Design and optimization of operating parameters for areca nut de-husker

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Abstract: Areca nut is one of the major commercial crops grown in South India. The raw areca nut has to be peeled (de-husked) to get its nut. The manual peeling practice is laborious process and is not safe for labor. Manual de-husking is time-consuming, and there is a shortage of labor. The existing machines developed are not so capable to completely remove the outer layer of the areca nut due to the difference in the size of the area nut, and the areca nuts damaged due to the non-availability of the optimal process parameters, and they are expensive. Damaged areca nuts have lesser value in the market. This paper deals with the design and development of an areca nut de-husking machine which can de-husk areca nuts of different sizes without damaging it. The flow of paper starts with the definition of the problem, relevant need analysis, field survey, and literature survey based on these data areca nut de-husking machine designed. Finally, the factor effect study using the Design of Experiment (DOE) method is presented in this paper.

Keywords: Design of Experiments (DOE); arecanut; optimization; de-husking

1. INTRODUCTION

Areca nut is the most important commercial crop, also known as betel nut, and it is the seed of the Areca nut palm. While it's freshly plucked, the husk is green, and therefore the nut inside is so soft that it can easily cut with a simple knife. Within the ripe fruit, the husk becomes yellow or orange and, because it dries, the fruit inside hardens to a wood-like consistency. Peeling by manual method proved to be labor-intensive, consumes more time, and dangerous to the labor. The automatic machines developed aren't efficient to completely remove the husk from the nut because of variation within the size of the betel nut, and therefore the areca nuts are damaged due to the non-availability of the optimum process parameters and that they are expensive. Damaged areca nuts have lesser value in the market. The problems faced by the earlier developed machines are very bulky, rigid in design, and inefficient peeling of areca nut.

Figure 1. Areca nut
The utilization of the dry areca nut and nut organic product has right off the bat to be de-husked into a nut. Figure 1 delineates the structure of the dry over-develop areca nut natural product. It is frequently observed that a nut is solidly appended to a husk as an afterthought that is nearest to the stem, while a hole exists on the contrary side due to the partition of the nut from the husk because of lost dampness. The mechanical properties of the betel nut in reference to de-husking were examined by Balasubramanian and Panwar [1]. They need found that parallel shear with a scouring activity could be reasonable for de-husking the organic product.

2. LITERATURE REVIEW

2.1 Manual de-husking
The areca nut can be peeled manually with sharp knives which is fixed on wooden piece to get its nut or kernel. In the peeling process of areca nut, the labor will face problems such as strain, fatigue and scares on hand because of continuous peeling, which is an intensive work. To overcome this manually operating machines can be used for peeling areca nut by hand or pedal operation [2, 3]. These machines will consume less time than that of manual peeling. But in these machines certain drawbacks are similar to manual peeling due to continuous operating. However the advantage of manual peeling is that the nut will not get damaged and careful removal is achieved [4, 5]. Figure 2 shows manual method of de-husking.

![Figure 2. Manual de-husking](image)

2.2 Mechanized de-husking
Semi mechanized areca nut peeling machines are driven by manually either through hand or pedal. The fully automated areca nut peeling machines are runs by electrical motor. These machines are not compact, comprising of a scissor mechanism, a frame, a platform and a pedal operated lever mechanism. The manually operated machine was developed by M J Francis- Kerala, requires skilled labor and operated bipedal solely depends on workability of men not suitable for long process to peel the areca nut [6, 7]. The semi mechanized machine was developed by Post Harvest Technology Centre, University of Agricultural Sciences (UAS), Gandhi Krishi Vigyan Kendra (GKV), Bangalore. The machine assembly consists of two sharp edged flaps, one being stationary and the other movable, operated by the pedal through a linkage mechanism. This is suitable only for de-husking freshly harvested mature green areca nuts of all varieties under cultivation. In this machine only half portion of the husk can be removed and the rest should be removed by hand [8, 9].

The existing machine comprises of a centralized server on which a rotational shelling drum having eight quantities of strong rubbers on its outskirts is mounted. Underneath this, a curved is put to help to shell and to pass the de-husked material down. After de-husking pieces and husk stream to the conduit and arrive at the air stream, created by a blower. The husk is tossed out and the bits/nuts are gathered at the base. Contingent on the size of natural products, the sunken must be changed for higher effectiveness and least breakage. Reviewing the dried natural products before de-husking will
likewise assist with expanding the de-husking effectiveness and lessen the breakage [10].

The problems faced by the earlier developed machines are very bulky, rigid in design and inefficient peeling of areca nut. Secondly frictional and scissor mechanisms are used to de-husk as it results in use various materials usage such as tyres and conveyor belts, these may increase mechanical dysfunction and failure often. Hence investigation is required towards designing the machine for different sizes of areca-nut and the parameters of the peeling process need to be addressed [11, 12].

2.3 Areca nut harvesting
Areca nuts are harvested in unripened (wet) and ripened (dry) states. The unripened (wet) areca nuts are de-husked and boiled in water followed by drying in sun light. The processing of the wet areca nuts has to start within 24 hours after harvesting. On the other hand ripened nuts are harvested when the areca nuts get orange color they are dried until they turn into brown color and loose most of the moisture. The processing of ripened areca nuts involves only de-husking and after that they are sold [13]. Figure 3 shows the wet and dry areca nuts.

![Figure 3. Wet and dry areca nuts](image)

2.4 Relation between wood and areca nut properties
The density of wood material and areca nut in mass per unit volume at some specific condition and wood and areca nut both are orthotropic and anisotropic material. The structure of wood is tracheid or fibre cells vary from 16-42 μm in diameter and from 870 – 4000 μm long and is also composed of combination of three chemical polymers such as cellulose, hemicelluloses and lignin. In areca nut the nut reaches hard state predominantly and it is covered by husk which is of a fibrous (hard and soft fibers) and is predominantly composed of similar structure called varying proportions of hemicelluloses, lignin, pectin and protopectin. The wood consists of micro and macro structure and its size varies with its grain size distribution in its entire three dimensional axis, where as areca nut is having nut covered by husk layer. The above relation and nature between the wood and areca nut gives insight into that both match their properties to certain considerable extent [14]. So the wood cutting process will be similar to some extent of areca nut peeling process, thus the parameters affecting the wood cutting process are also related to the areca nut peeling process.

3. METHODOLOGY

3.1 Functional analysis
The functional analysis method offers the sort of means of considering vital functions and the level at which the trouble is to be addressed. The vital capabilities are those who the tool, product or machine to be designed have to satisfy, irrespective of what bodily additives might be used. The problem stage is decided with the aid of setting up a boundary around coherent subset of functions.
Functions:
1. Feeding or orientation of nuts.
2. Loosening the areca nut.
3. Giving incision to the husk.
4. Ejecting the husk.

3.2 Design

Figure 4 shows the assembly of areca nut de-husker whereas figure 5 shows the model of it. The de-husking process is divided into two stages. The areca nuts are fed manually into the hopper. Areca nut is conveyed in the narrow passage between the tyre and the blades by the force of rotating tyre and the weight of the areca nut. In the first stage de-husking may happen completely and areca nuts are collected. The partially de-husked areca nuts move to the second stage where systems of gears which are meshed tightly pull the husk downwards and nuts are conveyed forward. The whole mechanism is powered by 1HP AC single phase motor and the power is transformed by using pulleys and v-belt system.

3.3 Detailed design (Design methodology)

The following critical parameters are considered for design through literature survey:
1. Optimal size of the dry areca nuts as shown in table 1
2. Husking clearance
3. Optimal tyre pressure.
4. Optimal tyre speed.
5. Pulley diameters.
Husking clearance is the clearance between tyre and the blades. Husking clearance affects the depth of cut.

Based on the sizes of the areca nut the husking clearance is determined to be 20mm.

Tyre pressure:
- Pressure in the tyre makes the tyre rigid and hence it exerts shear and compression forces on the dry areca nut.
- Too high pressure makes the tyre more rigid and it results in the damage of the nut (% of broken nuts increases).
- There exists an optimal value of pressure for which the performance of the machine is at the peak.
- The machine will be tested by varying the tyre pressures and the optimal pressure will be found out for which the performance is at the peak.

Tyre speed:
- Tyre speed affects the centrifugal force.
- Increased tyre speeds cause increased forces.
- Too high speeds results in damage of nuts.
- Therefore there exists an optimal speed for which the performance of the machine is at the peak.

| Sizes of Areca Nut | Length (mm) | Width (mm) | Height (mm) |
|-------------------|-------------|------------|-------------|
| Small             | 34 – 38     | 23 – 27    | 23- 27      |
| Medium            | 39 – 44     | 28 – 30    | 28 – 30     |
| Large             | 45+         | 31 – 35    | 31 – 35     |

Force required = 92.7 N/m²
Distance moved = π × r
Energy required = 92.7 × π × r
= 92.7 × 3.142 × 0.2 = 58.25 joules

Rotational kinetic energy of wheel = IW²/2 = mr²w²/4
58.25
w = 2.5 × 0.22 × w²
= 48.271
w = 2 × π × N/60
N = w × 60/2 × π = 460 rpm

Work done = F × a × r; a = angle
= T × a

T = E/a
= 58.25/3.14159 = 18 Nm

Power = 2 × 3.142 × N × T/60 = 2 × 3.142 × 460 × 18/60
= 740 Watts
Determining pulley diameters:

Figure 6 shows the schematic representation of pulley. Speed of driving pulley versus speed of driven pulley can be expressed as

\[ \frac{d_1}{n_1} = \frac{d_2}{n_2} \]  
\[ d_1 = \text{driving pulley diameter} \]  
\[ n_1 = \text{speed of driving pulley} \]  
\[ d_2 = \text{driven pulley diameter} \]  
\[ n_2 = \text{speed of driven pulley} \]  
\[ \frac{d_1}{n_1} = \frac{d_2}{n_2} = 50 \times \frac{1750}{460} = 190.21\text{mm (Std 200mm)} \]

4. DESIGN OF EXPERIMENTS

Design of Experiments (DOE) procedures empower fashioners to decide at the same time the individual and intelligent impacts of numerous variables that could influence the yield brings about any structure. DOE likewise gives full knowledge of the association between structure components; in this manner, it helps transform any standard plan into a strong one. Basically, DOE assists with sticking point the delicate parts and touchy territories in structures that mess up Yield. Planners are then ready to fix these issues and produce strong and better return structures earlier going into generation. In broad-spectrum, DOE is the structure of any data gathering practices where variety is available, regardless of whether under the full control of the experimenter or not. In any case, in measurements, these terms are normally utilized for controlled investigations. Formal arranged experimentation is regularly utilized in assessing physical articles, synthetic details, structures, segments, and materials. Different sorts of study, and their plan, are talked about in the articles on PC tests, assessments of public sentiment and measurable reviews (which are kinds of observational examination), common investigations and semi tests (for instance, semi test structure). See Experiment for the qualification between these sorts of analyses or studies.

There are three steps in the DOE:

1. Designing the experiment
2. Conducting the experiment
3. Analysis of the experimental results

4.1 Designing the experiment

This stage consists of identifying the factors effecting the output of the machine and determining the levels of these factors. The factors which affect the output of the machine are speed of the wheel, air pressure in the tyre and the clearance between the wheel and the teeth as seen in table 2.
Therefore the number of experiments to be performed are = 23 = 8. No of replications for each experiment are 3. The total number of trial runs = 8 × 3 = 24.

4.2 Conducting the experiment
In this phase 24 trial runs are conducted by using different combinations of the levels of the factors. The table 3 shows the results of experiments. For each trial 10 areca nuts are fed into the machine and the number of areca nuts de-husked (NDA) is noted down.

| StdOrder | Speed of wheel | Air pressure in tyre | Clearance | NDA |
|----------|----------------|----------------------|-----------|-----|
| 1        | 460            | 20psi                | 10mm      | 4   |
| 3        | 460            | 25psi                | 10mm      | 4   |
| 4        | 540            | 25psi                | 10mm      | 6   |
| 5        | 460            | 20psi                | 13mm      | 7   |
| 6        | 540            | 20psi                | 13mm      | 5   |
| 7        | 460            | 25psi                | 13mm      | 6   |
| 8        | 540            | 25psi                | 13mm      | 4   |
| 9        | 460            | 20psi                | 10mm      | 3   |
| 10       | 540            | 20psi                | 10mm      | 6   |
| 11       | 460            | 25psi                | 10mm      | 3   |
| 12       | 540            | 25psi                | 10mm      | 5   |
| 13       | 460            | 20psi                | 13mm      | 7   |
| 14       | 540            | 20psi                | 13mm      | 6   |
| 15       | 460            | 25psi                | 13mm      | 7   |
| 16       | 540            | 25psi                | 13mm      | 5   |
| 17       | 460            | 20psi                | 10mm      | 5   |
| 18       | 540            | 20psi                | 10mm      | 5   |
| 19       | 460            | 25psi                | 10mm      | 3   |
| 20       | 540            | 25psi                | 10mm      | 5   |
| 21       | 460            | 20psi                | 13mm      | 6   |
| 22       | 540            | 20psi                | 13mm      | 5   |
| 23       | 460            | 25psi                | 13mm      | 6   |
| 24       | 540            | 25psi                | 13mm      | 4   |
4.3 Results and discussions

| Source                                           | DF | Seq SS | MS   | F     | P    |
|-------------------------------------------------|----|--------|------|-------|------|
| Speed of wheel                                  | 1  | 0.0417 | 0.0417 | 0.10  | 0.756|
| Air pressure in tyre                            | 1  | 2.0417 | 2.0417 | 4.90  | 0.042|
| Clearance                                       | 1  | 7.0417 | 2.0417 | 16.90 | 0.001|
| Speed of the wheel×Air pressure in the tyre     | 1  | 0.0417 | 0.0417 | 0.10  | 0.756|
| Speed of the wheel×Clearance                    | 1  | 18.3750| 18.3750| 44.10 | 0.000|
| Air pressure×Clearance                          | 1  | 0.0417 | 0.0417 | 0.10  | 0.756|
| Speed of the wheel×Air pressure in the tyre×Clearance | 1  | 0.3750 | 0.3750 | 0.90  | 0.357|
| Residual error                                  | 16 | 6.6667 | 0.4167| -     | -    |
| Total                                           | 23 | 34.6250|       |       |      |

From Table 4, it is found that the interaction effect of speed of the wheel and clearance has the maximum effect on the performance of the areca nut de-husking machine. The contribution is 18.3570/34.6250=0.5306 i.e. 53.06 %. The next significant contribution is from the main factor i.e. clearance which has a contribution of 7.0417/34.6250=0.2033 i.e. 20.033 %. The main factors speed of the wheel, pressure of the wheel is found to have minimum contribution in effecting the performance of the machine with contribution of 0.1% and 5.89% respectively. The 2 way interactions of pressure and clearance, pressure and the speed have the contribution of 0.1% each. The 3 way interaction of all the main factors has a contribution of 1.08%.

Figure 7 shows pareto graph. From this it is observed that, the significance of each factor and their interactions on areca nut de-husking. It is clear that speed of wheel in not significant. Pressure and clearance are the significant factors. Clearance is found to be most significant factor on areca nut de-husking. The interaction between speed of the wheel and the clearance is also significant which can be seen in figure 8.
The results of the factor effect study:

- The effect of speed of wheel is 0.0833 which is positive. It indicates that there is a positive effect of speed of the wheel, as the speed is increased the number of de-husked areca nuts increases.
- The effect of air pressure in the wheel is 0.5833 which is negative. It suggests that there is a negative effect of air pressure on the number of areca nuts de-husked.
- The effect of clearance is 1.0833, which is positive. It suggests that there is a positive effect of clearance on the number of de-husked areca nuts. It is the most significant main factor.
- The interaction between speed and the clearance is the most significant interaction factor with an effect of -1.7500.
- The 2 way interaction of speed and pressure, pressure and clearance are insignificant with an effect of -0.0833 each.
- The 3 way interaction of speed, pressure and clearance is also insignificant with an effect of -0.2500.

The optimum settings of the factors is obtained from main effects plots as shown in figure 9, it is observed quantity of areca nut de-husked (response) at the following levels of each factor is found to be more, it is further concluded that optimum settings for factors i.e. speed of the wheel is 560 RPM, air pressure in the tyre is 20 psi and clearance is 13mm.
5. CONCLUSIONS

The areca nut de-husker is designed and fabricated to meet the objectives and constraints specified. It is found that the interaction effect of speed of the wheel and clearance has the maximum effect on the performance of the areca nut de-husking machine. The 2 way interactions of pressure and clearance, pressure and the speed have the contribution of 0.1% each. The 3 way interaction of all the main factors has a contribution of 1.08%. Areca nut de-husker works on a single phase power supply and it is easy to operate and repair. It accommodates different sizes of areca nuts. Areca nuts with husk of high adhesive strength and fibrous (beeli gotu) can be de-husked in the areca nut de-husker without damaging areca nuts.

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