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Development and performance evaluation of an areca nut deshelling machine

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Abstract

This research focuses on the development and evaluation of an innovative areca nut dehusking machine aimed at enhancing processing efficiency and reducing operational costs. The machine was rigorously tested under varying operational parameters, specifically rotor speed, blade angle, and moisture content, to determine its performance. The results demonstrated that the machine, operating at a rotor speed of 96 rpm, a blade angle of 135°, and a moisture content of 10%, achieved a production rate of 28.37 kg/hr and a breakout rate of 1.49 kg/hr. Additionally, the machine's operating cost was calculated to be Rs. 63.02/hr, showcasing its affordability and efficiency compared to conventional dehusking methods. This newly developed machine offers a practical and cost-effective solution for areca nut processing, particularly in regions with high areca nut production. The findings suggest that this machine has significant potential to improve productivity and reduce processing costs, thereby supporting the economic viability of areca nut cultivation.

Keywords: Areca nut dehusking machine, processing efficiency, production rate, breakout rate, cost-effective machinery

1. Introduction

Areca nut, commonly known as betel nut or Supari, is a significant agricultural product cultivated primarily in tropical regions, with India being the largest producer and consumer. The cultivation of areca nut holds substantial economic and cultural importance, particularly in states like Karnataka, Kerala, Assam, Tamil Nadu, Meghalaya, and West Bengal, where it is deeply intertwined with religious practices and traditional customs. The demand for areca nut spans various socio-economic strata, making it a vital cash crop for many farmers in these regions. Despite its cultural and economic significance, the traditional methods of processing areca nuts present several challenges [1]. The dehusking process, which is critical for preparing the nut for market, is often labor-intensive, inefficient, and inconsistent in quality. Manual dehusking requires significant labor input, leading to high costs and variable output quality. Semi-automatic and fully automatic machines currently available also face issues related to efficiency and consistency, which can lead to increased wastage and reduced productivity. By addressing these issues, the developed machine aims to provide a practical solution that can be widely adopted, particularly by small and medium-sized enterprises (SMEs) that form the backbone of the areca nut industry [2].

The dehusking of areca nuts, a critical step in the processing chain, has evolved through various methods, each with its own advantages and limitations. Traditional manual dehusking is labor-intensive and relies heavily on skilled workers to separate the husk from the nut. While this method is relatively low-cost, it suffers from inefficiencies and variability in dehusking quality, often resulting in inconsistent product output [3]. Semi-automatic dehusking machines have been developed to improve efficiency and reduce manual labor. These machines incorporate mechanized components to assist with the dehusking process, but they still require significant human intervention to operate effectively. Research by K. Patil [4] highlights that while semi-automatic machines offer improved productivity and reduced labor costs, they often face challenges related to maintenance and operational consistency. Fully automatic dehusking machines represent the most advanced technology in this field. These machines are designed to handle the dehusking process with minimal human intervention, using automated systems to control the operation and enhance processing speed. According to Chukwu *et al.* [5], fully automatic machines provide the highest level of efficiency and consistency. However, they are often associated with higher capital costs and complexity, which may be prohibitive for small-scale producers. Recent advances in agricultural machinery have introduced significant technological innovations aimed at improving the efficiency and effectiveness of areca nut processing. Automation has been a key focus, with new machines incorporating automated systems to control various aspects of the dehusking process, including feed rate, husk removal, and quality control [6]. Sensor technology and real-time monitoring have also seen notable advancements. Modern machines use sensors to monitor parameters such as moisture content, nut size, and husk integrity, allowing for precise adjustments during processing. As reported by Naik *et al*. [7], these innovations enable better control over the dehusking process, leading to higher product quality and reduced waste. The application of artificial intelligence (AI) in agricultural machinery has further enhanced the capabilities of dehusking machines. AI algorithms are being used to analyze data from sensors and optimize machine settings in real-time, improving the overall efficiency of the dehusking process [8]. These advancements represent a significant leap forward, offering the potential for fully automated systems that can adapt to varying conditions and improve processing outcomes. Despite the advancements in dehusking technology, several challenges remain in the processing of areca nuts. One of the primary issues is maintaining consistent quality throughout the dehusking process. Variability in nut size, moisture content, and husk toughness can affect the effectiveness of the dehusking operation, leading to inconsistencies in the final product [9]. Reducing labor dependency is another critical challenge. While automation has reduced the need for manual labor, the complexity and cost of advanced machines can be a barrier for small-scale producers. According to Lai *et al*. [10], there is a need for affordable and user-friendly solutions that can provide the benefits of automation without the high capital investment associated with fully automated systems. Overall, while technological innovations have improved the efficiency and effectiveness of areca nut dehusking, ongoing research and development are needed to address the remaining challenges. Ensuring consistent quality and making advanced technology accessible to small and medium-sized enterprises remain key areas for future focus in the field of areca nut processing [11].

Given these challenges, the primary objective of this research is to design and develop an efficient and cost-effective areca nut dehusking machine. The focus is on creating a machine that can significantly reduce labor costs, improve dehusking quality, and enhance overall productivity.

2. Materials and Methods

Freshly harvested areca nuts, as shown in Figure 1(a), were utilized in the study. These nuts were characterized using several instruments: a digital caliper as shown in Figure 1(b), was employed to measure the geometric mean diameter of 27.4 mm, while sphericity was assessed using image analysis software. Bulk density was determined with a graduated cylinder and a scale, providing a value of 0.56 g/cm³. True density was measured using a helium pycnometer, yielding a value of 0.80 g/cm³. Porosity was calculated using the equation 1 resulting in 29.1%. The angle of repose was determined using a flow meter and a protractor, measuring 23.4°.

$$Porosity = \frac{Bulk\,Density - True\,Density}{Bulk\,Density} x\ 100 \qquad (1)$$

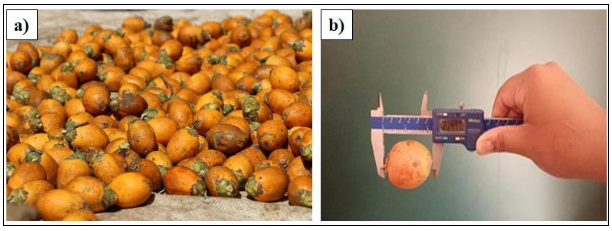

Fig 1: (a) Fresh areca nut, (b) measurement of geometric mean diameter

The design of the dehusking machine comprised several key components, each designed to optimize performance: The machine frame as shown in Figure 2(a) was constructed from mild steel, with dimensions of 1.5 meters in height and 1 meter in width. This design provided the necessary structural support and stability for the operation of the machine.

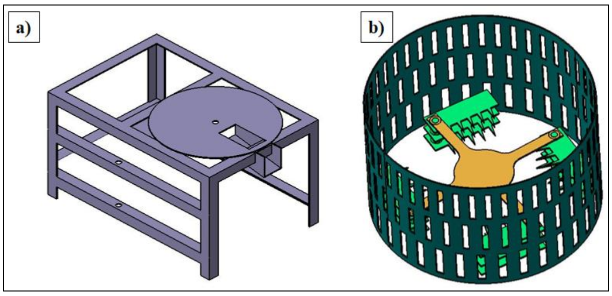

Fig 2: (a) Machine frame, (b) Drum with blades

The cutting drum, as shown in Figure 2(b), with a diameter of 300 mm, was fabricated from high-strength alloy steel. It was driven by a DC motor with a power rating of 3 HP through a pulley and V-belt system, achieving a peripheral speed of 2.5 to 3.7 m/s.

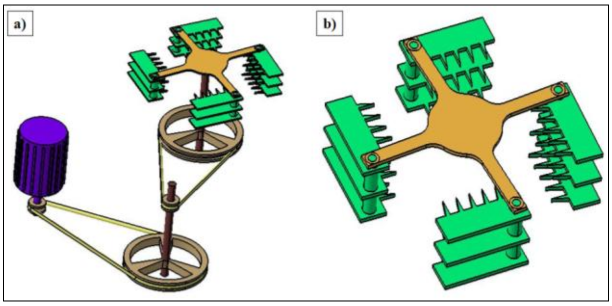

Fig 3: (a) Power transmission in machine, (b) Rotor attached with blade

The rotational speed of the drum was calculated using the equation 2.

$$Vp = \pi DN \qquad (2)$$

where D is the drum diameter (0.3 meters) and N is the rotational speed, estimated at approximately 1600 RPM. The speed ratio of the drive system was determined to be 1:1.75 based on $Speed\ ratio = N_{motor}/N_{drum}$.

The cutting drum was equipped with serrated blades made as shown in Figure 3(a) from hardened steel. Blade as shown in Figure 3(b), including angle and serration pattern, were optimized based on the required cutting speed and properties of the areca nuts to ensure efficient husking.

The shaft supporting the cutting drum was designed to handle operational loads, with diameter and material chosen based on load calculations. Shear stress on the shaft was calculated using $\tau = T/J$, where τ represents shear stress, T is the torque, and J is the polar moment of inertia. A screen with 10 mm openings was installed for separating dehulled nuts from husk and powder. The screen material was selected for durability and wear resistance, with mesh size optimized for effective separation. Bearings supporting the rotating components were chosen based on load calculations, using, $F = P/C$, where F is the load, P is the applied load, and C is the bearing capacity. The selected bearings ensured smooth operation and stability of the machine.

Fig 4: (a) CAD model of areca nut dehusking machine, (b) fabricated areca nut dehusking machine

Figure 4(a) shows the CAD model of the areca nut deusking machine. Preliminary tests were conducted on the fabricated machine shown in Figure 4(b) to evaluate the machine's cutting efficiency, nut damage, and throughput rate. Performance data as shown in Table 1 was compared with theoretical predictions and previous studies, leading to adjustments and re-testing to enhance machine performance.

Table 1: Observations

Sr. No.	Speed	Angle	Moisture (Rh)	Production Rate (Pr)	Breakout rate (W)
1	96	45	10	22.22	1.25
2	96	45	20	20.59	0.97
3	96	45	30	19.85	0.87
4	120	45	10	22.68	2.07
5	120	45	20	21.52	1.57
6	120	45	30	19.88	1.47
7	160	45	10	24.41	2.59
8	160	45	20	23.75	2.54
9	160	45	30	20.38	2.3
10	96	90	10	24.76	1.36
11	96	90	20	21.61	1.19
12	96	90	30	20.64	0.93
13	120	90	10	25.42	2.08
14	120	90	20	23.34	1.63
15	120	90	30	22.43	1.51
16	160	90	10	27.58	2.65
17	160	90	20	24.14	2.55
18	160	90	30	23.37	2.37
19	96	135	10	28.41	1.42
20	96	135	20	25.13	1.22
21	96	135	30	24.32	0.96
22	120	135	10	30.39	2.16
23	120	135	20	26.87	1.92
24	120	135	30	25.69	1.53
25	160	135	10	32.9	2.78
26	160	135	20	28.38	2.56
27	160	135	30	27.36	2.43

3. Results and Discussion

3.1 Effect on production rate

3.1.1 Effect of variation of speed on production rate

As discussed, the dehusking machine is designed for areca nut deshelling. It operates with a motor that transfers power to the rotor blade via various pulleys. For testing, three pulley sizes—9", 12", and 15"—were used, resulting in rotor speeds of 96 RPM, 120 RPM, and 160 RPM. The impact of these speeds on production rates is illustrated in Figures 5 through 7. Figure 5 shows that production rate increases with rotor speed, with the highest rate achieved at 160 RPM. At 10% moisture content, production rates ranged from 22.22 kg/hr at 96 RPM to 32.9 kg/hr at 160 RPM. Figure 6 depicts similar trends at 20% moisture content, with production rates from 22.22 kg/hr at 96 RPM to 28.38 kg/hr at 160 RPM, with the highest rate observed at a 135° blade angle. Figure 7 confirms these findings at 30% moisture content, showing production rates ranging from 19.85 kg/hr at 96 RPM to 27.36 kg/hr at 160 RPM. In all cases, increased rotor speed positively affects production rate, with the optimal performance observed at 160 RPM and a 135° blade angle.

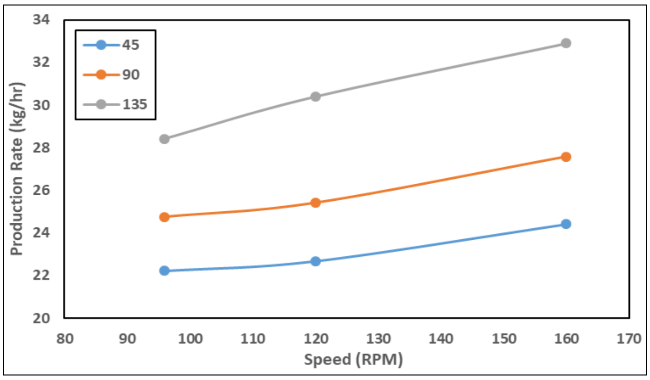

Fig 5: Effect of variation of speed on Production Rate for 10% Moisture

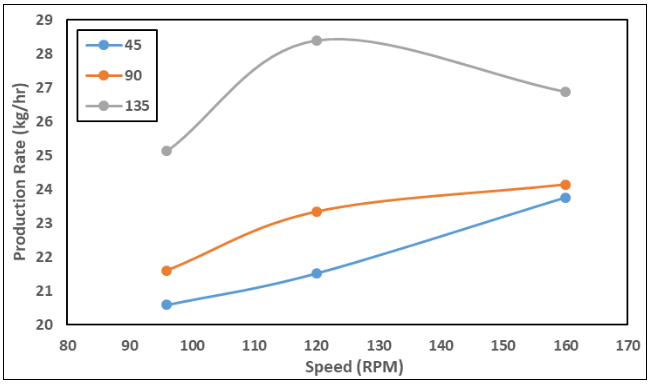

Fig 6: Effect of variation of speed on Production Rate for 20% Moisture

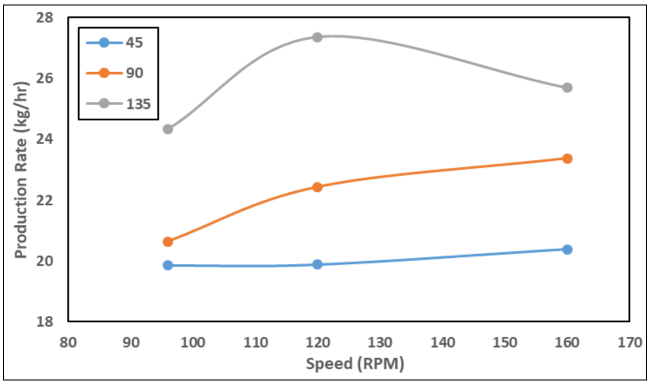

Fig 7: Effect of variation of speed on Production Rate for 30% Moisture

3.1.2 Effect of Variation of Moisture on Production Rate

Figures 8 through 10 illustrate the effect of moisture content on the production rate of the machine. All figures show a negative correlation between moisture percentage and production rate. Specifically, production rates decrease with higher moisture levels, with the lowest rates observed at 30% moisture and the highest rates at 10% moisture. In Figure 8, for a rotor speed of 96 RPM, the highest production rate of 28.41 kg/hr is achieved at 10% moisture with a 135° blade angle, while the lowest rate of 19.85 kg/hr occurs at 30% moisture with a 45° blade angle. Figure 9 demonstrates that at 120 RPM, the maximum production rate of 30.39 kg/hr is observed at 10% moisture and a 135° blade angle, whereas the minimum rate of 19.88 kg/hr is noted at 30% moisture and a 45° blade angle. Figure 10 indicates that at 160 RPM, the production rate peaks at 32.9 kg/hr at 10% moisture with a 135° blade angle, while the lowest rate of 20.38 kg/hr is seen at 30% moisture and a 45° blade angle. In summary, lower moisture content consistently improves production rates across all blade angles and rotor speeds.

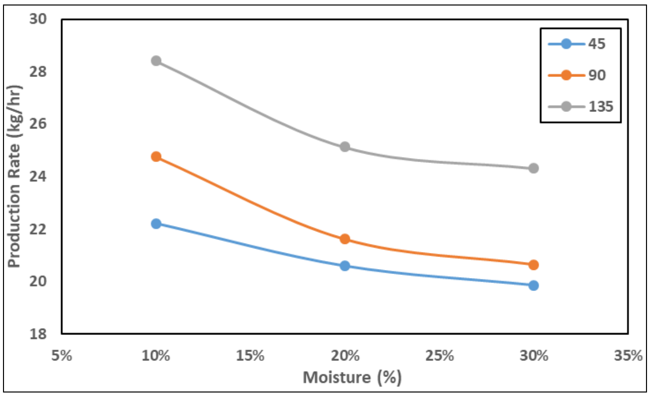

Fig 8: Effect of variation of moisture on Production Rate at speed rotor of 96 rpm

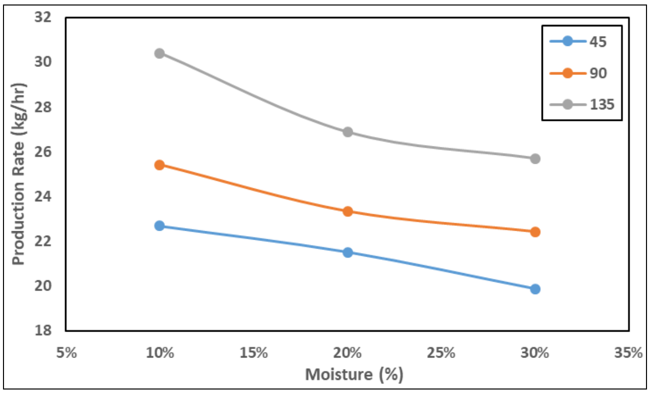

Fig 9: Effect of variation of moisture on Production Rate at speed rotor of 120 rpm

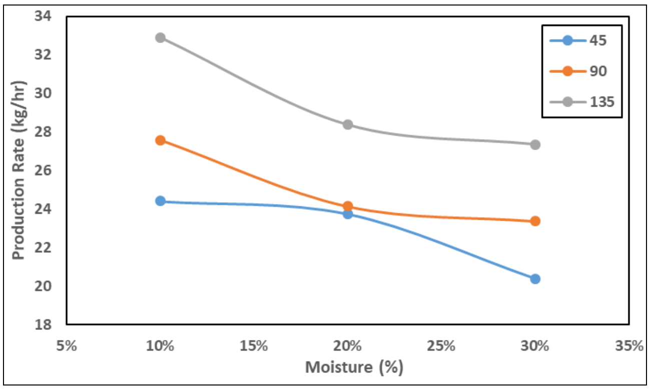

Fig 10: Effect of variation of moisture on Production Rate at speed rotor of 160 rpm

3.1.3 Effect of Variation of blade angle on Production Rate

Figures 11 through 13 depict the effect of varying blade angles on the production rate of the developed machine. Across all figures, a positive correlation is observed between blade angle and production rate. Specifically, the lowest production rates are recorded at a 45° blade angle, while production rates increase as the blade angle increases to 135°. This trend holds for all moisture levels. In Figure 11, with a rotor speed of 96 RPM, the highest production rate of 28.41 kg/hr is achieved at a blade angle of 135° and

10% moisture, while the lowest rate of 19.85 kg/hr occurs at a 45° blade angle and 30% moisture. Similarly, Figure 12 shows that at 120 RPM, the production rate reaches a maximum of 30.39 kg/hr at a 135° blade angle and 10% moisture, with the minimum rate of 19.88 kg/hr observed at a 45° blade angle and 30% moisture. In Figure 13, at 160 RPM, the highest production rate is 32.9 kg/hr at a 135° blade angle and 10% moisture, while the lowest production rate is 20.38 kg/hr at a 45° blade angle and 30% moisture. These results indicate that increasing the blade angle consistently enhances the production rate across all tested conditions.

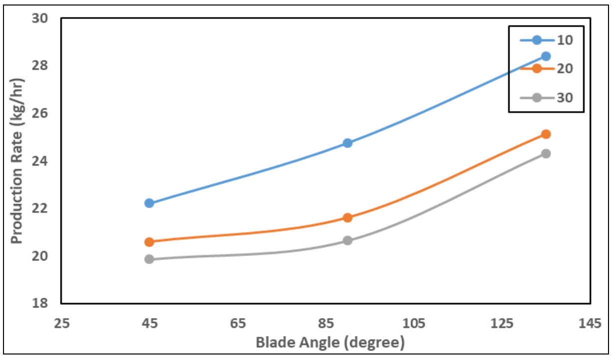

Fig 11: Effect of variation of blade angle on Production Rate at speed of 96rpm

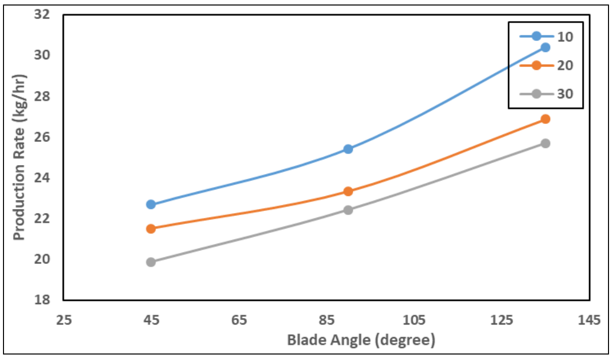

Fig 12: Effect of variation of blade angle on Production Rate at speed of 120rpm

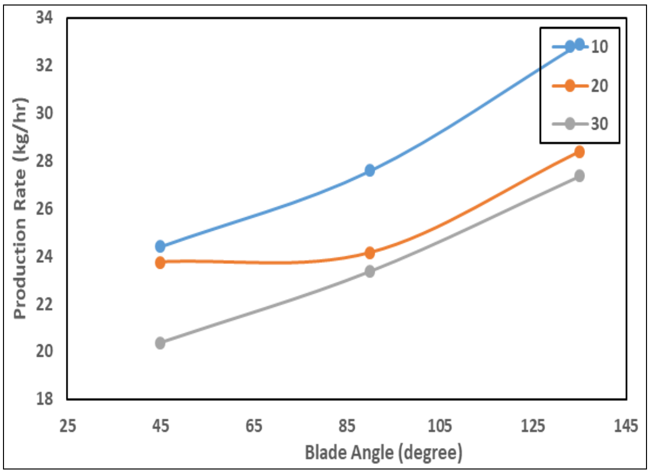

Fig 13: Effect of variation of blade angle on Production Rate at speed of 160rpm

3.2 Effect on breakout rate

3.2.1 Effect of Variation of Speed on Breakout Rate

Figures 14 through 16 illustrate the effect of varying rotor speeds on the breakout rate of the developed machine. Across all figures, a positive correlation is evident between rotor speed and breakout rate. Specifically, the breakout rate is lowest at 96 RPM and increases progressively as the rotor speed is raised to 160 RPM, regardless of the blade angle. In Figure 14, for a moisture content of 10%, the maximum breakout rate of 2.78 kg/hr is observed at 160 RPM with a blade angle of 135°, while the minimum rate of 1.25 kg/hr occurs at 96 RPM and a blade angle of 45°. Figure 15 demonstrates that at 20% moisture content, the breakout rate peaks at 2.56 kg/hr at 160 RPM and a 135° blade angle, with the lowest breakout rate of 0.97 kg/hr recorded at 96 RPM and a 45° blade angle. Lastly, Figure 16 shows that for 30% moisture content, the highest breakout rate of 2.43 kg/hr is attained at 160 RPM and a 135° blade angle, while the minimum breakout rate of 0.87 kg/hr is noted at 96 RPM and a 45° blade angle. These results indicate that increasing the rotor speed consistently enhances the breakout rate, with the effect being more pronounced at lower moisture levels and higher blade angles.

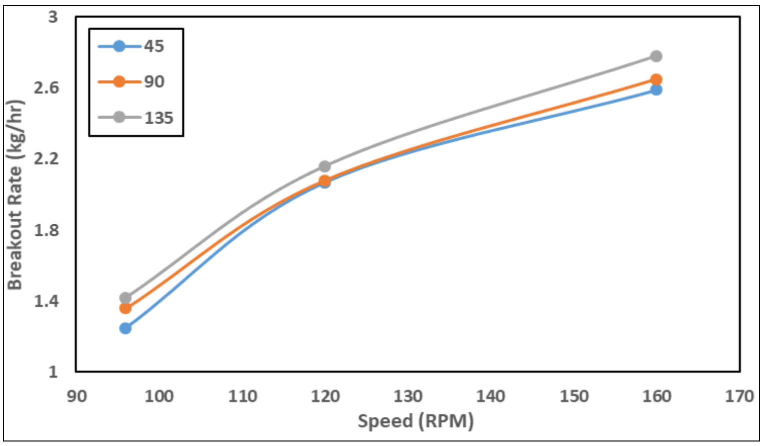

Fig 14: Effect of variation of speed on Breakout Rate for 10% Moisture

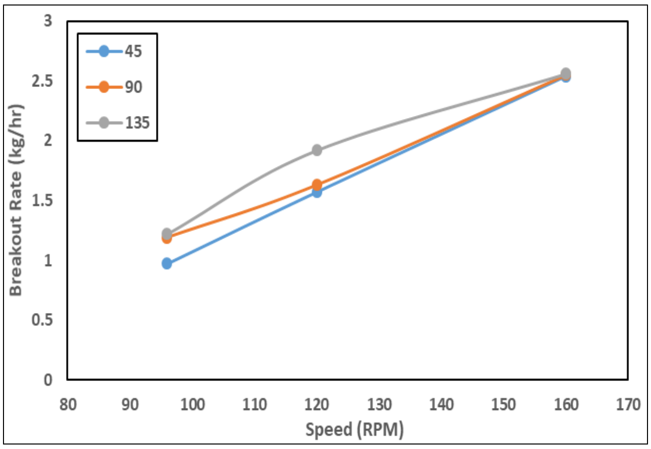

Fig 15: Effect of variation of speed on Breakout Rate for 20% Moisture

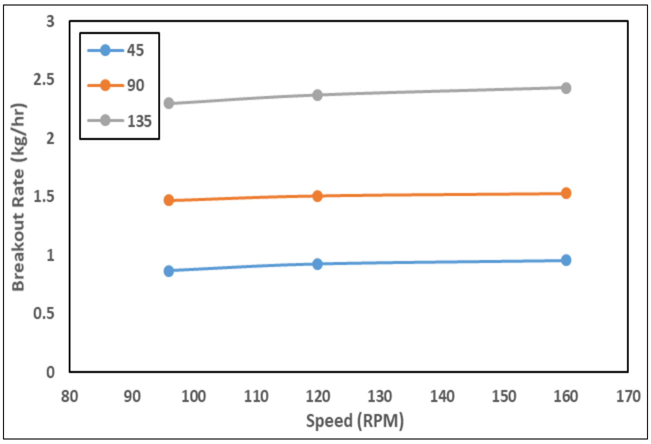

Fig 16: Effect of variation of speed on Breakout Rate for 30% Moisture

3.2.2 Effect of moisture variation on the breakout rate

Figures 17 to 19 illustrate the effect of moisture variation on the breakout rate of the developed machine. Across all figures, it is evident that the moisture content negatively impacts the breakout rate. As the moisture percentage decreases from 30% to 10%, the breakout rate increases consistently for all three blade angles. In Figure 17, at a rotor speed of 96 RPM, the maximum breakout rate of 1.42 kg/hr is observed at 10% moisture with a 135° blade angle, while the minimum breakout rate of 0.87 kg/hr occurs at 30% moisture and a 45° blade angle. Figure 18 shows that at 120 RPM, the breakout rate peaks at 2.16 kg/hr for 10% moisture and a 135° blade angle, with the lowest breakout rate of 1.47 kg/hr recorded at 30% moisture and a 45° blade angle. Finally, Figure 19 reveals that at 160 RPM, the maximum breakout rate of 2.78 kg/hr is achieved at 10% moisture with a 135° blade angle, while the minimum breakout rate of 2.3 kg/hr is noted at 30% moisture and a 45° blade angle. These results indicate that lower moisture content leads to a higher breakout rate, especially at higher rotor speeds and larger blade angles.

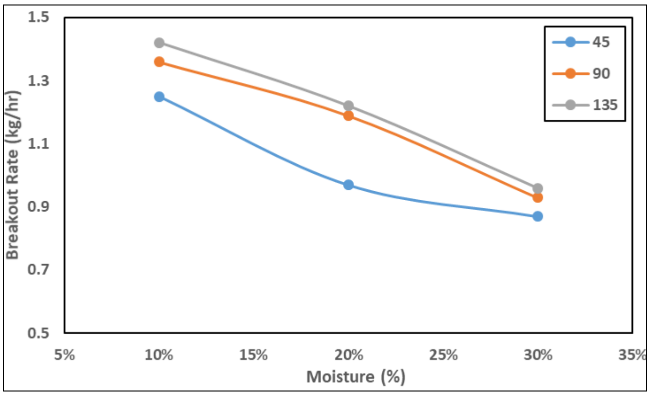

Fig 17: Effect of variation of moisture on Breakout Rate at speed rotor of 90 rpm

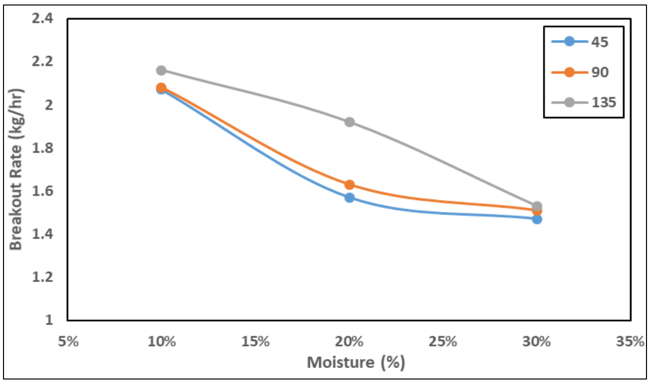

Fig 18: Effect of variation of moisture on Breakout Rate at speed rotor of 120 rpm

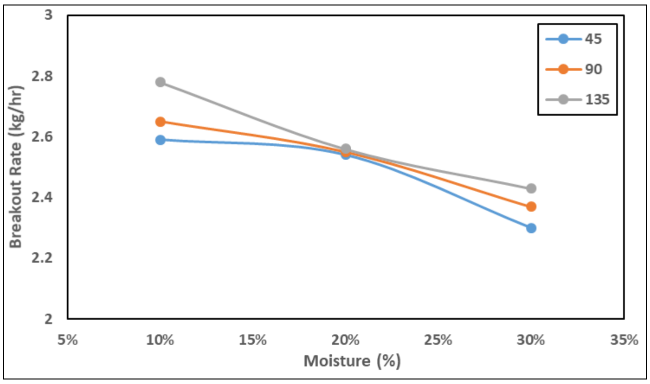

Fig 19: Effect of variation of moisture on Breakout Rate at speed rotor of 160 rpm

3.2.3 Effect of variation of blade angle on Breakout Rate

Figures 20 to 22 illustrate the effect of varying blade angles on the breakout rate of the developed machine. Across these figures, it is evident that the blade angle has a positive effect on the breakout rate, with larger angles leading to higher rates. In Figure 20, at a rotor speed of 96 RPM, the maximum breakout rate of 1.42 kg/hr is observed with a 135° blade angle and 10% moisture, while the minimum breakout rate of 0.87 kg/hr is recorded for a 45° blade angle and 30% moisture. Figure 21 shows that at 120 RPM, the breakout rate reaches its peak at 2.16 kg/hr for a 135° blade angle and 10% moisture. The lowest breakout rate of 1.47 kg/hr occurs with a 45° blade angle and 30% moisture. Finally, Figure 23 demonstrates that at 160 RPM, the maximum breakout rate of 2.78 kg/hr is achieved with a 135° blade angle and 10% moisture. The minimum breakout rate of 2.3 kg/hr is noted for a 45° blade angle and 30% moisture. These results confirm that increasing the blade angle enhances the breakout rate, particularly at higher rotor speeds and lower moisture levels.

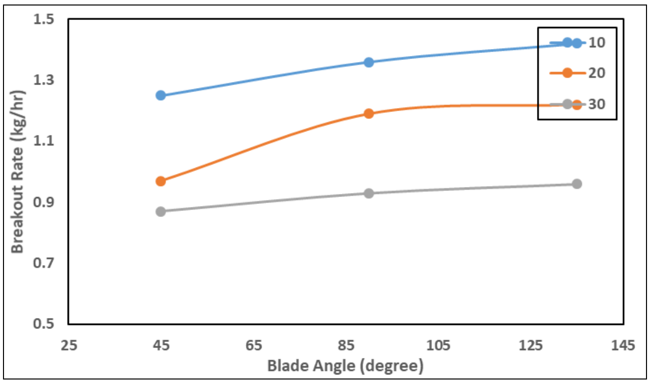

Fig 20: Effect of variation of blade angle on Breakout Rate at speed of 96rpm

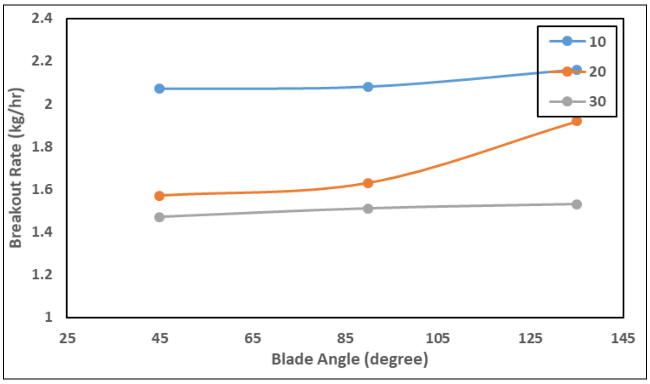

Fig 21: Effect of variation of blade angle on Breakout Rate at speed of 120rpm

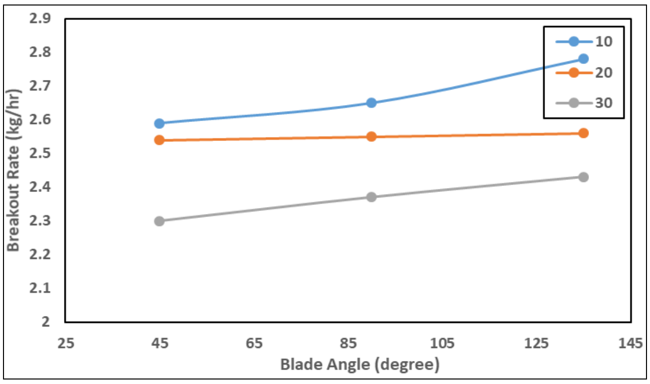

Fig 22: Effect of variation of blade angle on Breakout Rate at speed of 160rpm

4. Discussion

The newly developed areca nut deshelling machine demonstrated superior performance compared to existing machines in several key aspects. The machine's ability to achieve a maximum production rate of 32.9 kg/hr at a rotor speed of 160 rpm and a blade angle of 135° highlights its efficiency. This rate surpasses the 27.5 kg/hr reported by Kiran *et al.* [12] at a lower rotor speed of 140 rpm, indicating that the current design benefits from higher rotor speeds and optimized blade angles. Blade angle optimization played a crucial role in enhancing performance. Previous studies, such as that by Darmein *et al.* [13], utilized fixed blade angles, which limited efficiency gains. The adjustable blade angle in the current machine, particularly at 135°, consistently yielded higher production and breakout rates across varying moisture levels, demonstrating its advantage over fixed-angle designs. Moisture content significantly impacted the machine's performance. Hebbar *et al.* [14] identified 12% moisture as optimal, the current study found that a slightly lower moisture content of 10% yielded better results, with a higher production rate. This difference can be attributed to the machine's capacity to fine-tune operational parameters, leading to improved deshelling efficiency under different moisture conditions. In terms of breakout rate, the developed machine achieved a maximum of 2.78 kg/hr at 160 rpm and a 135° blade angle, outperforming the 2.3 kg/hr recorded by Kiran *et al.* [13] under similar conditions. This indicates that the machine's adjustable settings contribute to more efficient deshelling by reducing nut breakage and increasing usable output.

5. Conclusion

The development and performance evaluation of the areca nut deshelling machine demonstrated significant advancements in efficiency and productivity. The study found that the machine's production and breakout rates are positively influenced by the rotor speed and blade angle, while an increase in moisture content negatively impacts performance. Specifically, a rotor speed of 160 RPM and a blade angle of 135° yielded the highest production and breakout rates, particularly at lower moisture levels. The machine's ability to efficiently deshell areca nuts under varying operational parameters highlights its potential for improving the processing of this crop. Future studies could further optimize these parameters and explore additional variables, such as different nut varieties and moisture control methods, to enhance machine performance further. Overall, this research provides a solid foundation for the practical application of the developed deshelling machine in the areca nut industry, offering a promising solution to increase processing efficiency and reduce labor costs.

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