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# Effect and optimization of machine parameters of wild *Chironji* nut decorticator using response surface methodology

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■ **ABSTRACT :** The kernel contains the nuts of *Chironji.* Traditionally, it was removed by hand hammer, small stone disc (*Jatta*) or by the use of *Chironji* decorticator. Design experiments were conducted by using the response surface methodology (RSM) for optimizing the machine parameters of wild *Chironji* nut decorticator. The effect of three variables (disc speed, disc clearance and moisture content) with three levels of disc speed (1.05, 1.64 and 2.28 m/s), three levels of disc clearance (6, 7 and 8 mm) and five levels of moisture treatedsample (7.83, 8.34, 8.57, 8.68 and 9.04 %, wet basis.) was used for optimization. The maximum whole kernels percentage and minimum kernel breakage were taken as responses in order to optimize the machine parameters. The most suitable optimal results were found at disc speed 1.05 m/s, disc clearance 7 mm and moisture content 8.57 per cent, respectively. The capacity of decorticator, decorticating efficiency, whole kernel recovery and broken kernel recovery percentage at optimized independent parameters were 22.09 kg/h, 87.20 per cent, 16 per cent and 2.88 per cent, respectively.

■ **KEY WORDS :** Wild *Chironji* nuts, Decorticator, Pre-treatment, Response surface methodology, Optimization

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B*uchanania lanzan* (*Chironji*) is a tree species which belongs to the family Anacardiaceae and is commercially very useful. The tree is found as natural wild in the north, west and central India, mostly in the states of Madhya Pradesh, Chhattisgarh, Jharkhand, Bihar, Orissa, Andhra Pradesh, Gujarat, Rajasthan and Maharashtra (Malik *et al.*, 2010).

*Chironji* is regarded for its high value kernel. It is a common substitute of almond amongst dry fruits (Chauhan *et al.*, 2012). *Chironji* fruits as well as kernel are very nutritious. Its fruits contain 74.3 per cent moisture, 2.2 per cent protein, 0.8 per cent fat, 1.5 per cent fibre and 19.5 per cent carbohydrate. Its kernel contains moisture 3 per cent, protein 19 per cent, fat 59.1 per cent, carbohydrate 12.1 per cent, mineral matter 3 per cent and fibre 3.8 per cent. The kernel also contains 34-47 per cent oil (Gopalan, 1982).

The *Chironji* nut has very good demand in India as well as in foreign markets and thus, has become an important crop. Therefore, to earn foreign exchange the government and private agencies have evinced keen interest in developing this industry, both by increasing its production and processing capacity (Deshmukh *et al.*, 2017).

The presence of hard seed coat is one of the shelling problems in decortications of nuts, its small size let's to damage the seed at the time of decortications and spoil the seeds which reduce its economic value and also deteriorate the shelf-life of it which leads to low storage stability (Singh *et al.*, 2012).

According to currently available information harvesting and decortication of *Chironji* nut are still carried out manually in India, especially in Chhattisgarh, which increase cost and processing time for kernel extraction. Traditional processing method of *Chironji* nut is very cumbersome, time consuming and labour extensive. In this process dried *Chironji* nut is broken by rubbing between a pair of stone-slab or hammer followed by separation of kernels from the hull. In some areas local artesian developed motorized machines for breaking and separating, but the machine were not specially designed. So they are again manually separation (Kumar *et al.*, 2012).

To overcome the above problem in decortications of *Chironji* nut, Singh *et al*. (2015) designed and constructed a *Chironji* decorticator, to remove outer shell from the *Chironji* nuts to get kernels. Kernels are damaged or broken due to the mechanical force applied on the nut during the decortication operation. The operating condition of the decorticator machine is one of the most important factors which considerably affect the whole kernel percentage decortication efficiency and decorticator capacity. The optimization of such machine parameters to obtain the desired result was important. Thus, the objective of this study was to optimize the different operating machine and sample parameters and obtain the desired result.

## ■ METHODOLOGY

### Samples and experiments variable:

A power operated *Chironji* decorticator was developed by Department of Agricultural Processing and Food Engineering, IGKV Raipur, to remove outer shell from the *Chironji* nuts to get kernels, which is working on the principle of abrasive, impact and friction (Singh *et al.*, 2015). It consists of main frame, decorticating unit, separating (grader) unit and the power unit. For conducting the experiments wild variety of *Chironji* nut grown in Baster region of Chhattisgarh were chosen.

Designed experiments were conducted by using the response surface methodology (RSM) (Khuri and Cornell, 1987). The Box- Behnken design of three variables with three levels of disc speed, three levels of disc clearance and five levels of moisture content was used for optimization. The details of the variable selection are as follows:

### Disc speed:

Disc speed (1.05, 1.64 and 2.28 m/s) selected for the experimentation was according to the minimum and maximum force required for the decortication of the nuts wear and tear should be minimum. Trial runs were conducted to establish the levels of the speed.

### Disc clearance:

The values of the levels of disc clearance (6, 7 and 8 mm) were selected from calculating the average thickness of *Chironji* nut separately and conducting the preliminary experiment such that there is minimum possibility of broken kernel.

### Moisture content:

The levels of the moisture content (7.83, 8.34, 8.57, 8.68 and 9.04 %, wet basis) were selected as per the different pre-treated (30 min tray dying, 20 min boiling, 24 and 30 h soaking) and untreated (raw sample) nut and the minimum possible moisture content after drying of nuts till there is no considerable effect on the quality of the kernel.

### Experimental procedure:

Clean, dried and a wild variety of *Chironji* nut (Fig. A) grown in Baster region and procured from the Chhattisgarh state minor forest produce co-operative federation. Ltd. was selected for the experimentation. These selected cleaned samples were decorticated using *Chironji* decorticator developed by IGKV (Fig. B). Two man or women workers were required during experiment for continuous working, one for collecting the output sample and the other one for feeding the nut sample into the hopper. During experimentation, the required moisture content of the nuts was adjusted by drying the nuts or by giving the moisture treatment to the sample selected for that particular experiment as per procedure given by Nishad *et al.* (2017). All the machine parameters, *i.e.,* disc speed, disc clearance and pre-treated moisture content of nuts were set and then fed the sample into the hopper and run the machine. Collected the decorticated sample obtained from discharge chute of the decorticator machine and measured the required parameters. The process parameters were optimized for maximum decortication efficiency, whole kernel recovery,

**Fig. A : Dried *Chironji* nut**

**Fig. B : *Chironji* nut decorticator**

capacity and minimum kernel breakage using the, Design- Expert Software version 10.0.8.

**Design of experiments:**

On the basis of previously available review of literature and preliminary experiments, the variables: disc speed, disc and pre-treated moisture content of nut were selected as independent variables for decorticating of the *Chironji* nut. The three levels of variables with three levels of disc speed, three levels of disc clearance and five levels of moisture content were taken. The actual and coded values of all the variables are given in Table A.

**Table A : Independent process variable**

| Coded levels | Codes | | |
|---|---|---|---|
| | Disc speed (A), m/s | Disc clearance (B), mm | Moisture content (C), % |
| -1 | 1.05 | 6 | 7.83 |
| -0.5 | - | - | 8.34 |
| 0 | 1.64 | 7 | 8.57 |
| 0.5 | - | - | 8.68 |
| 1 | 2.28 | 8 | 9.04 |

**Response measurement technique:**

Following decortication parameters were calculated as dependent variable of the experiment and optimization of process and machine parameters (Ashwini *et al.*, 2015).

Decorticator capacity (kg/h)

$$= \frac{\text{Weight of total sample (kg)}}{\text{Decortication time (h)}} \quad .....(1)$$

Decorticator efficiency (%)

$$= \frac{\text{Weight of decorticated nut (kg)}}{\text{Total weight of sample (kg)}} \times 100 \quad .....(2)$$

$$\text{Whole kernel (\%)} = \frac{\text{Weight of whole kernel (kg)}}{\text{Total weight of sample (kg)}} \times 100 \quad ..(3)$$

$$\text{Broken kernel (\%)} = \frac{\text{Weight of broken kernel (kg)}}{\text{Total weight of sample (kg)}} \times 100 \quad ..(4)$$

## ■ RESULTS AND DISCUSSION

Fig. B shows the *Chironji* nut decorticator used for decortication experiment. Regression analysis for dependent parameters of decorticated wild *Chironji* nuts are given in Table 1. A complete second order polynomial model (Eq. 5) was fitted to the data and adequacy of the model was tested considering $R^2$ (the co-efficient of multiple determination) and F-test. The models were then used to interpret the effect of various independent parameters on the responses.

Optimization of process parameters was carried out and contours were developed for selected parameters. A second order response function for three independent variables had the following general form:

$$Y = \beta_0 + \sum_{i=1}^{4} \beta_i x_i + \sum_{i=1}^{2} \sum_{j=i+1}^{4} \beta_{ij} X_i X_j + \sum_{i=1}^{4} \beta_{ii} X_i^2 \quad ....(5)$$

where,

$\beta_0$, $\beta_{i,}$ $\beta_{ii}$ $\beta_{ij}$ are constants, $X_{i,}$ $X_i$ are variables

The experimental data were analyzed by employing multiple regression techniques to develop response functions and variable parameters optimized for maximum decortication efficiency, whole kernel recovery, capacity and minimum kernel breakage.

**Capacity of machine:**

The capacity of machine was observed to be ranging from 3.8 to 6.69 per cent depending upon various parameters. The maximum decortication capacity (32.15 kg/h), was observed again at the disc speed of 2.28 m/s and disc clearance of 6 mm for 8.57 per cent moisture content (24 h soaked) of *Chironji* nuts. This was perhaps due to the fact that the duration of decortications process was very short as analyzed by Okokon *et al.* (2007). The capacity of decorticator increased with increase disc speed from 1.05 to 2.28 m/s and decreased disc clearance from 8 to 6 mm (Fig. 1). The both parameters had shown a significant effect on capacity of decorticator.

A second order model of eq. (5) was fitted to the responses observed for levels of capacity of decorticator at various experimental conditions using multiple regression analysis. The co-efficient of determination ($R^2$) for the regression model for this parameter was 89.01 per cent, which implies that the model could account for 89.01 per cent of the data. The model was highly significant at 1 per cent level of significance ($p<0.01$) as lack of fit was found to be non-significant. Therefore, second order model was found to be adequate in describing change in decortication efficiency.

$$\text{Capacity (kg/h)}=0.44-0.0449A-0.013B-0.0746C+6.76AB+2.07AC+8.81BC+4.43A^2+4.78B^2+3.88C^2 \quad .....(6)$$

where, A is disc speed, B is disc clearance and C is moisture content (treated) of *Chironji* nut.

## Decortication efficiency:

During the decortication of wild *Chironji* nuts, decortication efficiency ranged from 83.4 per cent to 95 per cent (Table 1). The decorticating efficiency was significantly higher (95%) at the disc speed of 2.28 m/s and disc clearance of 6 mm for 8.57 per cent moisture content (24 h soaked) of *Chironji* nuts, compared to other combination of parameters. The higher decorticating efficiency with higher speed was because the quantity of unshelled seeds decreased. It was observed that disc speed and disc clearance were showing significant ($p<0.01$) difference as compared to pre-treated moisture content (Fig.2). It revealed that decortication efficiency increased with increase disc speed from 1.05 to 2.28 m/s and decrease disc clearance from 8 to 6 mm, respectively.

A second order model of eq. (5) was fitted to the responses observed for levels of decortication efficiency at various experimental conditions using multiple regression analysis.The co-efficient of determination ($R^2$) for the regression model for this parameter was 94.22 per cent, which implies that the model could account for 94.22 per cent of the data. The model was highly significant at 1 per cent level of significance ($p<0.01$) as lack of fit was found to be non-significant. Therefore, second order model was found to be adequate in describing change in decortication efficiency.

**Table 1 : Analysis of variance and regression co-efficients for dependent parameters of decorticated wild *Chironji* nuts**

| Source | df | Capacity | | Efficiency | | Whole kernel | | Broken kernel | |
|---|---|---|---|---|---|---|---|---|---|
| | | Coeff. | P value | Coeff. | P value | Coeff. | P value | Coeff. | P value |
| Model | 9 | 0.039 | 0.0001** | 0.011 | 0.0001** | 0.067 | 0.0001** | 0.23 | 0.0001** |
| A | 1 | -7.543 | 0.0001** | -4.219 | 0.0001** | 5.822 | 0.0001** | -0.095 | 0.0001** |
| B | 1 | 1.226 | 0.0118* | 1.184 | 0.0001** | -1.357 | 0.1053 | 0.063 | 0.0001** |
| C | 1 | 2.839 | 0.6187 | 4.465 | 0.8535 | -1.127 | 0.2674 | 4.557 | 0.9297 |
| AB | 1 | 4.161 | 0.9411 | 2.189 | 0.9271 | -1.706 | 0.8641 | -0.043 | 0.0001** |
| AC | 1 | 7.692 | 0.2722 | 8.283 | 0.7788 | -1.161 | 0.3473 | 1.643 | 0.7943 |
| BC | 1 | 5.323 | 0.4454 | -2.648 | 0.3717 | 3.747 | 0.7605 | -2.237 | 0.7228 |
| $A^2$ | 1 | 1.678 | 0.0415* | 1.111 | 0.0022** | -2.357 | 0.8675 | 0.021 | 0.0056** |
| $B^2$ | 1 | 4.784 | 0.5493 | 2.459 | 0.4688 | 4.641 | 0.0021** | 1.039 | 0.8858 |
| $C^2$ | 1 | 1.420 | 0.0945 | 2.569 | 0.0001** | 0.015 | 0.0001** | -0.027 | 0.0009** |
| $R^2$ % | | 89.01 | | 94.22 | | 83.08 | | 96.00 | |
| Adj. $R^2$ % | | 86.18 | | 92.74 | | 78.73 | | 94.98 | |
| F value | | 31.50 | | 63.42 | | 19.09 | | 9342 | |
| Lack of fit | | NS | | NS | | NS | | NS | |
| CV % | | 6.13 | | 0.95 | | 5.75 | | 9.84 | |

* and ** indicate significance of values at P= 0.05 and 0.01, respectively NS = Non-significant

**Efficiency (%) = 0.061 - 1.88A + 1.37B – 0.011C+ 3.56AB +2.23AC - 4.38BC +2.93A² + 2.46 B²+ 7.02 C²** .......(7)

$$\text{Efficiency (\%)} = 0.061 - 1.88A + 1.37B - 0.011C + 3.56AB + 2.23AC - 4.38BC + 2.93A^2 + 2.46B^2 + 7.02C^2 \quad \text{.......(7)}$$

## Whole kernels recovery:

The effect of disc speed, disc clearance and pre-treated moisture content of wild *Chironji* nut on whole kernel percentage was determined by keeping one variable constant with respect to others shown in Fig. 3. It could be evident that decreased with increased disc speed. It was also observed that the percentage of whole kernels first increased with increase in disc clearance then slightly decrease.This may be due to the fact that *Chironji* nut is having varying size. Higher percentage of whole kernels (16%) was recovered at disc speed 1.05 m/s rpm and 7 mm disc clearance for 8.57 per cent moisture content (24h soaked nut), respectively. Lowest whole kernels recovery (10.14%) was obtained at 2.28 m/s disc speed and 6 mm disc clearance for 7.83 per cent moisture content (30 min. tray dried nuts).

Multiple regression analysis reported in Table 1 shows that the model was significant at 1 per cent level of significance ($p<0.01$) as the co-efficient of determination ($R^2$) for the regression model for this parameter was 83.08 per cent, which implies that the model could account for 83.08 per cent data and lack of fit is non-significant. It was observed that only disc speed significantly affected the whole kernel percentage at 1 per cent level of significance at quadratic level. The second order model for the percentage of whole kernel was:

$$\text{Whole kernel (\%)} = 3.17 + 0.041A - 0.071B - 0.684C - 2.77AB - 3.12AC + 6.19BC - 6.23A^2 + 4.64B^2 + 0.041C^2 \quad \text{......(8)}$$

## Broken kernel:

The percentage of broken kernels varied from 2 to 9.30 per cent having significant effect of disc speed and disc clearance on the breakage of kernels. It was found to be lower (2%) at disc speed of 1.05 m/s and disc clearance of 8 mm for 8.68 per cent moisture content (30h soaked nuts). The percentage of broken kernels increased with decrease disc speed and disc clearance. It was also observed that the soaking time increase the broken per cent was decreased.The breakage percentage in case of 7.83 per cent moisture content (30 min. tray dried nuts) was highest (9.30%) at 2.28 m/s disc speed and 6 mm disc clearance. Due to removal of moisture content from kernel, it becomes harder than the shell itself.

Full second order model of eq. (5) was fitted to the responses observed for levels of capacity of decorticator at various experimental conditions using multiple regression analysis. The co-efficient of determination ($R^2$) for the regression model for this parameter was 96 per cent, which implies that the model could account for 96 per cent of the data. The model was highly significant at 1 per cent level of significance ($p<0.01$) as lack of fit was found to be non-significant. Therefore, second order model was found to be adequate in describing change in percentage of broken kernels.

$$\text{Broken kernel (\%)} = -6.00 + 0.112A + 0.196B + 1.27C - 0.0709AB + 4.41AC - 3.70BC + 0.0561A^2 + 1.039B^2 - 0.074C^2 \quad \text{....(9)}$$

Fig. 1-4 show the three dimensional contour surface graphs, graphical representation of the combined effect of the two independent variables on the different responses. During the drawing of graph between any two variables third variable put constant at the value of central point and optimum value of that response, alternatively.

## Optimization of parameters:

The optimization of the independent variables was carried out using response surface methodology (Design Expert 10.0.8). The optimized values of disc speed, disc clearance and moisture content (pre-treatments) were taken for further study. The maximum whole kernels (%) and minimum broken kernel (%) were taken as responses in order to optimize the machine parameters.

Based on mentioned criteria, the optimization was carried out. The most suitable optimal results were found at disc speed 1.05 m/s, disc clearance 7 mm and moisture content 8.57 per cent (24 h soaked nuts), respectively. The capacity of decorticator, decorticating efficiency, whole kernel recovery and broken kernel recovery percentage at optimized independent parameters were 22.09 kg/h, 87.20 per cent, 16 per cent and 2.88 per cent, respectively.

## Conclusion :

The study indicated that the *Chironji* nuts had higher decortications efficiency (95%), decorticator capacity (32.15 kg/h). minimum kernel breakage (2%) and maximum whole kernel percentage (16%).The best performance of the *Chironji* nut decorticator was obtained at 1.05 m/s disc speed,7 mm disc clearance and 8.57 per cent moisture content (24 h Soaked nuts).

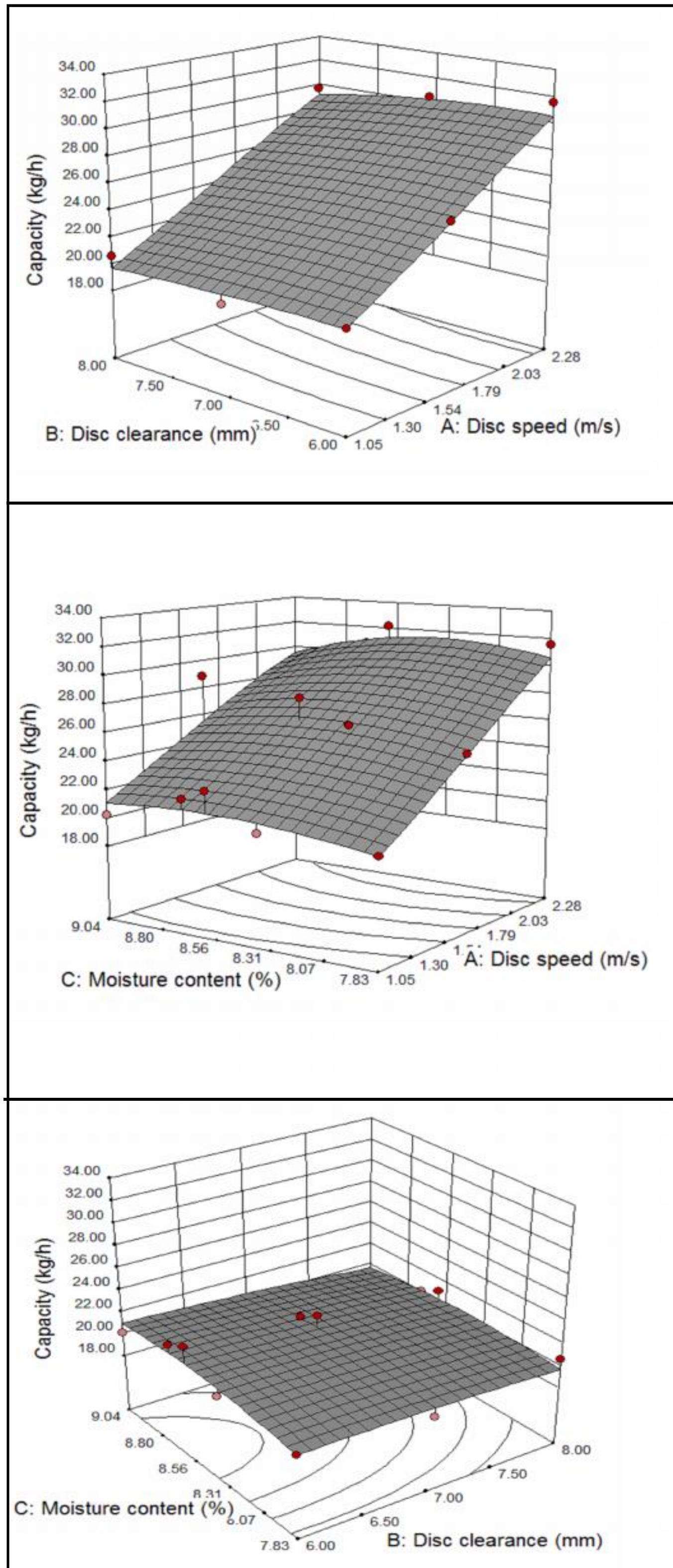


**Fig. 1 : Effect of disc speed, disc clearance and pre-treated moisture content on capacity of decorticator**

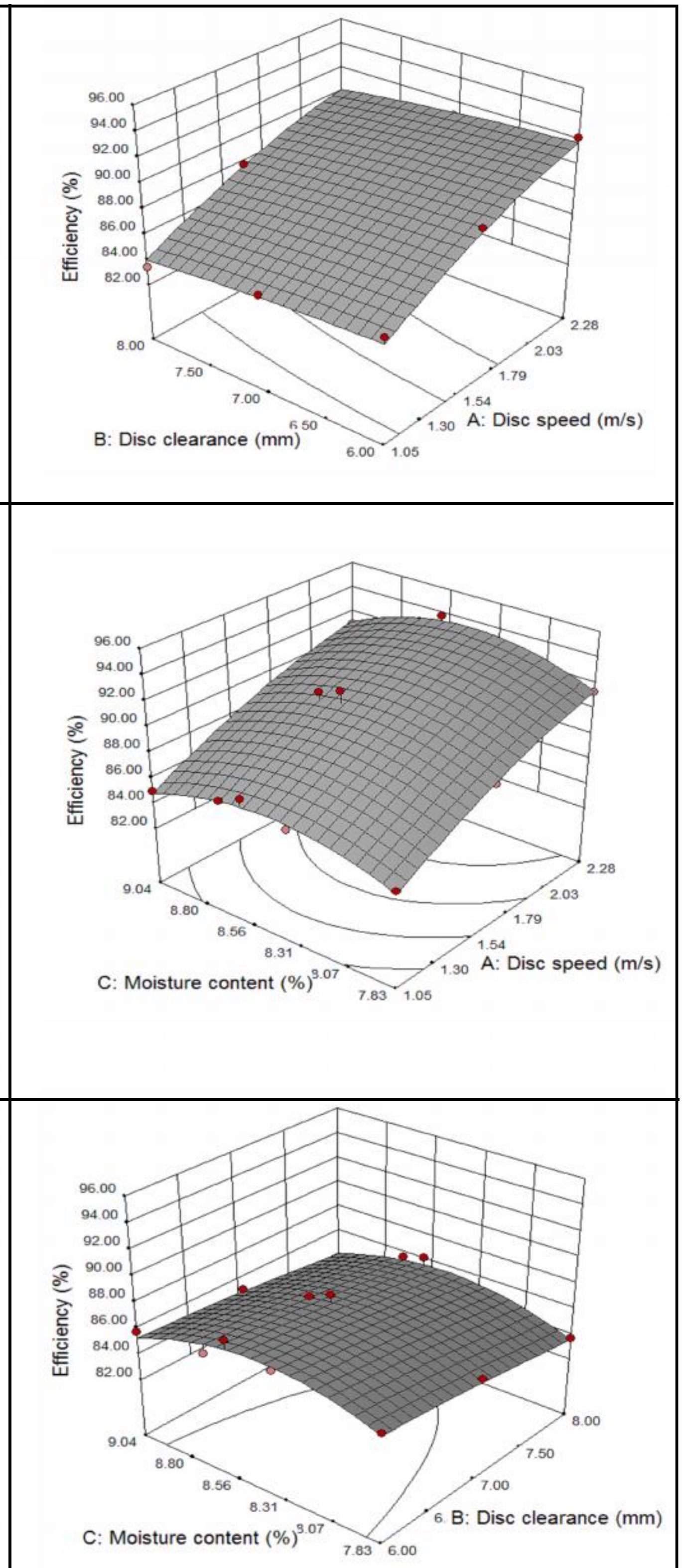


**Fig. 2 : Effect of disc speed, disc clearance and pre-treated moisture content on capacity of decorticating efficiency**

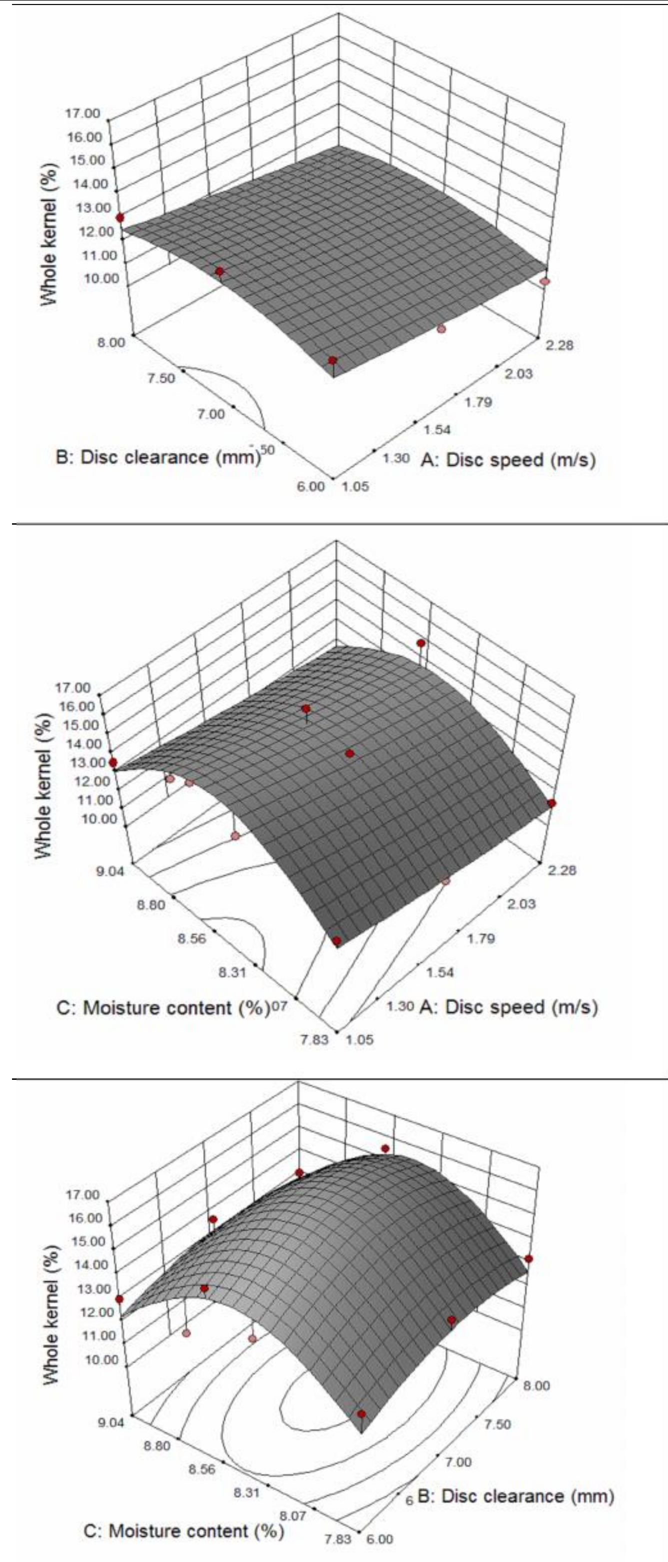


**Fig. 3 : Effect of disc speed, disc clearance and pre-treated moisture content on whole kernel percentage**

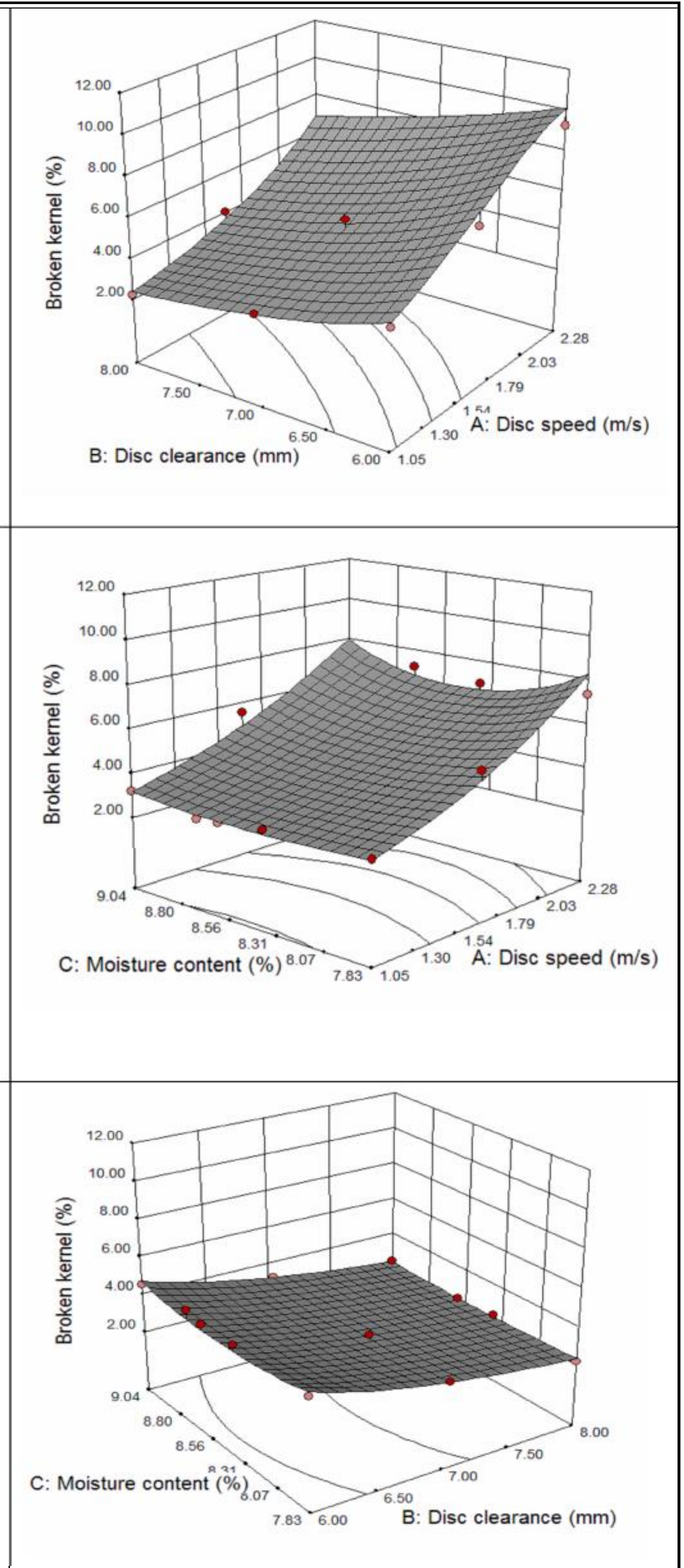


**Fig. 4 : Effect of disc speed, disc clearance and pre-treated moisture content on broken kernel percentage**

Decortication efficiency and decorticator capacity was highly affected by disc speed and disc impact clearance.

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