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Design and Development of Laboratory-Scale Cleaner for Paddy Grain with Magnetic and Pneumatic Separation

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ABSTRACT

Food security is a critical concern, and ensuring food quality is just as crucial as ensuring availability and affordability. In Indonesia, paddy is a staple crop with high production and consumption rates. To improve the quality of paddy, particularly in the harvesting and post-harvest processes, mechanization technology has been implemented. One way to assess the quality of harvested paddy is by measuring parameters such as cleanliness and yield loss rate. However, the manual separation process for local varieties is time-consuming and limited in terms of scale. To address this issue, a laboratory-scale paddy grain cleaner was developed based on the physical and aerodynamic characteristics of local paddy varieties. The proposed cleaner includes a hopper, vibration feeder, magnetic separation, pneumatic separation, paddy grain tray, and impurities tray. The vibration feeder prevents grain damage and ensures accurate and consistent seed flow. The feeding system uses a vibration motor with a rotating unbalanced mass within an angle of 30° on both sides and a slope of 7.8° supported by four stainless steel 304 springs with a theoretical displacement maximum value of 0.1593 mm. The feeding rate measurement results are directly proportional to the level of grain moisture content. The paddy grain cleaner has a rotating single-cylinder neodymium magnet for gravel separation and uses axial and centrifugal fans for pneumatic separation of empty grain and low-density impurities. Testing without a centrifugal fan shows better results for lower moisture content of paddy grain with an average separation efficiency, separation loss, and cleaning efficiency of 99.49%, 0.53%, and 99.81%, respectively.

1. Introduction

Quality is an important aspect besides availability and affordability in measuring the global food security index (GFSI) which has been developed by The Economist Intelligence Unit. Based on the global food security index (GFSI) in 2021, Indonesia has an overall rating of 69 out of 113 countries and this is still below other ASEAN countries such as Malaysia, Thailand, Vietnam, and Philippines. The quality aspect is the aspect with the lowest score compared to availability and affordability [1]. Paddy (*Oryza sativa*) is an important food crop which has a high level of production and consumption for

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residents in Indonesia. Paddy undergoes several processes before it is transformed into rice, which can then be used as an ingredient in various processed foods and industrial products [2].

Agricultural mechanization technology is utilized to enhance the quality of paddy. It is important to have optimum performance of mechanization technology for harvesting and post-harvest processes to meet grain quality standards [3]. Numerous studies have focused on improving grain cleanliness. Zhan Su *et al.,* (2020) adjusted the threshing gap on the combine harvester to improve the threshing and screening processes [4]. Wang *et al.,* [5] designed an optimal scheme for seed filtering with high efficiency and low yield loss in combine harvesters. Fan *et al.,* [6] conducted research to improve the performance and threshing efficiency of multipurpose harvesting machines by automatically adjusting the slope of the guide vane based on the feed rate during harvesting. However, the studies only aimed to improve the performance and efficiency of combine harvesters.

Parameters such as yield loss rate and level of cleanliness are crucial factors in assessing the performance of harvesting and post-harvest machines. Improper cleaning can lead to insect infestation, mold growth, off-flavors and colors, and equipment damage during processing [7]. Separating paddy grains from impurities like straw, empty grain, gravel, and dust is necessary to determine the level of cleanliness. Several studies have focused on developing machines to achieve this goal. Afolabi *et al.,* [8] designed, developed, and evaluated a pneumatic cum eccentric-driven grain cleaning machine. Krzyiak *et al.,* [9] analyzed the tilt angle of the sieve unit in a rotary cleaner for grain cleaning. Akatuhurira *et al.,* [10] developed and tested a pedal-operated seed cleaner [10]. Zhang *et al.,* [11] designed and optimized an air screen cleaning system for maize using the response surface method. Kahandage *et al.,* [12] developed and evaluated the performance of a medium-scale seed paddy cleaning machine. The grain cleaning machine (winnower) with pneumatics and a sieve, which uses the same working principle as the machine studied in this research, is also commonly used in the industry.

The existing machines face a significant obstacle in their inability to accurately assess the level of cleanliness when using the sampling method. Although an industrial-scale grain cleaning machine (winnower) is widely used in the community, its output capacity of over 1200 kg/hour results in a high loss rate when analyzing only 100 grams of grain weight as required by Indonesian National Standards (SNI) 8185:2019 about combine harvester test methods [13]. While laboratory-scale whole grain separation tools are available on the market, they are relatively expensive and may not produce accurate results due to differences in physical and aerodynamic characteristics of local varieties in Indonesia. Furthermore, pneumatics and sieves alone may not entirely remove dirt such as stones that have similar specific gravity to grain, leading to potential contamination [12]. Consequently, the analysis of grain cleanliness still requires manual labor, which can be repetitive and prone to operator fatigue and takes long time [14]. Therefore, this study aims to design, develop, and evaluate laboratory-scale cleaner based on the physical and aerodynamic characteristics of paddy grain local varieties.

2. Methodology

2.1 Concept Design

The paddy grain cleaner is designed to meet the need for testing instruments in measuring the level of cleanliness of grain. The grain to be analyzed is the result of harvesting and post-harvesting with agricultural tools and machinery. Table 1 shows four parameters that need to be considered in the development of a paddy grain cleaner, namely aspects of design, material, performance, and capacity. The requirements for each parameter were obtained through a survey of agricultural tools and machinery assessors in the Indonesian Agency for Testing and Standardization of Agricultural

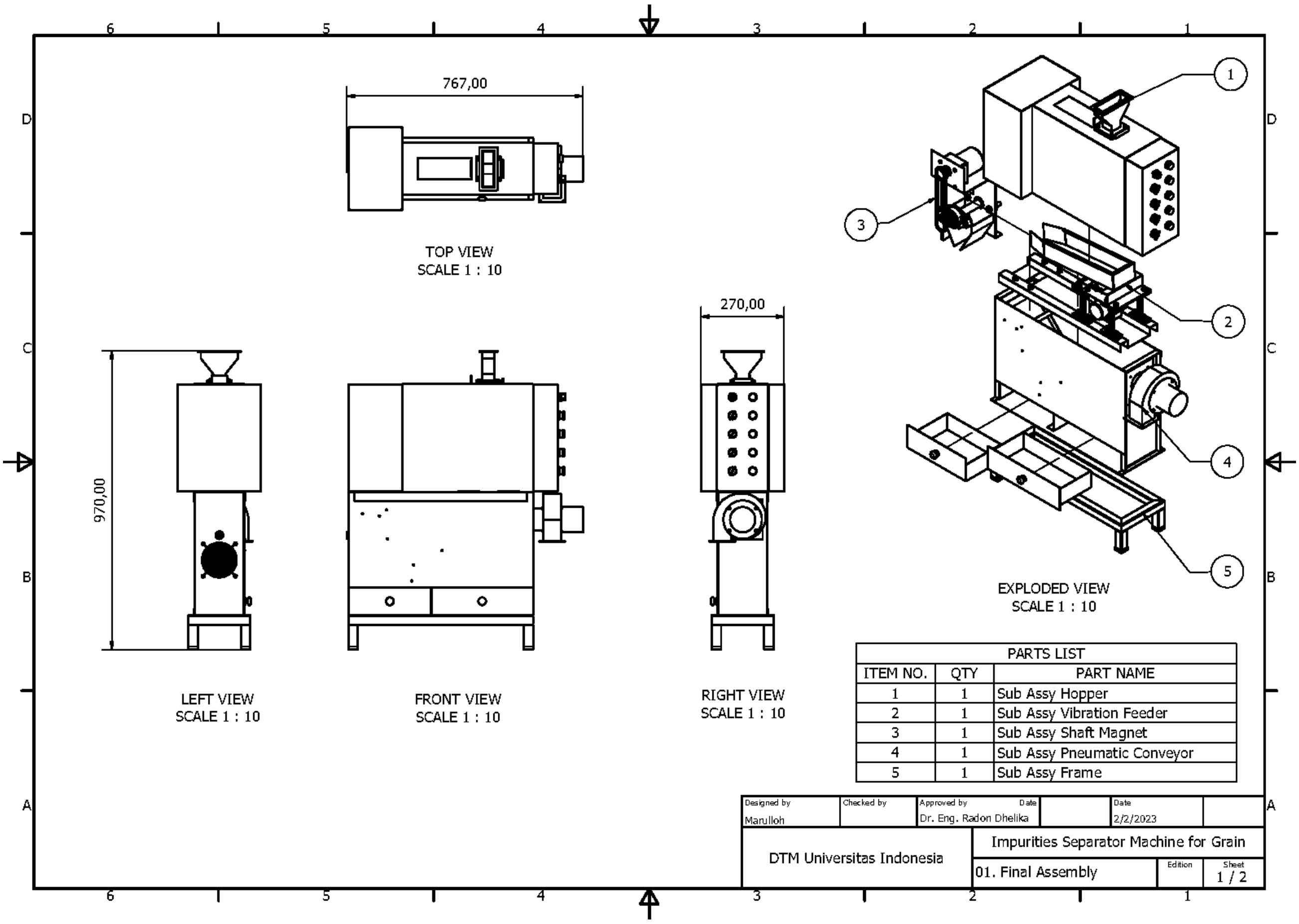
Mechanization Instruments. Meanwhile, technical characteristics are obtained by product benchmarking from previous studies and existing in market.

Table 1
The design characteristics of paddy grain cleaner

Parameter	Needs	Technical Characteristics
Design	Simple size and shape	Dimensions ≤ (100 x 100 x 100) cm^3
	Easy to assemble	Knockdown joint
	Easy to move	Ergonomic frame
Material	Strong framework	Hollow frame
	Food grade material	Stainless Steel/Acrylic/Coating mils steel plate
	Easy to manufacture	Coating mils steel plate
Performance	Material feeder without damaging grain	Vibration feeder
	Separate straw and unhulled grain	Pneumatic (positive pressure)
	Separate gravel	Magnetic (permanent magnet)
	Separate impurities at high grain moisture content	Pneumatic (negative pressure)
Capacity	Laboratory-scale	100 grams/process
	Process duration	< 2 minutes/process

The machine was designed to complete the cleaning process of paddy for the purpose of producing cleanliness data by four steps. At the first step of cleaning, the 100-gram sample of the test material obtained from harvesting or threshing using a machine is placed in a hopper. At the second step, the sample will fall towards the vibration feeder after the hopper partition is opened. The fallen grains will move according to the inclination of the vibration feeder. At the third step, the grains will go towards the single-cylinder neodymium magnet which is rotated by an electric motor. Impurities such as gravel will stick to the magnet cylinder, leaving whole grains and low-density impurities. At the fourth stage, impurities such as empty grains, straw, and dust will be blown away by axial and centrifugal fans using pneumatic separation, while whole grains will fall directly into the paddy grain tray. The machine is expected to be used for each 100-gram sample in less than 2 minutes. This operational capacity can reduce analysis time compared to manual separation, which takes up to 15 minutes for each process.

Technical drawing for the final assembly of the paddy grain cleaner is shown in Figure 1. Paddy grain cleaner consists of a hopper, vibration feeder, magnetic separation, pneumatic separation, paddy grain, and impurities tray. The result of the paddy grain cleaner design also shows the overall dimensions of the paddy grain cleaner with length of 767 mm, width of 270 mm and height of 970 mm. Several sub-assemblies and components on the machine have been designed considering the physical and aerodynamic characteristics of the local variety of paddy.



PARTS LIST		
ITEM NO.	QTY	PART NAME
1	1	Sub Assy Hopper
2	1	Sub Assy Vibration Feeder
3	1	Sub Assy Shaft Magnet
4	1	Sub Assy Pneumatic Conveyor
5	1	Sub Assy Frame

Fig. 1. Technical drawing for final assembly of paddy grain cleaner

2.2 Measurement of Physical and Aerodynamic Characteristics

Paddy grain with the local variety of Basmati Aromatik (Baroma) was obtained from the Indonesian Agency for Testing and Standardization of Agricultural Paddy Instruments, West Java, Indonesia. Baroma is a functional rice variety that has unique characteristics such as aroma, nutritional content that can overcome or complement deficiencies of certain substances in the body, and suitability for specific menus. This variety has a high productivity rate of up to 9.18 tons/ha [15].

The received grain is stored in a dry state with a moisture content of 10% on a wet basis. To accurately determine the physical properties of the milled dry grain (14% w.b.) and harvested dry grain (17% w.b.), it is necessary to adjust the moisture content of the test material [16, 17]. The desired moisture content was attained by adding the necessary amount of water based on the following equation [18]:

$$\mathrm{M_w} = \frac{\mathrm{M_1} - \mathrm{M_0}}{100 - \mathrm{M_1}} \cdot \mathrm{m} \tag{1}$$

where, M_w is the mass of water required to increase the moisture content of seeds (g), M_0 is the initial moisture content of seeds (%), M_1 is the required moisture content of seeds after water addition (%), and m is the sample mass (g). In this study, sample mass of 300 grams for each desired moisture content.

After adding water, the seeds are stirred, placed in air-tight containers, and stored in a refrigerator at a temperature of approximately 4°C for 48 hours. The samples are stirred several times to ensure uniform moisture distribution. One hour before the experiment, the samples are removed from the refrigerator and left to reach room temperature. Samples with a target moisture content of approximately 10.00% are left to air-dry at room temperature for 48 hours. The average moisture content of the seed samples was measured using a grain moisture meter (G-won GMK-303RS) and found to be at 10.26%, 14.42%, and 17.24%.

To measure the physical and aerodynamic properties of paddy grain, several instruments were utilized such as digital calipers (Mitutoyo), digital scales (ACIS-BC 500), measuring cups (500 ml), protractor, and digital stopwatch (CASIO HS-03). Each parameter was measured five times for accuracy. The method of measuring the physical properties of grain refers to the research by Utami *et al.,* (2019) [19]. The measurement results for axial dimensions and diameters of the grain samples under various moisture content are shown in Table 2 while for roundness, volume, surface area, and ratio of the grain samples are shown in Table 3.

Table 2

Axial dimensions and diameters of the grain samples under various moisture content

Grain Moisture (w.b.)	Axial Dimensions			Average Diameter		
[%]	Length (L) [mm]	Width (W) [mm]	Thickness (T) [mm]	Arithmetic (Da) [mm]	Geometric (Dg) [mm]	Quadratic (Dk) [mm]
10.26	11.09	2.16	1.89	5.05	3.57	3.57
14.42	11.20	2.28	1.93	5.13	3.66	3.67
17.24	11.24	2.35	1.95	5.18	3.72	3.73

Table 3

Roundness, volume, surface area, and ratio of the grain samples under various moisture content

Grain Moisture (w.b.) [%]	Roundness (ψ) (%)	Grain Volume (V) [mm^3]	Grain Surface Area (S) [mm^2]	Ratio (L/W) -
10.26	32.17	23.91	38.80	5.13
14.42	32.71	25.94	40.65	4.92
17.24	33.18	27.17	41.74	4.78

According to the measurement results presented in Table 2 and Table 3, Baroma paddy grains are classified as "very long" with a slim grain shape [20]. The results of measurements of density, angle of repose, and aerodynamic characteristics data in the form of terminal velocity for Baroma paddy grain are shown in Table 4.

Table 4

Density, angle of repose, and terminal velocity of the grain samples under various moisture content

Grain Moisture (w.b.) [%]	1000 seed mass [gram]	Bulk Density [g/cm3]	Angle of Repose [°]	Terminal Velocity [m/s]
10.26	24.71	0.52	25.23	5.77
14.42	26.32	0.53	28.96	6.48
17.24	28.28	0.55	32.82	7.19

Table 4 indicates that there is a direct proportional relationship between grain moisture content and bulk density, as well as angle of repose and terminal velocity. This finding is consistent with the results obtained by Masoumi *et al.,* (2020) for two local rice varieties of Iran, namely Hashemi and Gilaneh [21]. When designing the hopper capacity and tilt angle of the guide components in the pneumatic separation section, certain design parameters such as dimensions, bulk density, and angle of repose need to be taken into consideration. This is important to ensure that the grain flow does not accumulate and impede the process of separating impurities. Therefore, these design parameters play a crucial role in optimizing the efficiency of the pneumatic separation process.

2.3 Design of Vibration Feeder

In this study, a vibrating feeder is utilized to convey grains from the hopper to the separation unit. Even though the vibrating feeder produces noise, it possesses the benefits of a simple design, prevention of material loss, and reduction of material contamination during transport [22, 23]. The vibration feeder can be considered as a single degree of freedom (SDOF) system composed of a simple mass, spring, and damper. The external drive unit, which includes a motor driving an eccentric or unbalanced mass, generates periodic force to excite the mass.

The paddy grain cleaner's vibration feeder utilizes an unbalanced motor supported by four helical springs. The primary purpose of these springs is to minimize the transmission of the vibratory motor-generated force to the support structure. It is crucial for the structural integrity and long-term serviceability of the system that the force transmitted to the support structure is kept at a minimum level. The maximum value of displacement (X_{max}) and the maximum force transmitted to supports during steady state operation of vibratory feeder (F_T) can be calculated with equations below [24]:

$$F_0 = m \times e \times (\omega_0)^2 \tag{2}$$

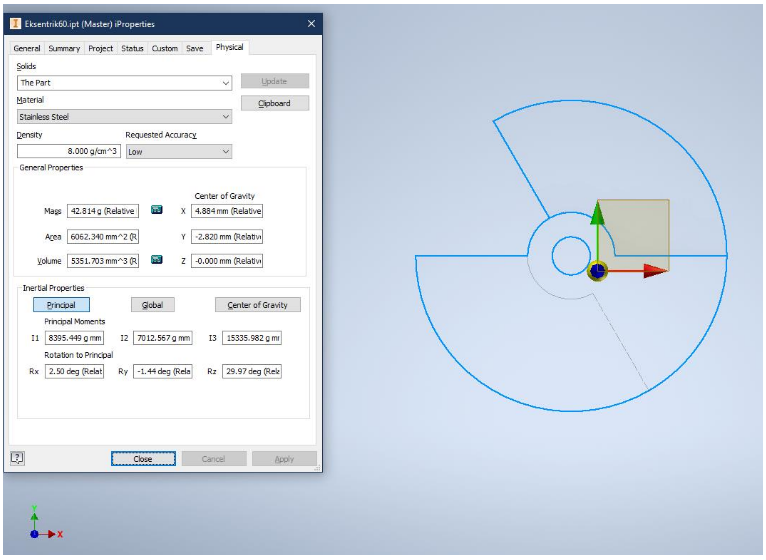
$$k = \frac{G\,d^4}{8\,N\,D^3} \tag{3}$$

$$X_{max} = \frac{F_0 / K}{\sqrt{(1-\eta^2)^2 + (2\zeta\eta)^2}} \tag{4}$$

$$F_T = \frac{F_0 \sqrt{1+(2\zeta\eta)}}{\sqrt{(1-\eta^2)^2 + (2\zeta\eta)^2}} \tag{5}$$

where m is the eccentric weight on the shaft of a motor (kg), e is the eccentricity of weight from shaft (m), ω_0 is the operating angular velocity of vibratory feeder (rad/s), K is the combined stiffness (N/m), k is the stiffness of single spring (N/m), d is the wire diameter of the spring (m), D is the mean coil diameter (m), N is the number of coils in the spring, L is the free length of the unloaded spring (m), G is the shear modulus of rigidity of material (N/m^2), F_0 is the maximum excitation force induced in the system, η is the maximum frequency ratio, and ζ is the critical damping ratio.

Eq. (2) - (5) illustrate that the maximum displacement is influenced by both the spring stiffness and the eccentricity of the weight from the shaft. During the design phase, theoretical calculations for maximum displacement are conducted with various configurations of weight eccentricity and two commonly available spring materials in the market, namely Carbon Steel A320 and Stainless Steel 304. The weight eccentricity configuration is determined by first identifying the center of gravity of the vibration feeder's mass in several positions using Autodesk Inventor Professional 2022 software as shown in Figure 2. The eccentricity value of the weight can be calculated using the Pythagorean equation based on the position of the center of gravity with respect to the x and y axes.



Solids: The Part
Material: Stainless Steel
Density: 8.000 g/cm^3
Requested Accuracy: Low

Mass: 42.814 g (Relative
Area: 6062.340 mm^2 (R
Volume: 5351.703 mm^3 (R

Center of Gravity
X: 4.884 mm (Relative
Y: -2.820 mm (Relativ
Z: -0.000 mm (Relativ

Principal Moments
I1: 8395.449 g mm
I2: 7012.567 g mm
I3: 15335.982 g mr

Rotation to Principal
Rx: 2.50 deg (Relat
Ry: -1.44 deg (Rela
Rz: 29.97 deg (Rela

Fig. 2. Center of gravity for 45 degrees

The calculation of maximum displacement and maximum force is carried out in two conditions, namely during operation and when it is about to be turned off. The difference in the maximum displacement and force theoretical values for Carbon Steel A320 and Stainless Steel 304 is shown in Figure 3.

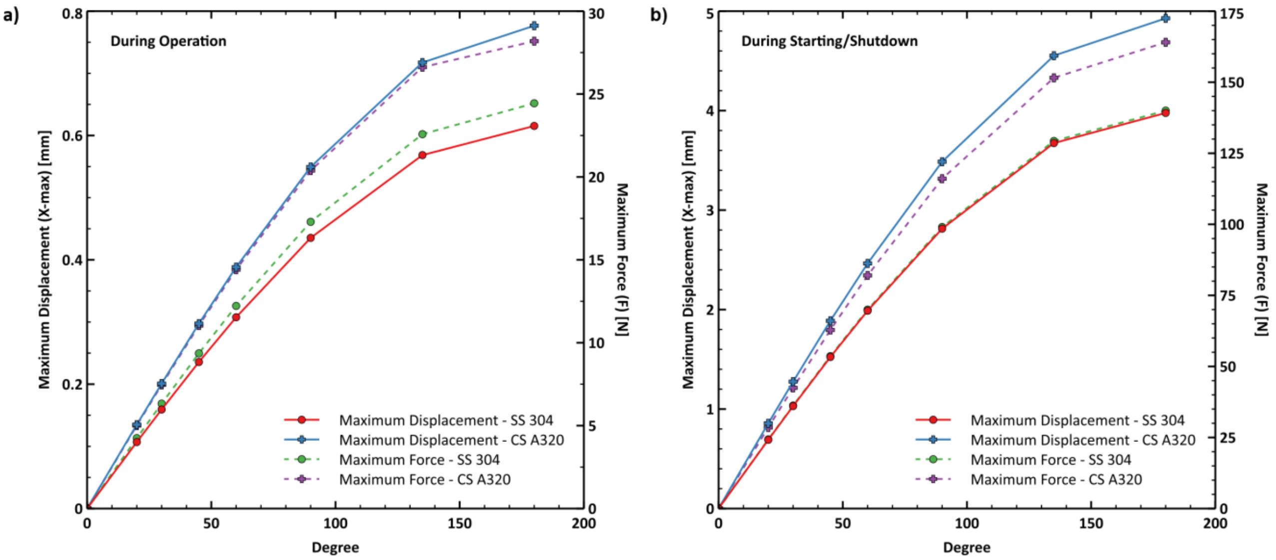


Fig. 3. Effect of materials of the spring and eccentricity on displacement (a) during operation and (b) during starting/shutdown

Figure 3 shows that a spring made of A320 carbon steel material will produce a larger maximum displacement than 304 stainless steel, both when the vibration feeder is operating and when it is started or turned off. Theoretically, the angle of eccentricity is also directly proportional to the maximum displacement and force transmitted. Based on these results and considering the angle of eccentricity, the type of material to be used for the four springs is stainless steel 304 with eccentricity angles of 30 and 20 degrees. It is necessary to calibrate the grain feeding rate by considering the slope angle of the vibration feeder container. The vibration feeder container is made of 316 stainless steel material with a length of 400 mm and slopes of 7.8° and 2.2° as shown in Figure 4.

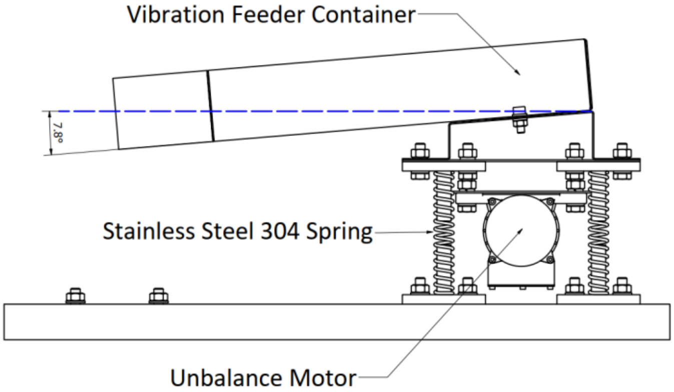


Fig. 4. Vibration feeder configuration

2.4 Design of Magnetic Separation

The separation of impurities in the form of gravel in this study was done using a neodymium magnet. Neodymium magnets are commonly used in magnetic separators, filters, ionizers, in the production of on-off buttons, and in the safety and security sectors [25]. Agricultural land in Indonesia, particularly on the island of Java, is located in close proximity to volcanic mountain regions. Numerous studies have confirmed the presence of magnetite in the volcanic soils and gravel in these areas, although in relatively small quantities [26, 27]. To extract the magnetized gravel, a strong permanent magnet such as neodymium is required. In this study, a neodymium magnet in the shape of a cylinder measuring 25 mm in diameter and 100 mm in length is used. The magnet is rotated by an electric motor at a speed of 55 rpm using a sprocket and chain mechanism as shown in Figure 5, allowing pebbles to adhere to all sides of the magnetic cylinder and optimizing the extraction process.

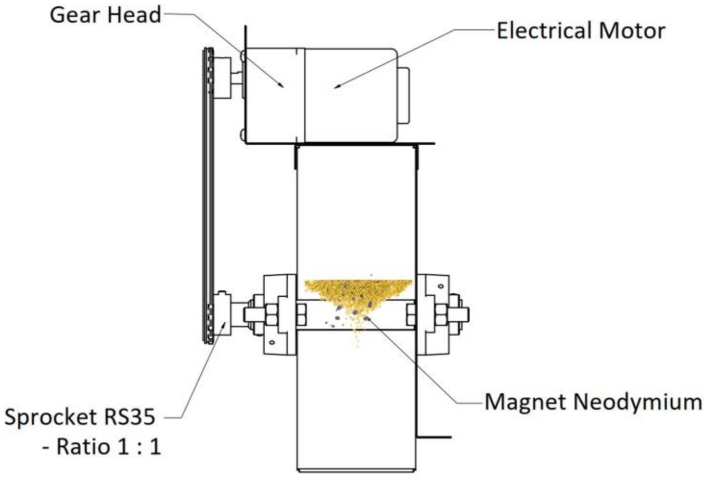


Fig. 5. Magnetic separation configuration

2.5 Design of Pneumatic Separation

The appropriate air velocity can be determined based on the differences in the aerodynamic properties of grain materials and undesired impurities, such as their terminal velocity and drag coefficient [28]. A similar increasing trend of terminal velocity with moisture content has been reported by Khodabakhsian *et al.,* (2018) for pomegranate arils, rind and locular septa [29]. The drag force of small particles, such as grain seeds and impurities, cannot be directly estimated or calculated using a horizontal wind tunnel. To determine the appropriate air velocity (v_{air}) at the suction channel of this pneumatic separation machine, the following criteria should be considered:

$$v_{tc} < v_{air} < v_{tp} \tag{6}$$

The terminal velocity of the contaminant is denoted as v_{tc}, while v_{air} represents the air velocity set up at the suction channel, and v_{tp} is the terminal velocity of the grain product. The terminal velocity of each material varies depending on its moisture content and form [28].

The inlet geometry of the pneumatic separation device has a role in enhancing the separation efficiency, similar to the separation system in a cyclone [30]. The angle of repose (AOR) is a crucial factor to consider when designing inlet geometry of pneumatic separation systems, as it can affect the aeration system and the pressure of grains on the walls. AoR is also commonly used to assess the flow characteristics and likelihood of flow issues in powders and other bulk grain products [31]. In the pneumatic separation of seed guides, an angle of repose of 45 degrees is utilized. This takes into account the flow of impurities, such as empty grains, which have a low bulk density and are considered to have poor flow characteristics [32]. Pneumatic separation configuration for paddy grain cleaner is shown in Figure 6.

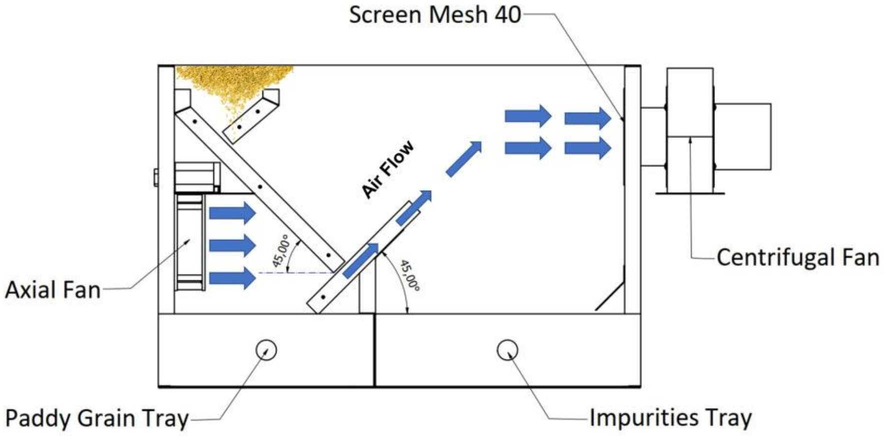


Fig. 6. Pneumatic separation configuration

Pneumatic separation consists of axial and centrifugal fan. Each fan is equipped with a dimmer to adjust the speed of the blower rotation so that the wind speed can be adjusted according to the moisture content of the grain. Both types of fans were measured prior to assembly, with parameters including propeller rotation speed using a digital tachometer (Ono Sokki HT-4200) and wind speed using a hot wire anemometer (Lutron AM-4216). Wind speed measurement was performed directly in front of the fan. The axial fan can rotate at a speed of up to 2480 rpm and generates positive pressure with a wind speed of 6.5 m/s, while the centrifugal fan can rotate at a speed of up to 2550 rpm and generates negative pressure with a wind speed of 9.6 m/s. Current measurements were taken with a digital clamp-on meter (Ditech COM 600 V) to estimate power requirements. The axial fan produces a current of 0.06 A, while the centrifugal fan produces a current of 0.11 A at the highest speed of rotation. These results indicate that 37.4 W of power are required for pneumatic separation operations.

2.6 Performance Evaluation Criteria

There are three parameters that are measured to evaluate the performance of the paddy grain cleaner, namely separation efficiency (SE), separation loss (SL), and cleaning efficiency (CE) [8]. The performance testing of the prototype in this study was conducted by referring to Indonesian National Standard (SNI) 8226.1:2016 concerning the test methods for grain cleaning machines, and SNI 8225.1:2015 concerning rice threshing machines.

$$\mathrm{SE}\ (\%) = 100\% - \mathrm{P_{sg}} = 100\% - \left[\left(\frac{\mathrm{M_1}}{\mathrm{M_2}}\right) \times 100\%\right] \tag{7}$$

$$\mathrm{SL}\ (\%) = \mathrm{P_{sg}} + \mathrm{P_{gl}} = \left[\left(\frac{\mathrm{M_1}}{\mathrm{M_2}}\right) \times 100\%\right] + \left[\left(\frac{\mathrm{M_3}}{\mathrm{M_2}}\right) \times 100\%\right] \tag{8}$$

$$\mathrm{CE}\ (\%) = \left[\frac{\mathrm{M_4}}{\mathrm{M_5}} \times 100\%\right] \tag{9}$$

where, P_{sg} is percentage of scattered grain (%), M_1 is the mass of paddy grain that enter the impurities tray after testing (g), M_2 is the initial mass of paddy grain before testing (g), P_{gl} is percentage of grain loss (%), M_3 is the mass of paddy grain that do not enter the paddy grain tray and impurities tray after testing (g), M_4 is the mass of paddy grain that enter the paddy grain tray after testing (g), and M_5 is the total mass on the paddy grain tray after testing, including mixed impurities (g).

To simplify the analysis of separation efficiency, a setup was created in which 93 grams of paddy grains and 7 grams of impurities (including empty grains and gravel) were used before the separation process took place. The mass of each parameter in Eq. (7) - (10) was measured using a digital scale (ACIS BC-500), and the level of paddy grain damage was analyzed using grain crack analysis (DC-50).

3. Results and Discussion

3.1 Measurement of Feeding Rate

The manufacturing process for the paddy grain cleaner was conducted at the Indonesian Agency for Testing and Standardization of Agricultural Mechanization Instruments in Banten, Indonesia. The prototype of the paddy grain cleaner for the laboratory scale is shown in Figure 7. The tool was equipped with a control panel to control the operation of electrical devices such as unbalanced motor for vibration feeder, electric motor for magnetic separation, and fans for pneumatic separation.

Prior to conducting the performance test, the feed rate was calibrated to achieve optimal performance and expected separation efficiency. The calibration results indicated variations in the feeding rate, with a tendency for slower feed rates as the grain moisture content was increased. This is due to the fact that grains with higher moisture content tend to be stickier and heavier, making it more difficult for them to flow through the vibrating feeder. Additionally, higher water content in grains can cause them to stick to the surface of the vibrating feeder, thereby reducing the flow of grains through the feeder.

Fig. 7. Developed prototype of paddy grain cleaner

Table 5 shows a direct correlation between the inclination feeder and eccentricity of weight parameters with the feeding rate. As the angle of eccentricity of weight increases, the maximum displacement resulting from the unbalanced vibration of the motor also increases. This indicates that higher values of inclination feeder and eccentricity of weight parameters can result in higher feeding rates due to the increased vibration intensity.

Table 5
Result of vibration feeder calibration

Moisture Content [%]	Inclination Feeder [°]	Eccentricity of weight [°]	Average Feeding Rate [gram/s]	STDV. Feeding Rate [gram/s]
10	2.2	20	0.38	0.02
		30	0.59	0.04
	7.8	20	1.33	0.09
		30	2.87	0.19
14	2.2	20	0.34	0.01
		30	0.48	0.02
	7.8	20	0.74	0.06
		30	2.30	0.10
17	2.2	20	0.27	0.01
		30	0.40	0.02
	7.8	20	0.56	0.03
		30	1.82	0.08

Based on the data presented in Figure 8, the highest average feeding rate was observed in the test configuration using grain with a 10% moisture content. Specifically, the feeding rate was 3.13 gram/second at an eccentricity of weight of 30 degrees and an inclination of the feeder of 7.8 degrees. On the other hand, the slowest average feeding rate was observed in the test configuration using grain with a moisture content of 17%. In this case, the feeding rate was 0.26 gram/second at an eccentricity of weight of 20 degrees and an inclination of the feeder of 2.2 degrees.

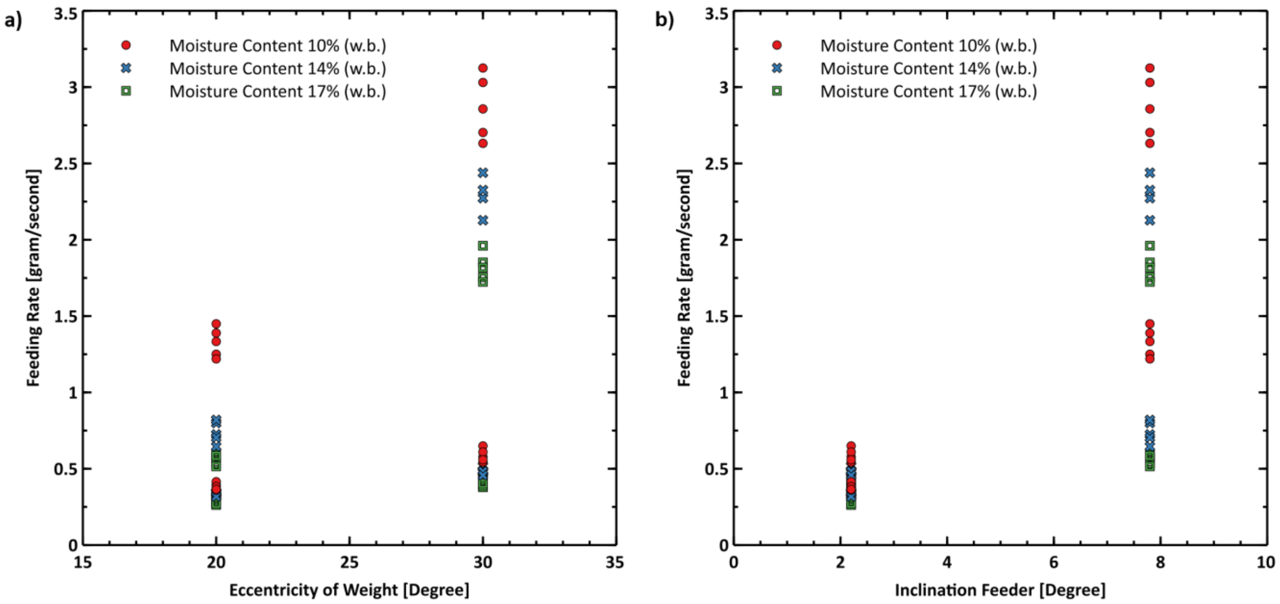


Fig. 8. Result of vibration feeder calibration

Based on these results, the performance of the paddy grain cleaner was evaluated using a vibration feeder configuration with an eccentricity of weight of 30 degrees and an inclination of the feeder of 7.8 degrees. The evaluation also considered the maximum displacement of the grain, ensuring that it did not exceed the axial dimension of the intact grain as shown in Figure 9. This is important to prevent grains from advancing in an overlapping manner or causing piles during pneumatic separation.

Fig. 9. Vibration feeder of paddy grain cleaner

3.2 Separation Efficiency

This study evaluated the separation efficiency of laboratory-scale cleaner for paddy grain using three different configurations: (1) without using a centrifugal fan, (2) without using a axial fan, and (3) using axial fan and centrifugal fan. The testing was conducted three times with the use of Baroma paddy grain variety under a moisture content condition of 10%. Table 6 presents the results of the tests, indicating that the paddy grain cleaner has a higher efficiency for grain with a moisture content of 10% without using centrifugal fan. The separation efficiency between paddy grain and impurities reached 99.49%, which suggests that there is still some intact grain mixed in the impurities tray. The percentage of separation efficiency tends to decrease as the air velocity in the separation system increases. The lower terminal velocity of the grains compared to the terminal velocity of the separation system results in these intact grains being easily thrown and entering the impurities tray as shown in Figure 10. A similar result was reported by Afolabi *et al.,* (2019) that the separation efficiency increased with a decrease in the air velocity for maize [8].

Table 6
Result of performance evaluation

Variety	Moisture Content	Axial Fan	Centrifugal Fan	Separation Efficiency SE %	Separation Loss SL %	Cleaning Efficiency CE %
Baroma	10%	On	Off	99.49	0.53	99.81
	10%	Off	On	99.14	0.89	99.21
	10%	On	On	91.79	8.26	100.00

The results indicated a loss of output during the separation process, particularly with low-density dirt material that tended to impede smooth flow and accumulate in the vibration feeder and casing areas during pneumatic separation. The second configuration showed a higher separation loss due to the presence of empty grains stuck in the filter mesh that did not fall on the impurities tray. Additionally, the cleaning efficiency, which reflects the level of cleanliness of intact grain from the separation results compared to the initial composition minus the intact grain mixed with dirt, was influenced by the presence of dirt or intact grain that did not fall on the tray. The cleanliness level of an axial fan tends to yield a higher level of cleanliness compared to a centrifugal fan and can be influenced by the airflow generated. Axial fans produce a unidirectional airflow moving along the fan's axis and are suitable for situations where low-pressure changes are required. In contrast, centrifugal fans produce a curved or rotating airflow. The airflow from centrifugal fans causes empty grain mixed with intact grains not to be optimally separated as they rotate according to the direction of the airflow and could potentially collide with other materials or the plate walls of the pneumatic separation system.

Fig. 10. Pneumatic separation with centrifugal fan

Furthermore, the gravel separation process was observed with magnetic separation as shown Figure 11. The test results showed optimal results, with no gravel falling into the paddy grain or impurities tray. This suggests that the use of neodymium magnets is appropriate for separating dirt in the form of gravel mixed with paddy grain. This is in accordance with the results of recommendations from research conducted by Kahandage *et al.,* (2021) for adding a magnetic separator for removing iron particles in a seed paddy cleaning machine [12].

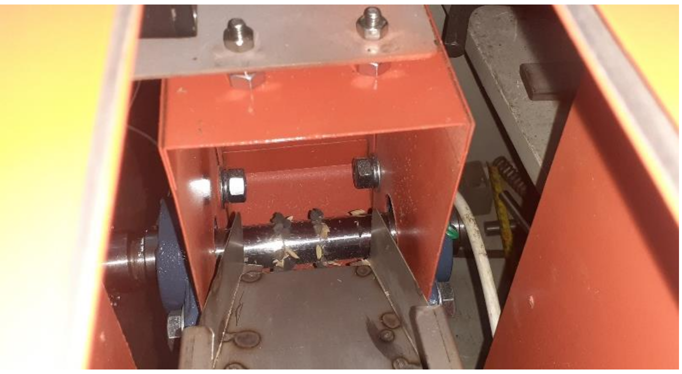


Fig. 11. Magnetic Separation

4. Conclusion

Paddy grain cleaner has been developed and tested. It consists of a hopper, vibration feeder, magnetic separation, pneumatic separation, paddy grain, and impurities tray. The feeding system used a vibration motor with rotating unbalanced mass within an angle of 30° on both sides and a slope of 7.8° which was supported by four springs made of stainless steel 304 with a theoretical displacement maximum value of 0.1593 mm. The result of measuring the feeding rate showed results that are directly proportional to the level of grain moisture content. The paddy grain cleaner is equipped with a rotating single-cylinder neodymium magnet for gravel separation. The pneumatic separation of empty grain and low-density impurities use the axial and centrifugal fan. Testing without a centrifugal fan showed better results for lower moisture content of paddy grain with an average separation efficiency, separation loss, and cleaning efficiency of 99.49%, 0.53%, and 99.81%, respectively. Further experiments are needed for performance evaluation of paddy grain cleaner with grain with higher moisture content and the rotational speed of each fan can be controlled to optimize the performance of the laboratory-scale grain cleaner.

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