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Study and Analysis of Areca-Nut Peeling Process Using Design of Experiment

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Abstract **- Areca nut is one of the most important commercial crops. The raw fruit has to be pealed in order to get its nut (kernel). Manual pealing process which is labor intensive and not safety to the labor. The automatic machines developed are not efficient to completely remove the husk from the nut due to variation in the size of the areca nut and the non availability of the optimum process parameters. The wood cutting process is related to the areca nut peeling because the areca nut husk will have wood like constituency. The parameters affecting the wood cutting will have significant effect on the areca nut husk removal, like speed of the cutter, depth of cut, hook angle of cutter and the condition of areca nut. In this research a prototype areca nut machine is developed suit to peel three different sizes of the dried areca nut and experiments are conducted for determining the optimum peeling process parameters using Taguchi approach.**

Key Word **- Areca nut, Anova, DOE, Peeling.**

I. Introduction

Areca Nut is one of most important commercial crop also known as betel nut and it is the seed of the areca nut palm. While it is being freshly plucked, the husk is green and the nut inside is so soft that it can easily be cut with an average knife. In the ripe fruit the husk becomes yellow or orange and, as it dries, the fruit inside hardens to a wood-like consistency. The study is towards peeling process of areca nut which are classifieds, as manual and automatic. Peeling by manual method proved to be labour intensive, consumes more time and dangerous to the labour. The various studies towards automatic peeling process is not up to the satisfactory level and are still in the improvisation stage.

A. Manual Areca Nut Peeling

The areca nut can be peeled manually with sharp knifes which is fixed on wooden piece to get its nut or kernel. In the peeling process of areca nut, the labour 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. 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.

B. Mechanized Areca Nut Peeling

Semi mechanized areca nut peeling machines are driven by manually either through hand or pedal. The fully automated areca nut peeling machine are runs by electrical motor. These machines are not compact, inefficient in peeling of areca nut due to variation in the size of areca nut

Fig.1. Manual Peeling of Areca Nut

and improper using peeling parameters such as speed, hook angle of cutter, depth of cut and condition of areca nut. Thus there exists enough scope for analyzing the areca nut peeling process and achieving the best peeling parameters.

II. Literature Survey

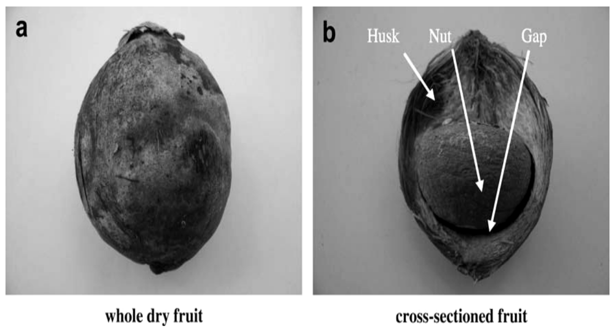

Fig.2. Cross-section of areca nut after natural drying

A. Areca nut peeling

The areca nut has to be made use from separating the husk, the nut fruit has firstly to be de-husked to get a nut. Areca nut comprises of a husk firmly attached to a nut on the side that is closest to the stem, while a gap exists on the other side because of the separation of the nut from the husk as a result of loss of moisture. Thus the outer husk layer to be peeled off as the nuts to be cut effectively far better from the existing process.

The mechanical properties in relation to de-husking of the areca nut are found that lateral shear with a rubbing action might be suitable for de-husking the fruit. The moisture content of the dry fruit has to be in the range of 5–6% of areca nut weight [1]. Prior to the properties a device for de-husking dry areca nut fruit was developed comprising of a scissor mechanism, a frame, a platform and a pedal operated lever mechanism [2]. A mathematical model for the design of a frictional roller for husking machine and the model along with indicating that both friction and normal forces caused the husking also revealed the estimate of roller size [3]. Similar to Wang concept, a dry betel nut shelling machine developed by a farmer was tested [4]. The husking mechanism featured is 10-5.00 tyre and a sieve constructed from steel rods which was curved under the tyre. The design concept of the shelling machine was similar to the idea proposed [3] in that husking was exerted by both friction and normal forces although a point of difference was that husking did not occur between two rollers but through the use of a single rotating tyre and a stationary sieve. However, the sieve which was supported by a spring proved to be rather inefficient because it often came loose, causing a high degree of incomplete husking. A new design [5] is introduced for a betel nut fruit husking machine. Its husking mechanism comprised two commercial 10-5.00 rubber tyres hinged to and parallel with a concave sieve. This design failed to conclude its efficiency properly.

The manually operated machine was developed by M J Francis- Kerala, requires skilled labour and operated by pedal solely depends on workability of men not suitable for long process to peel the areca nut.

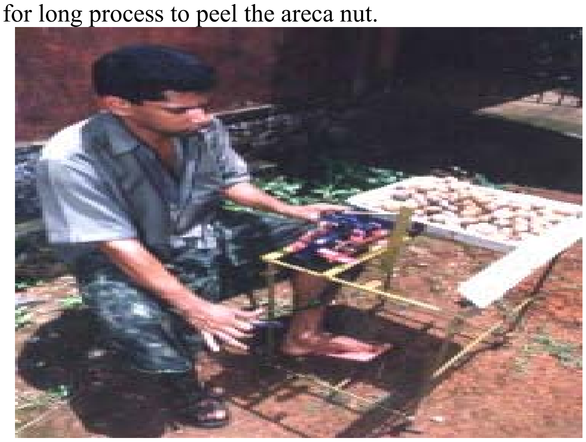

Fig.3. Areca nut de-husking device developed by M J Francis-Kerala.

Fig.4. Areca nut De-husking machine at GKVK, Bangalore

The semi mechanized machine (Fig:4) was developed by Post Harvest Technology Centre, University of Agricultural Sciences (UAS), Gandhi Krishi Vigyan Kendra (GKVK), 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.

Fig.5. Areca nut peeling machine with rotary assembly

The automatic operated machine (Fig:5) consists of a mainframe on which a rotary shelling drum having 8 numbers of solid rubbers on its periphery is mounted. Below this a concave is placed to aid shelling and to pass the de-husked material down. After de-husking kernels and husk flow to the duct and reach the air stream, produced by a blower. The husk is thrown out and the kernels/nuts are collected at the bottom (Fig:7). Depending upon the size of fruits, the concave has to be changed for higher efficiency and minimum breakage. Grading the dried fruits before de-husking will also help to increase the de-husking efficiency and reduce the breakage.

Fig.6. Areca nut Dehusker

Fig.7. Areca nut peeling machine

It was observed in the Areca Nut machine developed by Bhandari that the areca being slightly wet not detach from the peeler on its own and need to be pull it up slightly. The areca and the shell not get completely separated and further peeling was required. To improve the productivity, Bhandari has developed two different machines to process areca nuts (Fig:8). These machines are designed to peel areca nut of any size and are more efficient. In the first manual husking machine, a wheel need to be rotated by hand, which made it slower than the second automatic machine. For better peeling of dry areca nuts, Bhandari modified the machine using the relative motion between the high-speed rotating cushioned discs.

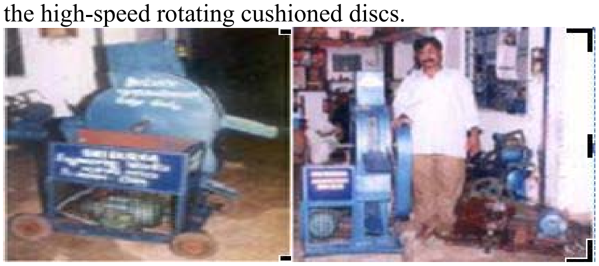

Fig.8. Bhandari's areca nut peeling machine.

Krishnamurthy Bhat (Fig:9) used a vehicle tyre as the flywheel and made more modifications compared with the e x i s t i n g machines for peeling ripe areca nuts. He has attached a c o n v e y o r belt to a tin. The belt picked up the Areca Nut from the tin, one by one, and put it in the machine for peeling. The peeling was better in this case as compared to the results achieved with Bhandari's machine, possibly because this machine dealt with dry areca nut and the cost seemed to be less.

Fig.9. Krishnamurthy bhats areca-nut peeling machine.

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.

B. Factors Affecting wood cutting and Areca Nut peeling process.

Moisture Content: The wood shrinks and swells due to variation in moisture content

Grain Orientation: Grain Orientation influences cutting mechanism, processing along the grain or with the grain with narrow angles usually results in removal of chip.

Width of Cut: Depends on the width of the cutter. The width of cutter may vary depending on the type of cutting required to process.

Depth of Cut: Higher the depth of cut more aggressive in the removal of outer shell [6,7,8].

Cutting Speed: Higher the cutting speed more the centrifugal force, lesser the speed cutting is not efficient[6].

Rake Angle/Hook Angle: Control the geometry of the chip formation for any given material and, therefore, it controls the mechanics of the cutting action of the tool. Rake angle used in the cutter are [7,8] with 10°, 15°, 20° and 25° rake angles for various wood specie. Hardwoods, knives with rake angles of 20° or less are advisable for reduced chipped grain and hence better surface finish [7,8].

Wedge angle: The greater the wedge angle, the stronger will be the tool. The greater the angle of the wedge the quicker the heat generated by the cutting process will be conducted away from the cutting edge.

Clearance angle: Less clearance angle influence the rubbing of the tool and more clearance angle weaken the tool.

C. 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 fibres) 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, areca nut fruit is a fibrous, ovoid drupe, yellow to orange or red when ripe pericap fibrous.The above relation and nature between the wood and areca nut gives insight into that both match their properties to certain considerable extent. 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.

D. Design of Experiments

Design of Experiments (DOE) gives a powerful means to enhance and achieve breakthrough improvements in product development and process efficiency. This can reduce the number of required experiments while taking into account the numerous controlling factors affecting experimental results. DOE can determine how to carry out the fewest number of experiments while maintaining the most important information and controlling factors. Taguchi proposed an improved DOE which adopts the fundamental idea to simplify and standardizes the factorial and fractional factorial designs so that the conducted experiments can produce more consistent results. Orthogonal arrays are a set of tables of numbers, each of which can be used to lay out experiments for a number of experimental situations. The DOE technique based on this approach makes use of these arrays to design experiments. Through the orthogonal arrays, it will carry out fewer fractional experiments and identifies the influencing factors and its influence on the variation of results. Through fractional experiments, optimal conditions can be determined by analyzing the S/N ratio (Signal-to-Noise ratio) as a performance measure, often referred to as ANOVA (Analysis of Variance) [7].

III. PROBLEM DEFINITION

The areca nut de-husked on machines are not completely removes the outer shell due to variation in size of the areca nut and improper using of peeling parameters. In the existing pealing process there is inefficiency in areca nut pealing process due to parameters like speed of cutter, hook angle of cutter, condition of an areca nut, depth of cut and operating condition as well as areca nut machine design. Therefore there is an enough scope for study, analysis and investigation of best parameters, relating to the peeling process.

IV. METHODOLOGY

The research is carried out in two phases such as

1. Developing a prototype machine for Areca Nut peeling and
2. Experimentation considering parameters such as speed of cutter, hook angle of cutter, depth of cut and condition of Areca Nut

A. Phase 1: Development of a prototype machine for Areca Nut peeling

Fig.10. Prototype machine for Areca nut peeling

The assembly (Fig:10) consists of two electrical motor each connected to shafts, one is for cutting process called as cutter shaft and the other is connected to Geneva wheel mechanism to drive three holding cups to hold the three different sizes of the areca nut peeling against the cutter. The peeled of areca nuts are collected in the back side of the machine and husk is collected down. The cutter shaft consisting three cutter blades of TCT saw blade used for cutting the wood of 4'' 40 teeth's blade.

Different sizes of areca nut and holding cups

Areca-nut are graded and sorted into large, medium and small based on their height, width and length as tabulated below in table 1 and the different size of areca nut holding cup which is assembled to Geneva wheel shaft are given in table 2.

Table:1 Different sizes of Areca Nuts

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

Table:2 Different sizes of areca nut holding cups.

Sizes of Cup (Areca Nut Holder)	Length (mm)	Width (mm)	Height (mm)
Small	50	35	35
Medium	55	40	45
Large	60	40	50

B. Phase 2: Experimentation considering arameters such as speed of cutter, hook angle of cutter, depth of cut and condition of areca nut

This experiment is conducted with by varying the different cutter speeds, hook angle of cutter, depth of cut and condition of areca nut[9,10] at their different levels as mentioned (Table:3).

Design of experiment:

Table :3 Control factors and their levels

Symbol	Factors	Levels		
		1	2	3
A	Speed(rpm)	125	92	62
B	Hook Angel (deg)	14	17	20
C	Depth of Cut(mm)	1	2	3
D	Condition of Areca Nut	Dry	Moderate Wet	Wet

The thickness of areca nut fibre is approximately around 4mm, so the depth of cut will be kept for 1mm, 2mm and 3mm. Areca Nut are conditioned into Dry, Moderate wet and wet with the moisture content 17-25%, 30-35% (immersed in water for 15 minutes at room temperature) and more than 35 % (immersed in water for 30 minutes at room temperature) respectively.

Selecting an Orthogonal Array:

Four factors and three levels (3^(4) L9 orthogonal array which consists of nine set experiments (Table:4).

Table:4 Four factors and three levels the orthogonal array is L9.

Experiment number	Column			
	1	2	3	4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1
Factors	A	B	C	D

A = Speed (rpm), B = Hook angle,
C = Depth of Cut (mm) D = Condition of Areca nut

The experiments are as per ANOVA table is conducted. In each trial 30 areca nuts are fed to the machine and three trial where conducted for each experiment. The average number of areca nut peeled (NAP) are noted (Table: 5).

Table:5 Experiment conducted

Experiment number	Factors				No. of areca nuts peeled out per trail			Average N A P
	A	B	C	D	Trail			
					1	2	3	
1	1	1	1	1	7	6	9	7
2	1	2	2	2	10	13	14	12
3	1	3	3	3	16	15	19	17
4	2	1	2	3	5	7	8	7
5	2	2	3	1	11	9	12	11
6	2	3	1	2	7	9	8	8
7	3	1	3	2	6	5	9	7
8	3	2	1	3	6	8	5	6
9	3	3	2	1	5	8	7	7

Analysis:

ANOVA table is used for analysis which consists of sum of squares (SS), mean of sum of squares variance (MS) and percent contribution (F&P).

Table:6 Completely peeled out Areca Nut

Experiment no.	Trial Number			Sum of each experiment
	1	2	3	
1	7	6	9	22
2	10	13	14	37
3	16	15	19	50
4	5	7	8	20
5	11	9	12	32
6	7	9	8	24
7	6	5	9	20
8	6	8	5	19
9	5	8	7	20

Total sum of observations, T = 244
Total number of experiments, N = 27

SST = 72 + 62 + 92 … - 2442/27 = 350.962
Error,
Since, SST = SSA + SSB + SSC + SSD + SSe
SSe = SST - SSA - SSB - SSC - SSD
SSe = 350.962 – 143.629 – 64.29 – 79.185 – 12.51
SSe = 51.348
(SS = sum of squares)

Degree of freedom:

Total degree of freedom is equal to the degree of freedom is associated with number of levels plus degree of freedom is associated with error. Therefore, the total degree of freedom is equal to N-1. It can be calculated by this formula:

Total degree of freedom, VT = N – 1 = 27 – 1 = 26,

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Average of total sum of observation $\check{T} = \frac{T}{N}$ = 244/27= **9.037**

Table:7 Sum of Squares

Factors	Level			Number of Experiment.	Sum of Squares
	1	2	3		
A	109	76	59	9	$SS_A = [\sum_{i=1}^{ka}\left(\frac{Ai^2}{nAi}\right)] - \frac{T^2}{N} = \frac{A1^2}{nA1} + \frac{A2^2}{nA2} + \frac{A3^2}{nA3} - \frac{T^2}{N}$=143.63
B	62	88	94	9	$SS_B = [\sum_{i=1}^{kb}\left(\frac{Bi^2}{nBi}\right)] - \frac{T^2}{N} - \frac{B1^2}{nB1} + \frac{B2^2}{nB2} + \frac{B3^2}{nB3} - \frac{T^2}{N}$=64.29
C	65	77	102	9	$SS_c = [\sum_{i=1}^{kc}\left(\frac{Ci^2}{nCi}\right)] - \frac{T^2}{N} = \frac{C1^2}{nC1} + \frac{C2^2}{nC2} + \frac{C3^2}{nC3} - \frac{T^2}{N}$=79.19
D	74	81	89	9	$SS_D = [\sum_{i=1}^{kd}\left(\frac{Di^2}{nDi}\right)] - \frac{T^2}{N} = \frac{D1^2}{nD1} + \frac{D2^2}{nD2} + \frac{D3^2}{nD3} - \frac{T^2}{N}$=12.51

Sum of Squares:

The sum of squares is a measure of the deviation of the experimental data from the mean value of the data. Summing each squared deviation emphasizes the total deviation. The sum of squares analysis (SSA)for the factors and total variation is determined (Table:7)

Total sum of squares, $SS_T = [\sum_{i=1}^{n} Yi^2] - T^2/N$

Table: 8 Degree of Freedom

Factors	V_F=K-1 where F=A,B,C,D and K= Number of levels =3
A	2
B	2
C	2
D	2

For Error, V_e

$V_e = V_T - V_A - V_B - V_C - V_D = 18$

Mean Square Deviation (MS):

Mean square deviation is the ratio of sum of squares to the degrees of freedom of the respective data and are calculated for each factor (Table:9)

Table: 9 Mean Square Deviation

Factors	**Mean Square Deviation (MS)**
A	MS A = $\frac{SS\ A}{V\ A}$ = 71.8145
B	MS B = $\frac{SS\ B}{VB}$ = 32.145
C	MS C = $\frac{SS\ C}{VC}$ = 39.59
D	MS D = $\frac{SS\ D}{VD}$ = 6.255
Error	MS e = $\frac{SSe}{Ve}$ = 2.852

F-test/Variance ratio:

F-test/ variance is used to measure the significance of the factor under investigation with respect to the mean square of all the factors included in the error term.

Table:10 F-Test/Variance Ration

Factors	**F-test/Variance ratio**
A	Fa = $\frac{MS\ A}{MS\ e}$ = 25.18
B	Fb = $\frac{MS\ B}{MS\ e}$ = 11.27
C	Fc = $\frac{MS\ C}{MS\ e}$ = 13.88
D	Fd = $\frac{MS\ D}{MS\ e}$ = 2.19

Pure Sum of Squares (SS'):

Factor i = $SS'_i = SS_i - (MSe \times V_i)$

Where i= A,B,C,D

Table:11 Pure Sum of Squares

Factors	Pure Sum=**Factor i = $SS'_i = SS_i - (MSe \times V_i)$**
A	137.93
B	58.59
C	73.48
D	6.81

Error, $SS'e = SSe + [MSe \times (V_A + V_B + V_C + V_D)]$

= 51.348 + [2.852 x(2+2+2+2)]

SS'e = 94.164

Percent Contribution:

The percentage contribution is obtained by dividing the pure sum of squares for that factor by Total Sum of

Squares and multiplying the result by 100. The percentage contribution is denoted by P and is calculated (Table:12).

Table:12 Percent Contribution of Parameters

Factors	Percent Contribution
A	$P_A = \frac{SS' A}{SS\ T} x\ 100 = 39.29\%$
B	$P_B = \frac{SS' B}{SS\ T} x\ 100 = 16.69\%$
C	$P_C = \frac{SS' C}{SS\ T} x\ 100 = 0.93\%$
D	$P_D = \frac{SS' D}{SS\ T} x\ 100 = 1.94\%$
Error	$P_e = \frac{SS' e}{SS\ T} x\ 100 = 21.13\%$

Table:13 ANOVA

Factors	Degree of freedom	Sum of Squares	Mean Square(MS)	F	Pure sum SS'	Percentage (%)
A	2	143.629	71.814	25.1	137.9	39.29
B	2	64.29	32.14	11.2	58.58	16.69
C	2	79.18	39.59	13.8	73.48	20.93
D	2	12.51	6.255	2.19	6.806	1.94
Error	18	51.348	2.852		74.16	0
Total	26	350.96				99.9

Signal to Noise ratio (S/N ratio):
The higher value of Signal to Noise ratio will result in smaller product variance around the target value.
For Larger the better-type
S/N = -10 $\log_{10}$ (MSD)
Mean Square Deviation, MSD =

$$1/n \sum_{i=1}^{n} \frac{1}{(y1)^2} + \frac{1}{(y2)^2} + \frac{1}{(y3)^2}$$

Sum of Squares, SS = $\Sigma(\frac{1}{y^2} + \frac{1}{y2^2} + ..)$

Where the n=number of repetition, y = value

Table: 14 Signal to Noise ratio

Sl no.	Sum of square	Mean square deviation	S / N
1	0.06053	0.02017	16.95
2	0.02101	0.007006	21.54
3	0.0112	3.7069 x 10^(-3)	24.30
4	0.07603	0.02534	15.961
5	0.02755	9.814 x 10^(-3)	20.37
6	0.04837	0.01612	17.924
7	0.08012	0.0267	15.73
8	0.0834	0.0278	15.50
9	0.0760	0.02534	15.96

Factor and their levels affecting the areca nut peeling that is affecting on the output which is calculated (Table:15) from the L9 Orthogonal array.

Table: 15 Factors and their levels affecting

Factors	Level 1	Level 2	Level 3
A	12	9	7
B	7	10	11
C	7	9	12
D	8	9	10

For factor A, level 1
Ex1 + Ex2 + Ex3 = (7 + 12 +17) / 3 = 12
Similarly,
For factor A level 2
Ex4 + Ex5 + Ex6 = (7+11+8)/3 = 9

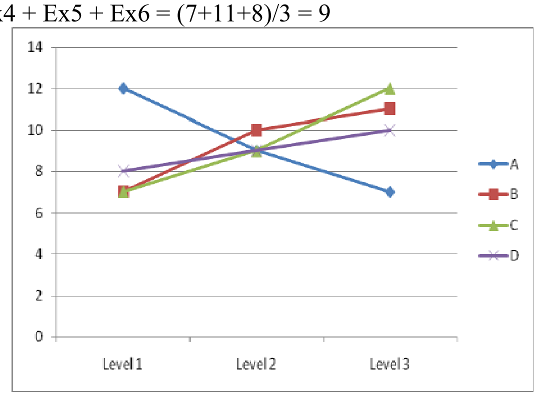

Fig.10. Showing NAP (number of Areca Nuts peeled) Vs Factors value as per calculations

V. Results and Discussion

The areca nut peeling process parameters such as speed, hook angle, depth of cut and condition of areca nut are determined using experimental design. A prototype areca nut peeling machine is developed and the experiments are conducted by varying the controllable process parameters. The results obtained from the experiments are analysed using Design of experiments. Taguchi's L9 Orthogonal Array is selected for four factors each of three levels 3^(4) and the experiments are conducted according to the ANOVA table. Three sets of trials were conducted for each experiment and in each trial 30 areca nuts are fed to the machine. Completely peeled out areca nuts are tabulated. The experimental results are shown in table 5 for 9 set of experiments. Analysis is done through ANOVA procedure and tabulated in table number 13. The experiment number 3 give the best result on the basis of signal to noise ratio (largest is the best) which are mentioned in table number 14. The process parameter such as cutter speed 125 rpm, hook angle of cutter 20 degree, depth of cut 3mm and wet condition of areca nut are the optimum process parameters (table 5 and 14). The parameters are analyzes to know the effect on peeling process and are tabulate. Speed is a most important factor which will contribute 39.29%.

VI. Conclusion

The areca nut peeling process with major factors affecting are selected as Speed of cutter, Hook Angle, Depth of Cut and Condition of Areca Nut with three different levels are used for conducting the experiment to obtain the optimum condition for areca nut peeling using DOE. Analysis is carried out using the ANOVA procedure and the Signal to Noise ratio (larger the better type) is used. The experiments conducted and the results are analyzed. The peeling process parameters A, B, C, and D at their levels of 1, 3, 3 & 3 are giving the better results.

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