha fruit decorticator increase with decrease in the cylinder-concave clearance while the percentage whole seed recovered generally increased then decreased with the cylinder-concave clearance. Sudajan, et al. (2005) [10] investigated the effect of cylinder-concave clearance on the performance of a sunflower seed shelling machine using clearance values of 17, 23, 29 and 35mm and established that machine capacity increased with increase in the cylinder-concave clearance because the resistance between the head and the drum decreased when the

concave clearance increased. Thus, the force and frequency of impacts was also reduced.

The rubbing effect would not take place when the clearance exceeded the height of the sunflower head; however grain damage was found to decrease with increase in the cylinder-concave clearance. Romuli, et al. (2017) [32] modeled the decortications process of jatropha fruit using discrete element method simulation with the maximum upper and lower cylinder-concave clearance being 25mm and 35mm. It was established that the compressive force increased as the upper and lower clearance decreased. The best concave clearance that would generate adequate compression was found to be between 21.2 and 23.6 mm for the upper concave clearance while that of the lower clearance was between 14.1 and 15.7 mm. Sharma, et al. (2013) [16] also determined the effect of clearance on the performance of a tung fruit decorticator using clearance of 50, 75, 100 and 125mm. It was established that the percentage whole kernel increased to a certain point and then decreased with increase in clearance. Kumar, et al. (2016) [17] optimized the the performance of a sal decorticator using 2 factorial model based on cylinder-concave clearance of 10, 13, 16 and 19mm. The optimum cylinder-concave clearance was established to be 13mm with maximum machine efficiency and percentage whole kernel recovered of $93.62 \pm 0.87\%$ and $62.71 \pm 1.73\%$ respectively. Decorticating efficiency decreased with increase in concave clearance i.e. from 10 mm to 19 mm.

Design Factors Affecting Seeds Shelling and Fruits Decortications

Design factors are also referred to as machine factors. These are the factors that determine the configuration and geometry of the working mechanism of a machine. In process optimisation of agricultural processing machines, design factors are not insignificant. These factors determine the quality, appearance as well as acceptability of the processed agricultural materials. Maduako, et al. (2006) [22]; Oluwole, et al. (2004); [13] Odigboh (1979) [33] and Srivastava, et al. (2013) [23] reported some of the design factors affecting the performance of a sheller and these include type of cylinder, cylinder diameter, concave length, number of bars on the cylinder and fan speed, vane configuration, concave hole or aperture shape.

Sudajan, et al. (2005) [10] investigated the effect of concave aperture on performance of a sunflower threshing machine. It was reported that the concave aperture significantly affected the capacity, grain damage, grain losses, and the total grain-MOG separated by the concave, but did not affect the threshing efficiency. The

concave aperture increased with increase in the capacity of the sunflower threshing machine while it decreased with increase in percentage grain damage. Also investigated the effect of different impeller designs on the performance of bambara nut decorticator and reported that the impellers with eight slots consistently gave the best performance. Makanjulola (1975) [12] also worked on melon seed shelling process using three different types of impellers with four and eight slots respectively with third having two parallel plates. The impeller with four slots was the most efficient of the three types tested.

Management of Shelling, Threshing, De-hulling and Decorticating Machines

Management of most agricultural processing equipment involves routines that are taken into consideration while operating the equipment. Maintenance of agricultural processing machine is also important after operation. In operating decorticating and shelling machines, the following steps are very important:

- Ensure that the crop is free from any foreign materials that could damage the working components of the machine.
- The machine should be run for some time before it is loaded.
- The agricultural materials to be processed must be at the appropriate moisture content.
- The feed rate must also be adjusted in order to enhance the efficiency of the machine.
- All safety measure must be observed while operating the machine.

The following are routine maintenance in processing equipments:

- There should be periodic tightening of bolts and nuts.
- Machines should be cleaned and dislodged of remnant materials.
- Machines should be kept from environmental hazard.
- Worn-out components of the equipment should be replaced.
- Clogged straws should be removed from the screen from time to time.
- Adjustment of clearance between the cylinder and screen should be carried out periodically.

Conclusion

Shelling, threshing, de-hulling and decorticating processes have been identified as post-harvest operations which improve the quality and value of agricultural

materials such as grains, seeds and pods. The principle of operations some types of shelling, threshing, de-hulling and decorticating machines were reported to be dependent on their engineering properties. Moreover, the crop condition, operation and design parameters affecting the performance of shelling, threshing, de-hulling and decorticating machine were considered to be significant in maximizing the capacity and efficiency of these machines. Proper management and maintenance of shelling, threshing, de-hulling and decorticating machines would extend their useful life having discovered that the performance of most post-harvest machinery tend to reduce as a result of poor management and routine maintenance. Kernels, seeds and grains breakage have been identified as peculiar bottleneck in most of these machines; further research should be veered to production of whole kernels, seeds and grains with minimal breakage.

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