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A Review of Decorticators for Various Industrial Crops: Design, Working Principle, and Parameters Affecting the Efficiency

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***Abstract:** Traditional knowledge in India is plenty, but its reporting for knowledge sharing is needed. A decorticator is a machine traditionally used to augment local farmers' needs. Decortication is the phenomenon of discarding the seed pods or casing and separating the seed pod or enclosure from the seed or kernel. Many developments in the decorticators have happened in the last one or two decades. They are either manually operated or power-driven. Few of the developed technologies are available in the Indian market. One of the drawbacks of these machines is their adaptability to different seeds or fruits. Efforts are made to increase the efficiency of the decorticators by reducing the drudgery and hazards. The economic aspect of the design and developments have also been looked into. Decorticator machines are available for groundnut, jatropha, nutmeg, sal, apricot, hemp, tamarind, mango stone, mahua, tung, chironji, castor, sunflower, etc. The principle of operation of all the developed decorticators is different, like the type of forces used for the removal of the seed coat. The working principle of each developed machine is highlighted in this review. The efficiency of the decorticator is dependent on many factors such as crop maturity stage, shape and size of seeds, moisture content, etc. Also, various machine parameters like feed rate, operating speed, clearance, operator's experience, and skill will affect the efficiency of decorticators. A critical review is made to understand all the mentioned factors and their influence on decorticator efficiency. Agricultural scientists will highly benefit from this compiled review work and it will be helpful in the design and development of decorticators for any specific seeds.*

***Keywords:** Centrifugal Force, Clearance, Decortication, Efficiency, Kernel, Pod, Seed.*

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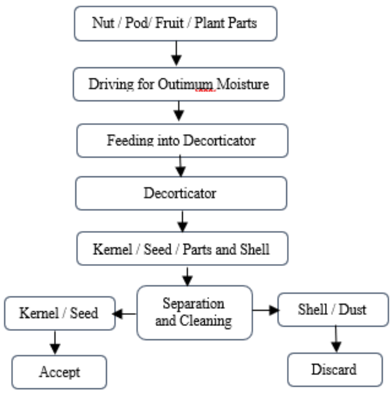
Abbreviations:
Kg/H: Kilogram Per Hour
SD: Standard Deviation
W.B: Wet Basis
D.B.: Dry Basis
%: Percentage
MM: Millimeter
G: Gram
I.E.: That Is
RPM: Revolution Per Minute
M/S: Meter Per Second

I. INTRODUCTION

The word decorticate originated from two Latin words, 'Decorticare' and 'Cortex'. The meaning of the decorticare word is 'to be rid off' & the noun is the cortex. The bark or cortex denotes the external layer of an anatomical or botanical object, particularly a stratum that lies just underneath the exterior side, which may be a shell, husk, rind, wood, bark, etc. [1]. It includes de-hulling, cracking, husking, splitting, shelling, and popping. Decortication is more common than the shelling method. Decortication is a phenomenon of eliminating the seed pods or cover to release the seed from any outer layer. It is generally followed before sowing, milling, pulping, or extraction of oil [2]. Good seeds are highly essential for farming, consumption, and value addition. Some seeds are available to farmers after the proper decortication process. This can be done manually or mechanically. Before the development of decorticators, farmers were using traditional methods to decorticate seeds. For example, stones were used as hammers in decorticating mahua seed kernel (Fig. 1).



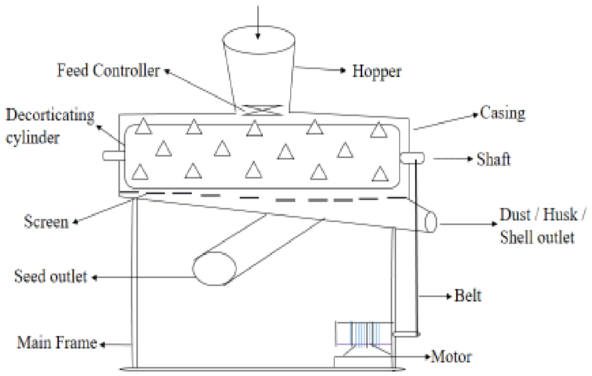
[Fig.1: Process Flow-Chart of Decortication [1]]

Many advancements have been made in the development of decorticating machines for different crops. Decorticator machines are available for groundnut, jatropha, nutmeg, sal, apricot, hemp, tamarind, mango stone, mahua, tung, chironji, castor, sunflower, etc. During decortication, if the seed is damaged or cracked, then the seed will not germinate, and value addition can't be done. So, the farmers or business people will be the losers. The decorticator is a post-harvest processing machine that removes the outer seed cover of agricultural commodities, usually adhesive materials or pods by applying different forces. The process of decortication is similar to shelling. In this work, a decorticator is used to separate the seed pods, the bark of a stem, etc.

Most of the decorticators apply both shear and impact force. It is an essential operation in the processing of crops because the structure of the desired material or seed should not be deformed or damaged. In some decorticating machines, the process is "semi-automatic", having several stops, while decorticators are fully automatic in modern systems. In manual decortication, the percentage of kernel breakage is less. Still, it is tedious, labor-intensive, and leads to "sore thumb syndrome" and more energy consumption when huge quantities are handled [3]. The decorticating machine can minimize the labor costs, drudgery, and time associated with cleaning, decortications, and preparation for further processing. Decortication of most agricultural products is to increase their value by separating their inner part, kernels, or seeds from their outer cover.

II. WORKING PRINCIPLE OF SEED DECORTICATOR

The general process of decortication is given in Fig. 2.



[Fig.2: Schematic Diagram of a Decorticator]

Seeds or pods are fed into the hopper across a feeding channel and passed into the decorticating chamber. Inside the decorticating chamber, the moving rods/blades move, which press the seeds contrary to a connected fixed concave screen. This compression and shear force assists the seed cover in rupturing. Because of non-stop rotation or oscillating operation, the blades produce shearing and impact forces inside the chamber, which causes the cracked seed coat to break and detach from the seed. After that seed coat, seed and other parts such as dust, broken seed, partially decorticated or fully decorticated seeds, if any, come out from the discharge unit and are collected. Then seeds are separated from the rest undesired materials manually or mechanically by the grader. The decortication principles may vary for different seeds/fruit. A list of seeds/fruit and the type of forces required for the decortication is given in Table I.

Table-I: Principle of Decortication for Different Crops

Sl. No.	Name of seed/fruit	Principle of Decortication	Reference
1	Groundnut	Impact, shear, compressive, and tangential force	[26]
2	Castor	Rubbing action	[27]
3	Sunflower	Centrifugal force and impact	[28]
4	Jatropha	Rotating impact	[3]
5	Nutmeg	Impact and shearing forces	[6]
6	Sal	Impact, compression, and shearing	[6]
7	Apricot	Impact and compressive	[15]
8	Tamarind	Impact and cutting	[26]
9	Mango stone	Cutting	[8], [24]
10	Tung	Centrifugal impaction	[2]
11	Chironji nut	Impact	[29]
12	Neem	Impact and shear	[9]
13	Pongamia	Shear, compressive, and impact	[30]
14	Mahua	Compression, impact, and shear	[31]
15	Bambara nut	Impact and shear	[32]
16	Banana fiber	Compression and wringing	[17]
17	Melon	Impact	[16]
18	Moringa oleifera	Impact and shear	[33]
19	Muskmelon	Abrasion	[11]
20	Sisal	Cutting and compression	[10]
21	Black Cumin	Abrasion and friction	[18]
22	Shea nut	Impact	[4]
23	Snake guard	Impact	[19]
24	Black pepper	Compression and shear	[13]

A. The decorticator is operated on the attrition process.
B. The inputs, such as the pods or fruits, are fed to the decorticator through the hopper, and the seed comes in contact with the two components. One is a rubber mount arranged rotating shaft, and another is semi-circular mesh.
C. The Semi-circular screen is a stationary component while the rubber mount arranged rotating shaft is a rotating part. The attrition occurs when the seeds come in contact with these two components.
D. The pods get ruptured and separated into two parts, i.e., the seed and shell, because of attrition action.
E. Some clearance is kept between the sheet and the rolling shaft. It depends upon the varying size of the seed.
F. After shelling the pod, the seeds and shells of the crop fall into the conveyer from the semi-circular mesh in the downward direction.
G. One blower is fitted, providing a centrifugal force on the shells of the pod and seeds.
H. The seeds get moved downward due to more weight and are collected in a separator. However, the shell of the pod is blown outside the machine due to its lighter weight.

The different parts of a decorticator include a decorticating cylinder, casing, inlet hopper, separating mesh, discharge system for decorticated seed and husk, and the power transmission system. The design of decorticating cylinders may vary depending on the type of forces required for a particular fruit. Different decorticating cylinders are shown in Fig. 3.

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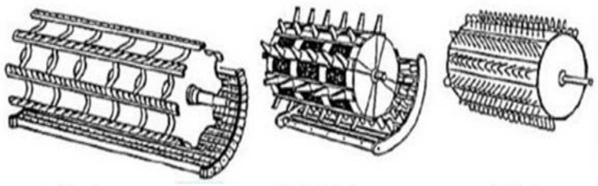

[Fig.3: Different Types of Decorticating Cylinders]

III. FACTORS AFFECTING DECORTICATING PROCESSES

Several factors affect the performance of decorticators. These can be classified into (a) seed, (b) operation, (c) design parameters, or machine parameters and crop factors. These parameters influence the performance of decorticators, threshing, shelling, and de-hulling machines with the recovery of seed and kernel.

A. Crop Factors Affecting Decorticating Processes

Crop characteristics are the crop's physical and textural properties that affect machine output or performance and the final seed or grain. These include crop maturity, moisture content, shapes, sizes, species, and cultivars. There is little clearance between the shells and kernels which facilitates the separation. The kernels or seeds do not fill the inner space of the nuts or shells at low moisture content. The optimum moisture content for the shelling of melon seed was recorded to be 8.6% on wet basis. The effects or result of moisture content for decortication of jatropha fruit was investigated by Pradhan et al. [3]. A maximum of 67.94 ± 2.48 % whole kernel was found at an optimum moisture content of 7.97 %. It was concluded that the fruit becomes more brittle and vulnerable to mechanical damage due to less moisture content.

Oluwole et al. [4] Fabricated and tested a shea nut cracker considering different moisture contents of the nut. The maximum working performance of the decorticator was observed at a moisture content of 23.1%, with its best 100 % cracking effectiveness, breakage of 0 %, percentage of partially broken nut as 0 %, and uncracked nut as 0 %, and winnowing efficiency of 97.9 %.

Ogunsina and Bamgboye [5] discovered that the moisture content of the seed is considered one of the crop factors that significantly affect the output of the whole kernel during the shelling operation of cashew nuts. The whole kernel recovery was 62.2 % at an optimum moisture content of 8.34 %. Said et al. [6] investigated the pretreated nutmeg for its decortications at a varying moisture content of 12 % to 14 %. At a moisture content of 12%, the highest value of 99.2 % decorticating efficiency was found for the decortication of the nutmeg. Sharma et al. [2] tested a tung fruit decorticator to know the performance with the moisture content ranging from 8.65 % to 15.61 % (d.b) of the fruit. The highest percentage of whole kernel recovery was 52.24 % at 8.6 5% (d.b.) moisture content of the fruit with a machine efficiency of 74.63 %.

Shashi Kumar et al. [7] developed and evaluated a sal fruit decorticator with the different moisture content of the fruit ranging from 10.49 % to 21.95 % (d.b). The highest percentage of the whole kernel recovery was 62.71 ± 1.73 % at a moisture content of 13.63 % (d.b). The nut or seed sizes are another factor influencing decorticating and shelling processes.

Some researchers have worked on fruits and seeds to know the effects of sizes on their decortications and shelling. The size of agricultural commodities is mainly divided into three groups small, medium, and large. The size and shape of the fruits are primarily dependent on the thickness of the shell for most of the seeds. The kernel or seed sizes are not strictly associated with the outer dimension of the nut. Deformity or irregularities in the seed or nut sizes should be managed by prior sorting or grading based on size. Still, it would be a complicated task to set up a feasible decorticator for each size grade that will acknowledge a justifiable balance between the recovery of whole and broken kernels.

Karthickumar et al. [8] developed a pneumatic mango stone decorticator and reported that moisture content of 12-15 % (wb) in the mango stones kept in the jaw slot got cut in a single stroke. After that, the kernel could easily be separated from the shell. The mango stone needed more than one stroke to cut it completely when the moisture content was more than 15 %. Solanki et al. [9] developed and evaluated a manually operated neem seed decorticator. It was reported that the highest decortication efficiency of 78 % and capacity of 20 kg/h was obtained for seed moisture content of 11.6 %, sieve size of 20 x 5 mm oblong holes, flat belt beater, and concave clearance of 4 mm. Ahmad et al. [10] developed and tested a sisal leaf decorticator and reported that the machine's production capacity was 15.94 kg/h (dry fiber) when the moisture content of leaves was 81 % (wb) and 2.1 mm was the decortication pitch.

B. Operational Parameters Affecting Decortication

Operational parameters are the factors that influence the performance of a decorticator during an activity or a process. Some of the parameters have been described by different researchers and scientists who worked on decorticating, threshing, shelling, and de-hulling machines. An increase in loss was found with the feed rate during shelling, but the decrease in separation efficiency was due to the rise in the feed rate. Also, the increasing trend of feed rate impacts a cushioning effect which may minimize the mechanical damage of grain. Some researchers and scientists who investigated the decorticating and shelling processes of pods or seeds considered feed rates varying from 3 kg/h to 215.8 kg/h. Ranjeet and Sukhdev [11] described the values of 3, 4, 5, 6, and 7 kg/h as feed rate. The best decorticating efficiency of 51.2 % was achieved when a feed rate of 6 kg/h was fixed and the decorticating efficiency improved concerning feed rate. Gupta and Das [12] validated the feed rate starting from 20 to 200 kg/h in the de-hulling of sunflower seed. The de-hulling efficiency was found to increase with a decrease in feed rate, and the maximum feed rate of 100 kg/h was considered for sunflower seed de-hulling. Oluwole et al. [4] established the relationship between the feed rate and shelling of shea nut, considering the values of 11.4, 15.5, 23.1, and 45.2 kg/h as feed rate. The feed rate of the shea nut, which gave the best performance indices for the machine operation, was recorded to be 11.4 kg/h.

Chithra [13] worked on the performance of a black pepper decorticator estimated the

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efficiency at different disc speeds from 63 to 81 rpm, and found the highest decorticating efficiency of 69.52 % at 71 rpm of the machine. It was reported that there was an initial increase in decorticating efficiency concerning speed, which may be attributed to the loosening of the skin due to soaking, and a further decrease in efficiency at a higher speed may be due to the crushing of berries.

Gupta and Das [12] worked on sunflower seed to optimize the de-hulling process considering different impeller speeds from 34 to 54 m/s and 28.3 to 41.9 m/s. It was derived that the maximum efficiency value between 69 to 77 % and 74.15 % was found at an optimum impeller speed of 40.7– 44.5 m/s and 32.5 m/s, respectively. In addition, the operating clearance is another parameter that governs the performance of decorticating or shelling machines. The operating clearance can be expressed as the spacing or gap between two different mechanisms that give rise to a process.

The operating concave clearance for nut/seed decortication and shelling varies relatively depending on their shape and sizes concerning longest, intermediate, and smallest dimensions, arithmetic, and geometric mean diameter. Pradhan et al. [3] examined the impact of cylinder-concave clearance on the output and performance of a jatropha fruit decorticator considering the values of clearance as 18 mm, 21 mm, 24 mm, and 27 mm, with the highest performance of 67.94 % whole seeds and 90.96 % of machine efficiency at a cylinder-concave clearance of 21 mm. It was confirmed that the decorticating efficiency of the jatropha fruit decorticator increased with a decrease in the cylinder concave clearance, but the percentage of whole seed recovery gradually increased and then decreased concerning the cylinder concave clearance.

Romuli et al. [14] worked on jatropha fruit and modeled the decortication process applying discrete element method simulation with the maximum lower and upper cylinder-concave clearance of 35mm and 25 mm, respectively. It was found that the compression force increased as the lower and upper clearance decreased. The optimum concave clearance that would create sufficient compression was between 14.1 and 15.7 mm for the lower concave clearance, while the upper concave clearance was between 21.2 and 23.6 mm. Sharma et al. [2] worked on a tung fruit decorticating machine and established the impact of clearance on the machine's performance with clearance of 50, 75, 100, and 125 mm. It was determined that the percentage of the whole kernel increased to a certain point and then declined with an increase in clearance.

The best performance of the apricot pit decorticator with the lowest percentage of broken kernels for maximum decortication efficiency was found at a moisture content of 15% (w.b), crankshaft speed of 85 rpm, impact clearance of 0.8 mm, and feed per stroke of 18 g/stroke. Broken kernel and decortication efficiency percentages were obtained in the range of 8.97–30.17 % and 67.25–77.49 %, respectively [15].

The melon decorticating machine was evaluated for the percentage of damaged and decorticated seeds, decorticating efficiency, machine capacity, and performance. The outcomes from the fabricated machine show a 73.1 % shelling efficiency and 14.3 % seed damage while using a moisture content of 30% (d.b.). The manual shelling was reported to have shelling efficiency of 10 %, 15.7 %, and 20.2 %, but 20.2% being its maximum efficiency which was noticed to be much less than that of the developed machine [16].

One banana fiber decorticator with a wringer was designed and fabricated to extract fiber from the pseudo stem of the banana plant [17]. Keeping the length of the pseudo-stem 355 mm, the thickness of the stem 10 mm, and the motor speed 2800 rpm, the fiber recovery was found to be 0.4-0.5 %, 0.6-0.7 %, 0.8-1.0 %, and 1.5 to 2.5 % when the distance between two rollers was kept 7.0 mm, 6.5 mm, 5.2 mm, and 4.0 mm, respectively.

Thilakarathna et al. [18] designed and developed a black cumin decorticator to explore the use of cumin seed for commercial use and traditional medicine by removing the thick and black seed coat. The seeds were soaked in cold water for 5mins, and the decortication efficiency was found as 48 %, 55 %, 64 %, 76 %, and 85 % after 1st, 2nd, 3rd, 4^{th,} and 5th term of decortication, respectively.

Idowu and Owolarafe [19] developed and tested a snake gourd seed decorticator and reported that shaft speed, hammer diameter, soaking time, and feed rate affected the decorticating efficiency. Decorticating efficiency was increased with the increase in soaking time, hammer diameter, and hammer speed but decreased with an increase in feed rate. The best decorticating efficiency of 97.61 % was obtained at a hammer diameter of 150 mm, hammer speed of 400 rpm, soaking time of 20 min, and feed rate of 90 kg/h.

Karthickumar et al. [8] developed and evaluated a power-operated continuous tamarind de-seeder. It was reported that the moisture content of the fruit, wooden roller speed, feed rate, and horizontal clearance affected the deseeding efficiency of the machine. The best deseeding efficiency of 89.15 % was obtained at 22.5 % moisture content (db) with a feed rate of 45 kg/h, wooden roller speed of 3.4 m/s, and a horizontal clearance of 16 mm. This machine showed 93.34 % savings in time and 74.9 % savings in operation.

C. Design Factors Affecting Decortications

Various decorticators developed to date are given in Fig. 4. The design of decorticators cannot be generalized for all the fruits. Many factors influence the process efficiency like, type of forces, size and type of fruit, etc. So, these factors govern the geometry and configuration of a machine's working principle and mechanism. During the optimization of agricultural processing machines, the design parameters are highly considered, which are highly significant. These factors regulate the appearance, quality, preference, and cost of processed agricultural commodities [1]. Odigboh [20] stated that some of the design factors influencing the working of a decorticator are the number of bars on the cylinder, type of cylinder, cylinder diameter, concave length, concave aperture or hole shape, fan speed, and vane configuration. Sudajan et al. [21] studied the impact of concave aperture size on the output of a sunflower thresher. It was found that the shape and size of the concave aperture remarkably affected the machine output, grain losses, seed damage, and the total grain or seed separated by the concave but did not hamper the threshing efficiency significantly. The concave aperture kept increasing with

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an increase in the capacity of the sunflower thresher, but it decreased with an increase in the percentage of grain damage. It also tested the influence of different impeller designs on the performance of the bambara nut decorticator. It was found that the impellers with eight slots invariably showed the best performance. Makanjuola et al. [22] investigated the shelling process of melon seed considering three different types of impellers with eight and four slots, respectively, with the third impeller containing two parallel plates. The impeller having four slots was cost-effective and the most efficient out of the three types tested.

Chithra [13] developed a power-operated decorticator for black pepper to remove its black cover to get white pepper, which has high export potential. The highest decortication efficiency of 93.4% was obtained with a soaking period of 17 hours and a speed of 71 rpm with the grinding stone and polyurethane. Similarly, the decortication efficiency of 67.45% was obtained with a soaking period of 18 hours and a speed of 57 rpm having the grinding stone coupled with a teflon sheet. For the resin sheet, the decortication efficiency of 77.00 % was obtained with a soaking period of 17 hours and a speed of 71 rpm.

Nayak et al. [23] developed and evaluated a hand-operated mango stone decorticator with the highest decortication capacity of 1.92 ± 0.04 kg/hr and whole kernel recovery of 85.95 ± 1.53 % was found than the traditional method with 1.10 ± 0.09 kg/hr and 58.37 ± 1.76 %, respectively. The material loss percentage of 5.28 % in the conventional method was very high as compared to that achieved by the developed decorticator, which was 2.78 %.

Jambh and Kumar [24] developed and tested a pneumatic mango stone decorticator cutting 18 mango stones in a batch. It was tested by applying 6-8 bar pressure on the cutter to cut the stones. The results showed that the machine cuts the stones more efficiently into two pieces at high pressure and low temperature.

Sahu and Gulhane [25] developed and tested a tamarind seed decorticator and predicted that the throughput capacity of the machine was 100 kg/h having 90 % cover removal and 75 % seed separation efficiency [34].

Nowadays, cryogenic seed decorticators are being developed to maintain temperature during decortication because more heat is generated inside the decorticating chamber due to frictional force. Here liquid nitrogen is used as a cooling medium [35]. The quality of seed or kernel for therapeutic and nutritional value is retained due to low-temperature decortication.

Pradhan et al. [3] suggested different formulae to calculate some of the parameters for the various components of decorticators which are as follows-

$$P = 2\pi NT \quad \dots \quad (1)$$

Where P is the power requirement, W; N the revolution per second; T is the torque applied, Nm

$$T = F \times r \quad \dots \quad (2)$$

Where F is the force required to break the fruit, N; r is the width of the rotating blade, cm

$$Mc = \frac{P}{12} \times \left(\frac{l^2 \times r^2}{\sqrt{l^2 + r^2}}\right) \quad \dots \quad (3)$$

Where M_c is the moment of the couple, N m; l the length of the rotating blade, cm;

$$Mr = \frac{f \times t^2}{6} \times \sqrt{(l^2 + r^2)} \quad \dots \quad (4)$$

Where M_r is the bending moment, N m; f the permissible stress, kg/cm^2; t the thickness of the rotating blade, cm

$$M = \frac{W \times l}{8} \quad \dots \quad (5)$$

Where M is the maximum bending moment, N m;

$$Te = \sqrt{(M^2 + T^2)} \quad \dots \quad (6)$$

Where T_e is the equivalent torque, Nm;
Or

$$Te = \frac{\pi}{16} \times d^3 \times Fs \quad \dots \quad (7)$$

Where F_s is the shear stress of the material, kg/cm^2; d is the diameter of the shaft, cm

$$L = 2C + \frac{\pi}{2}(D_1 + D_2) + (D_1 - D_2)^2/4C \quad \dots \quad (8)$$

Where D_1 is the diameter of the big pulley, D_2 is the diameter of the small pulley, and C is the center-to-center distance between the two pulleys; L is the length of the belt.

IV. MANAGEMENT OF DECORTICATING MACHINES

Management of decorticators is considered both in idle condition and during the operation of the machine. Maintenance and care of any agricultural processing machines are necessary after the completion of work. The following steps are very much essential while operating the decorticators.

A. Ensure that no foreign materials can damage the decorticator's different components and spare parts.
B. The decorticator should be run without load for some time before it starts working on load.
C. The agricultural products to be decorticated must have the desired moisture content.
D. The feed rate should be controlled to increase the efficiency or output of the machine.
E. The protection and safety measures should be followed during the operation of the machine.

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V. THE ROUTINE PREVENTIVE MAINTENANCE OF THE DECORTICATORS

A. There should be routine tightening or loosening of nuts and bolts as per requirement.
B. The machine should be lubricated for moving parts and cleaning before or after the operation as required for remnant materials.
C. The machine should be kept away from environmental hazards.
D. The machine's worn-out spare parts or components should be replaced or repaired.
E. The screen should be kept clean, and the clogged foreign materials, if any, should be removed from the screen.
F. The gap between the screen and cylinder must be adjusted as per requirement.

VI. CONCLUDING REMARKS AND PROSPECTS

Considerable works on the development of decorticators have been made in recent times. Efforts have been made to increase the efficiency of the machine by reducing drudgery and hazards. Loss of the seeds in the form of broken depends on various parameters starting from crop maturity to machine parameters such as the speed of the rotor, even the skill of the operator influences the loss. There is a huge scope for developments to eliminate these factors which influence the efficacy of decorticators. The decorticators are designed for specific crops that do not accommodate other crops. So, efforts should be made to make the decorticators universal at least for similar kinds of crops. Refinement in the design of existing decorticators for their improvement is needed. Care and preventive maintenance should not be overlooked to minimize the hazards. So, this piece of work would help the research community to look into the limitations highlighted and work to improve the efficiency of the decorticators in the future.

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DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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- **Authors Contributions:** The authorship of this article is contributed equally to all participating individuals.

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