

DESIGN DEVELOPMENT AND PERFORMANCE EVALUATION OF PSYLLIUM (ISPAGHOL) HUSK SEPARATOR CUM GRADER

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ABSTRACT: Psyllium (Ispaghool) is an important therapeutic plant usually cultivated in several areas of Pakistan, India, Bangladesh and Iran. The most important portion of Ispaghool crop is its husk, which is the outermost skin of the seed. High medicinal value of Ispaghool husk enables it and its by-products for numerous usages in pharmaceutical industry. The husk can be collected from seed by various conventional and mechanical grinding methods. However, farmers in Pakistan have no mechanized post-harvest processing facility available for the Ispaghool crop. Conventional methods for husk separation from seed core (de-husked seed) are time-consuming and labour-intensive and also reduce husk quality and quantity. Husk separation from de-husked seed is a big challenge, therefore a machine has been developed and tested for its performance evaluation. This machine boosts the processing capability of Ispaghool more than manual techniques, which can process 160 kg of de-husked seed in 1 hour. The machine compared to manual can save 60-70% time and 50% labour cost. The performance of the machine was evaluated at three blower air speeds (8, 9 and 10 m/s) and three drum speeds (80, 110 and 140 rpm). The machine performed better at the circular centrifugal spreader speed of 110 rpm and blower air speed of 9 m/s, the husk separation was quantified to be 98% and also the obtained husk was free of core and other impurities and provided dust-free and healthy surroundings. Commercialization of such machinery is the need of the hour to enhance productivity and maintain quality, resulting in increasing exports and contributing to a better economy.

Keywords: Ispaghool Husk Processing; Mechanized Husk Separation; Husk Grading; Design and Development.

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INTRODUCTION

Psyllium, commonly known as Ispaghool, is scientifically classified as *Plantago Ovata* and belongs to the Plantaginaceae family. The term "Psyllium" is derived from the Greek word "psulla," meaning flea, because the seeds resemble tiny, whitish fleas. The name "Ispaghool" comes from Persian, where "Isap" and "ghol" refer to "horse ear," reflecting the seed's unique shape [1]. The plant itself is a small, erect, multi-branched herb that typically grows to about 40 cm. It features numerous flowering shoots emerging from its roots, and its seeds are housed in spherical structures that split open when mature. The seed's outer coat is thin, translucent, and boat-shaped, with a slightly mucilaginous taste [2].

Ispaghool is widely used for its medicinal properties, especially the husk, which is employed both as a therapeutic agent and in the food industry. The husk is rich in dietary fibre, making it an effective remedy for health issues such as diabetes, obesity, high blood pressure, constipation, diarrhoea, and high cholesterol.

These benefits make it a popular ingredient in processed foods and medicinal products worldwide [3].

Ispaghool is cultivated across many regions, notably the Mediterranean, West Asia, and areas like Sulej and Sindh in modern-day Pakistan. The plant thrives in arid environments and has a root system with an extensive taproot and fibrous secondary roots. India is the leading producer and exporter of Ispaghool, accounting for 98% of the global supply and contributing Rs. 30 million annually to its economy. In contrast, Pakistan, despite having ideal conditions for its cultivation, particularly in the Cholistan and Thar regions, lags in production. Pakistan imports around \$1.3 million worth of Ispaghool from India annually, though its potential for self-sufficiency is high [4]. The crop also shows resilience in salt-affected areas, tolerating high pH levels without significant reductions in yield [5] [6].

However, in Pakistan, the unavailability of mechanized processing technology and outdated and manual processing methods pose a major hurdle to expanding production. These labour-intensive techniques

make husk extraction inefficient and expose workers to health risks such as asthma and other lung diseases [7]. Currently, Pakistan has about 46 traditional Ispaghool processing units, particularly in Hasilpur, with a combined processing capacity of about 15 tons per day. These units are insufficient to meet both local and

international demand, highlighting the need for technological advancement in processing techniques [8] [9]. As Ispaghool husk got separated from its seed their grading and separation is a much more difficult task using manual techniques involving pedestal fans and manual sieving as shown in figure 1 and figure 2.



Figure 1: Husk separation with traditional method



Figure 2: Husk grading with traditional method

Air classification is a technique for sorting particles based on their shape, size, and specific gravity. Static air classifiers control the product size by adjusting the airflow direction and magnitude [10] [11]. Dynamic classifiers, however, utilize a rotating cage to feed and determine product size. In first-generation classifiers, a scattering plate disperses the material into classification walls, and air helps separate particles. Air is forced through a separator in this process [12] [13]. Second-generation classifiers incorporate cyclones to enhance fine material collection, increasing productivity. The classification fan is located outside the separator, further improving efficiency [14] [15]. High-efficiency classifiers, also known as third-generation classifiers, are designed for optimal performance and efficiency [16] [17].

Air classification is a valuable innovation for grading materials, using air as the separation medium. The technique categorizes materials based on their shape, size, and weight. Key goals of air classifier studies include improving design and understanding how various parameters affect grading efficiency. Classifiers can be fed directly into the air stream or mechanically into the machine. The type of classifier selected depends on technological and product-specific requirements [18] [19]. The performance of high-efficiency classifiers depends on factors such as feed loading, airflow, and rotor speed. The rotation speed affects the overall flow rate, while the sharpness of separation and the transmission pattern depend on fixed guide vanes [20].

In an energy audit of an Ispaghool processing plant, the feed rate and clearance settings between the

under-runner disk were optimized for husk recovery. Four feed rates (2500–3500) and four sets of disk clearances were tested to improve energy efficiency and husk recovery at maximum capacity [21].

The objectives of the current study were to design, develop and evaluate its performance by investigating the effect of fluctuating feed rate that is the disk rotational speed and airflow speed to husk removal percentage and to observe the variation of husk removal percentage with the variation of clearance. With varying clearance, the air speed varies and the husk is separated in fractions and cleaned from dust. This mechanism will provide an efficient means of Ispaghool husk separation, cleaning and grading to get improved quality husk production and add value to post-harvest processing.

MATERIALS AND METHODS

This section include the study area and methodology for the development of psyllium (ispaghool) husk separator cum grader;

Study Area

The experiment for the design and development of psyllium (ispaghool) husk separator cum grader was conducted in Agricultural Engineering Institute (AEI), National Agricultural Research Center (NARC), Islamabad, Pakistan

Ispaghool Seed Characteristics: To analyse the mean dimension of seeds, 100 seeds were randomly selected

and three dimensions of seeds, length, width, and thickness, were assessed with the help of Digital Vernier Calliper model number SV-03 of Taiwan and the scale of accuracy was 0.01mm. Arithmetic mean diameter (D_a) and geometric mean diameter (D_g), sphericity and surface area of seeds were also calculated.

A Mettler Toledo AT261 electronic balance was used to weigh the seeds with a readability of 10 grams. Thus, bulk density is defined as the granule mass in a given volume in which it is possible to place a determined amount of free and membrane air, true density is determined by the granule mass and its volume excluding air in the box containing samples, and angle of repose were measured. The permeability of the grain bulk was determined by the results of the true density and bulk density of the seeds [22].

Physical Properties of Ispaghool Seed: The following are the physical properties of Ispaghool seed:

Table 1: Physical properties of psyllium seed [25].

| Properties | Mean (SD) |
|--|---------------|
| Length (mm) | 2.70 (0.15) |
| Width (mm) | 1.33 (0.10) |
| Thickness (mm) | 0.72 (0.09) |
| D_g (mm) | 1.37 (0.09) |
| D_a (mm) | 1.58 (0.08) |
| Sphericity (%) | 51.1 (1.20) |
| Volume (mm ³) | 1.47 (0.25) |
| Surface area (mm ²) | 5.02 (0.60) |
| 1000 seed mass (g) | 1.30 (0.10) |
| True density (kg m ⁻³) | 1350.6 (5.80) |
| Bulk density (kg m ⁻³) | 647.4 (4.02) |
| Porosity (%) | 52.06 (0.09) |
| Angle of repose (°) | 33.8 (0.12) |
| Terminal velocity (m s ⁻¹) | 1.47 (0.04) |

Table 1 shows the physical and aerodynamic characteristics of the seeds. Thus, the mean length, width and thickness of the seed were 2.70, 1.33, and 0.72 mm, respectively. By geometric (D_g) and arithmetic (D_a) diameters were 1.37 and 1.58 mm, respectively. The dimensions of the seed taken along the axis have significance in the identification of the aperture sizes in the designs of the grain handling machinery. Moreover, axial seed dimensions can be included by taking the geometric mean for the description of the peculiarities of the behaviour of irregular seeds. Sphericity is a relative degree of non-roundness for a body of solid grain, which is its deviation from the sphere with the same volume and made of the same material. Thus, the conical features of the cluster and, therefore, the sphericity value of 51.17% were noted for Ispaghool seed.

Thus, it became evident that the mean of a thousand seed mass was 1.3 g. The mean of the real and apparent density and the porosity of the seeds were 647.4, 1350.6 kg/m³ and 52.06%, respectively. Hence, the apparent seed density was more than that of rape (612.1 kg/m³) and cotton (642 kg/m³) seeds. Also, the true density of the seed was higher than sesame (1222 kg/m³) and black cumin (1040 kg/m³) seeds. The extent of porosity of Ispaghool seeds is 49.55% and 52.35%. In certain trials, the angle of repose was 33.8°, it is indicated that Ispaghool seeds have moderate fluidity. The angle of repose is crucial information that is required to be used in developing the right incline of grain discharge hoppers. This implies that for grain hopper the manageable angle has to be greater than the angle of repose to ensure easy flow during seed release. The terminal velocity of Ispaghool seeds was found to be 1.47 m/s [25].

Mechanical Properties of Ispaghool Seed: The following are the Mechanical properties of Ispaghool seed in Table 2:

Table 2: Mechanical properties of psyllium seed [25].

| Orientation | Mean (SD) |
|-------------|--------------|
| Energy (mJ) | |
| Horizontal | 1.09 (0.02) |
| Vertical | 0.96 (0.01) |
| Force (N) | |
| Horizontal | 19.74 (0.09) |
| Vertical | 7.63 (0.03) |

These properties are used as the defining characteristics in the measurement of the compression property and movement characteristics of materials needed for scheming seed silos and other containers. The average energy and force necessary to achieve a break in Ispaghool seed under loading in both the approaches; namely, horizontal and vertical axes were 19.74 N and 1.09 mJ and 7.63 N and 0.96 mJ respectively. From these outcomes, it can be concluded that psyllium seeds are more likely to assume a horizontal position rather than a vertical position. In other words, if the seeds are put in the vertical position Ispaghool seeds interact with contacting plates with a lesser area, and thus the seeds are subjected to increased stress with the contacting surface [25].

Static and Dynamic Friction Coefficients of the Ispaghool Seed: The following are the static and dynamic friction coefficients of Ispaghool seed:

Table 3: Dynamic and static friction coefficients of Ispaghool seed on different surfaces [25].

| Surfaces | Mean (SD) |
|----------|-----------|
|----------|-----------|

| Dynamic | |
|-----------------------|--------------|
| Galvanized iron sheet | 0.445 (0.04) |
| Glass | 0.286 (0.06) |
| Stainless steel | 0.353 (0.05) |
| Plywood | 0.324 (0.01) |
| Static | |
| Galvanized iron sheet | 0.404 (0.02) |
| Glass | 0.263 (0.01) |
| Stainless steel | 0.383 (0.02) |
| Plywood | 0.409 (0.03) |

The mean static friction coefficients of Ispaghool seeds with different material structures such as plywood galvanized iron stainless steel are glass is 0. 409, 0. 404, 0. 383, and 0. 263, respectively. As a result, the plywood sheet was higher than the other sheet materials in terms of coefficient of static friction because of more rough surface than other mentioned sheets. Also, the average dynamic friction coefficients for galvanized iron, stainless steel, plywood and glass sheets are 0.445, 0.353, 0.324, and 0.286, respectively as shown in Table 3 [25].

Particle Settling Air Velocity: In an air classifier, the separation of particles is influenced by air velocity which depends upon varying density, size and shape of particles and is proceeded by gravity, buoyancy forces and fluid drag. Buoyancy forces are often ignored since air density is smaller than the density of solid particles. Fluid drag is the main factor that remains with every particle causing upward movement opposite to the weight of the particle and sweeping out it from the top of the classifier if the weight gets higher particles travel downward and are collected at the bottom [24].

$$Drag\ force = \frac{\pi C_d \rho_g V^2 d_p^2}{8 C_c}$$

$$Weight = \frac{\pi \rho_p g d_p^3}{6}$$

By combining the equation of particle weight and drag force, particle settling velocity (v) is given as:

$$v = \left[\frac{4 \rho_p g d_p C_c}{3 C_d \rho_g} \right]^{1/2}$$

Where; ρ_g = air density, ρ_p = particle density (kg/m^3), v = particle settling velocity, d_p = particle diameter, C_c =

Cunningham slip factor (It is significant for the particle sizes $<15\mu m$, for air at ambient conditions), C_d = Drag coefficient, g = gravitational acceleration ($9.81m/s$). The angular velocity can be found using the given formula:

$$v = r\omega$$

Where; r = radius of rotor (m), ω = rotor rpm, v = linear velocity of particle

Design and Development of Psyllium (Ispaghool) Husk Separator Cum Grader

Blower Impeller Design: Consideration of rotor design is found essential parameter for designing of efficient air classifier. Classifiers having a capacity of 5 tons per hour have to be manufactured for splitting particles less than or equal to 2.36mm [12]. Input parameters like classifier capacity, bulk density, static pressure, airflow and static pressure are needed to make the optimal design of the rotor. The following equation depicts the relation between these parameters [23].

$$D_{pc} = \frac{(k\sqrt{Q})}{N}$$

Where

D_{pc} = particle size,

K = constant,

Q = Air flow in m^3/min ,

N = rotor speed

Airflow per ton (m^3/hr)= capacity (ton/hour) \times bulk density(kg/m^3)

Peripheral velocity of rotor= $(\pi \times$ Rotor blade tip diameter (mm) \times Rotor speed(rpm))/(60×1000)

Description of the utility design with details of components: To impart a better understanding of this equipment model, a preferred embodiment of the invention is discussed in detail. After completing the theoretical study regarding the seed characteristics and design parameters, the utility model was designed using CAD utility packages like AutoCAD and Solid Works for precise and perfect design before prototype development. An isometric view of the present equipment model, the psyllium (Ispaghool) core separator and the husk classifier is presented in Figure 3.

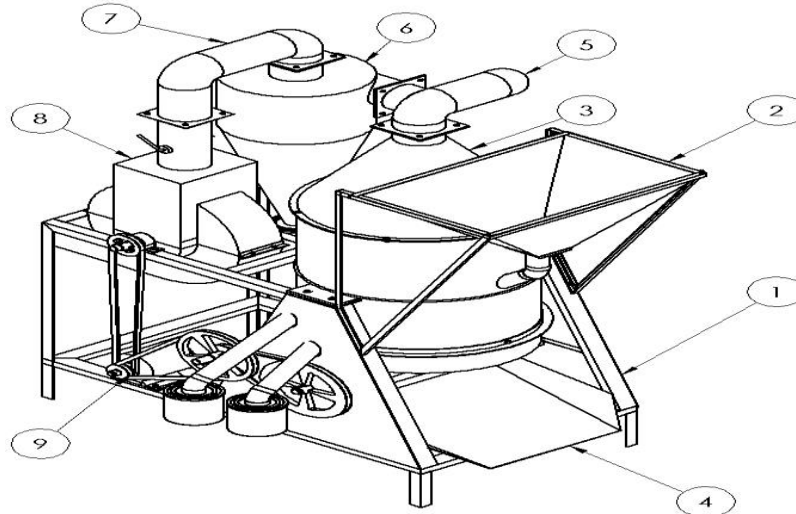


Figure 3. Isometric view of the present equipment model, the psyllium (Ispaghul) core separator and husk classifier

Description components: In Figure 3 the Ispaghul core separator and husk classifier consist of different assemblies, viz., 1 - main frame, 2 - hopper, 3 - husk classification drum, 4 - seed core collection tray, 5 - husk conveying pipe, 6 - cyclone, 7 - suction blower pipe, 8 - suction blower, 9 - motor, belt and pulleys arrangements, 10 - circular centrifugal spreader with the gearbox. The 3D models of important component assemblies are shown in Figure 4.

The mainframe assembly is a rigid frame made of MS channel and angle iron and consolidated by a welding process to carry all other assemblies of the utility model. The hopper assembly is fixed on the right side of the mainframe assembly using bolts and nuts. The husk classification drums assembly is mounted on the mainframe between the hopper and cyclone assemblies. The circular centrifugal spreader with gearbox assembly is installed at the bottom of husk classification drums that receive the mixture of seed core and husk at the central position from the hopper through a material conveying pipe.

The gearbox is mounted at the bottom of the circular centrifugal spreader to transmit the horizontal rotation of the shaft member to vertical rotation at an angle of 90° with belt and pulley arrangements. The suction blower assembly with an airflow controller is fixed on the left side of the main frame to create suction pressure within the cyclone and husk classification drums. The belt and pulley drive system is provided vertically between the suction blower and electric motor on the front side of the utility model. The husk classification drums, cyclone and suction blower assemblies are connected through husk conveying pipes. The core collection tray is installed at the bottom of the circular centrifugal spreader at a downward angle to collect the core dropped from the circular centrifugal spreader.

The hopper assembly is employed on the right side of the main frame assembly. The hopper assembly consists of a hopper stand made of MS angle iron, a feeding hopper, a feed slider and a slot for the to and fro motion of the feed slider. Four inclined hopper walls are adjusted in such a way that forms a narrow opening at the bottom of the hopper assembly. The feed slider is provided at the bottom of the hopper opening to control the discharge of input material (seed core and husk) dropped at the centre of the circular centrifugal spreader. The hopper is mounted on a stand to raise its height to easily transport input material from the hopper through the pipe.

Development of the Equipment Prototype: The prototype of the equipment by component component-wise and all developed components were assembled according to the designed model. The followings are the components/ parts as shown in Figure 4, their development and main operational functions of the Ispaghul husk separator cum grader machine:

- a. **Main frame:** The main frame is the part of the machine which holds the other essential components together. The base of the main frame is made with MS channel 4×6". An angle iron is used for the remaining structure.
- b. **Air Classifier:** This is the main unit in which the husk is separated from the de-husked seed and two types of husk graded, complete husk and broken husk. This consists of an outer drum, inner drum and complete husk collecting cone.
- c. **Outer drum:** Outer drum was made with an 18 gauge Mild steel sheet having a diameter of 36" and length of 48". Two holes for the complete husk and the broken husk exit pipe. The lower side of the outer drum is open and the upper end

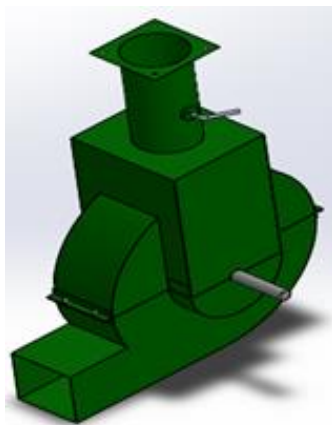
is closed with a cone having a slant height of 25". A 14" pipe is attached at the upper cone for air suction having a height of 8". This pipe is attached to the cyclone for suction.

- d. **Inner drum:** The inner drum has a height of 36" and dia. on top 30" and at bottom 28" with a slant height of 38". This inner drum is open at the top and closed from the bottom with a tilt plate at 45 degrees to collect the complete husk.
- e. **Complete husk collection cone:** A small cone of dia. 12" and bottom 4" with slant height 14" attached in the centre of the inner drum to collect broken husk. A 3" pipe is attached at the bottom.
- f. **Centrifugal plate spreader:** A rotating plate having a dia. of 36" with a side round plate of the height of 6" is attached to the bottom of the outer drum in 3" inside of the outer drum. This rotating plate is mounted on the centre shaft attached with a 90-degree gearbox drive by a driven pulley. This plate gets seed from the hopper and flows towards the edges of the plate by centrifugal force. The de-husked seed falls on the tray by weight and the husk is sucked by suction and moves towards the upper cone. Due to the pressure drop the complete husk falls first and collects from the inner drum broken husk

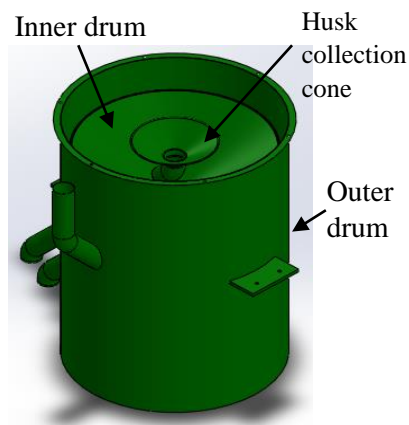
with slightly less weight falls into a smaller cone and powder moves in the cyclone due to very little weight.

- g. **Cyclone:** Cyclone is made with MS sheet 18 gauge length 45" plate area 10" and has a 3" opening at the bottom for powder husk. In the cyclone, the husk powder is separated and fresh air is removed from the blower attached to the cyclone.
- h. **Suction Blower:** A suction blower having an outer casing 8" diameter 24" having an impeller of 4 wings each wing 4*6". The function of this blower is to suck the husk as it is operated on the exact airflow speed, which is slightly more than the terminal velocity of the Ispaghul husk.
- i. **Feeding Hopper:** The Hopper is made with an MS sheet having a capacity of 80 kg attached to the main frame and an inlet feeding pipe of 3" is attached to the hopper to feed at the centre of the rotating plate. The feed controller is attached to control the seed flow rate.

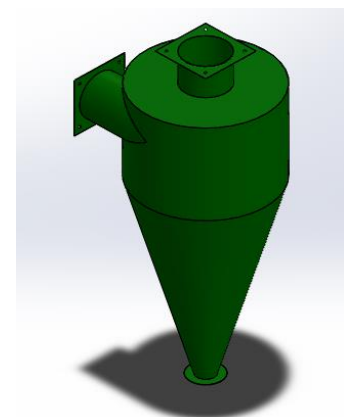
All these components as described were developed individually and then assembled with a designed arrangement to get the complete operational processing unit. Initially, it was operated idly to assess the operational performance of the machine.



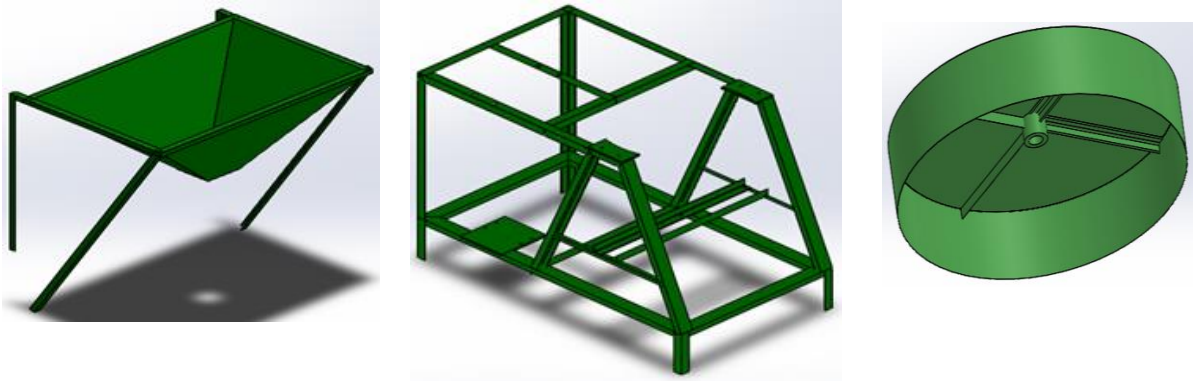
Suction blower assembly



Husk classification drum assembly



Cyclone assembly



Feeding hopper assembly

Main frame of the machine

Rotating plate

Figure 4. Various components of the Ispaghool husk processing machine prototype

Operation of Equipment: A single-phase 2-hp electric motor is used to operate the machine. Pulleys and v-belts are mounted in a combination of vertical and horizontal directions to give drive to the gearbox and blower.

This typical utility model is a very essential unit of the agricultural processing industry that is capable of separating psyllium cores from husk along with classifying husk into three grades.

Performance Evaluation of Psyllium (Ispaghool) Husk Separator Cum Grader: On satisfactory operation, it was tested for Ispaghool husk separation and grading and was evaluated for its effectiveness and working efficiency for the purpose it was designed and developed.

Separation and Grading Process: The circular centrifugal spreader with gearbox assembly consists of a circular centrifugal spreader, a vertical shaft member, a horizontal shaft member, couplings and a gearbox. The circular centrifugal spreader rotates at a constant low speed (i.e., 100-120 rpm) to scatter the input material uniformly around it by centrifugal force. A circular centrifugal spreader has a downward extension to provide a continuous narrow path to increase the suction pressure and time to pick up husk particles by air suction.

The husk classification drums are supported with the main frame in the middle position and consist of an outer drum and an inner drum, husk conveying pipes and an inverted cone at the top. The outer drum has a uniform diameter and then has a neck at the top, which is connected to the cyclone. The inner drum has a slightly wider diameter at the bottom and a slightly narrow diameter on the top to decrease the opening between the inner drum and the outer drum at the bottom to increase suction pressure to separate the husk particles from the seed cores.

With upward movement, the opening area between the inner drum and outer drum gradually increases, whereas the terminal velocity of husk proportions decreases. When the terminal velocity equals

to the gravity force, the large husk particles fall in the large conic collector. The small husk particles being lighter, move a bit further and drop in the middle on the small conic collector. The large and small husk particles move out using material-conveying pipes in airtight collectors respectively. The pipes intersect the inner and outer drums to bring out husk products from inside to collectors.

The cyclone assembly is connected with the husk classification drums through a PVC pipe. The powdered husk material moves out of the classification drums and comes into the cyclone assembly where the powdered husk drops in the airtight collector fitted below the cyclone assembly using a suction blower.

The data of various performance parameters, effectiveness on separation and grading of husk and operational efficiency were collected, statistically analysed and drawn results that are presented in the next section of results.

RESULTS AND DISCUSSION

The results and important findings of the experiments conducted for the performance evaluation of the machine and effectiveness of husk separation from seed and the effective and efficient grading of the separated husk are presented and elaborated. The machine was evaluated at three drum speeds ($DS_1 = 80$, $DS_2 = 110$ and $DS_3 = 140$ rpm) and three blower air speeds ($AS_1 = 8$, $AS_2 = 9$ and $AS_3 = 10$ m/s). The statistical analysis revealed that the machine performed better at the drum speed of 110 rpm and air speed of 10 m/s with maximum husk separation of 99.2 % but the problem observed was that some of the core was also added in the separated husk due to high air speed (10 m/s).

While, at the drum speed of 110 rpm and air speed of 9 m/s, the husk separation was quantified to be 98 % and also the obtained husk was free of core and

other impurities as shown in Figure 9 and Table 4. The results are parallel with the findings of [26] who found that the optimum operation conditions for cyclone separation were, the air velocity of the cyclone cylinder was 15.3 m/s, the air volume was 0.479 m³/s and the

linear velocity of the forced conveyor belt was 1.57 m/s (the roller speed of the forced conveyor belt was 500 r/min). Under these conditions, the cleaning ratio was found to be 96.98%.

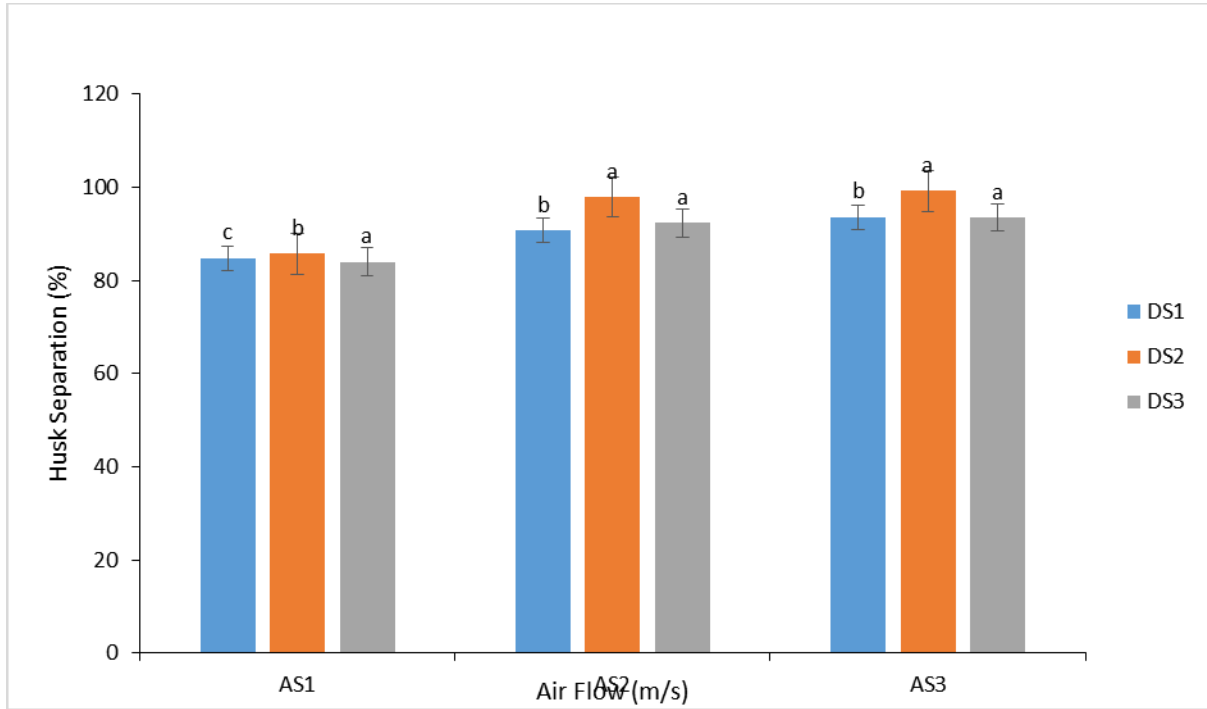


Figure 5: Husk separation (%) for psyllium husk separator cum grader

The results are significant and are in line with the set hypothesis and targeted objectives. The machine performed well and excellent results were found on the effectiveness, performance and efficiency of husk

separation from the seed and sorting of the husk into three grades according to the size, quality and fineness of the produced husk that separated from the seed core.

Table 2: Husk separation (%) at different air speeds and drum speeds

| Drum Speed (rpm) | Air Speed (m/s) | | | Mean |
|------------------|-----------------|-------|-------|-------|
| | 8 | 9 | 10 | |
| 80 | 84.8c | 90.8b | 93.6a | 89.7b |
| 110 | 85.7b | 98.0a | 99.2c | 94.3a |
| 140 | 84.0c | 92.3a | 93.5b | 89.9a |
| Mean | 84.8c | 93.7a | 95.4b | |

The performance evaluation of the husk separation machine involved experiments conducted at three different drum speeds (DS1 = 80 rpm, DS2 = 110 rpm, and DS3 = 140 rpm) and three blower air speeds (AS1 = 8 m/s, AS2 = 9 m/s, and AS3 = 10 m/s). The objective was to determine the optimal conditions for maximum husk separation efficiency and to assess the quality of the separated husk. The findings revealed significant variations in husk separation performance based on the different operating conditions [12] [20].

At a drum speed of 110 rpm and an air speed of 10 m/s, the machine achieved the highest husk separation efficiency of 99.2%. However, this high air speed also caused some seed cores to be mixed with the separated husk, affecting the purity of the product. In contrast, when the airspeed was reduced to 9 m/s while maintaining the drum speed at 110 rpm, the husk separation efficiency slightly decreased to 98%. However, this lower speed produced a cleaner husk, free from core material and impurities. These results demonstrated that a balance between airspeed and drum

speed is essential for optimizing both separation efficiency and product purity [20] [21].

These results were consistent with previous findings, such as those from cyclone separation studies, where optimal air velocity and conveyor speeds yielded a cleaning ratio of 96.98%. In both cases, airflow and rotational speed played critical roles in separating the husk from other components [16] [21].

Overall, the experiments validated the effectiveness of the machine in separating husk from seed and sorting the husk into different grades based on size, quality, and fineness. The findings showed that optimal settings for drum speed and air speed could significantly enhance the efficiency and purity of the separated husk, fulfilling the intended objectives of the evaluation. The results align well with the theoretical expectations and practical requirements for husk separation and grading.

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