Results and Discussion

CHAPER IV

RESULTS AND DISCUSSION

This chapter presents the properties of dehusked coconut and the results obtained during performance evaluation of size and weight grader. The study was conducted by varying the belt speed and inclination angle for size grader, angular velocity and settling time for weight grader and their effect on grading efficiency were determined and discussed.

4.1. Engineering Properties of Dehusked Coconut

It is known that engineering properties of dehusked coconut such as size, shape, bulk density and true density are the important properties for the design of processing equipments. Therefore in the present study the above listed properties were studied and their results are reported and discussed.

4.1.1. Physical properties

4.1.1.1. Major Diameter and Weight

The frequency distribution of major diameter (width) and the weight of nut are shown in Fig. 4.1(a) and Fig. 4.1(b) for 100 samples. From the figure it was found that the minimum and the maximum major diameter of dehusked coconut were found to be 70 mm and 120 mm, respectively. The frequency of major diameter at the range of 90 mm to 100 mm was found to be highest. The minimum and maximum weight of nut was 180 g and 725 g, respectively. From the selected samples, maximum number of nuts were in the range of 400 to 600 g. The shape of the curves of major diameter and weight of nut showed a normal distribution.

The sample fruits taken were exhibited a wide range of sizes with the length, width and thickness. These dimensions might be useful in designing the size of machine components.

4.1.1.2. Sphericity, Density, Surface Area

From the Table 4.1 it was found that the width of dehusked coconut was found to be 92.5±9.5 mm. The mean sphericity of the coconut was found to be 0.90, and indicative of the tendency of the shape towards a sphere. The properties such as true density, bulk density and surface area of dehusked coconut were 998 kg.m^{-3}, 483 kg.m^{-3}, and 274.2 cm^{2}, respectively. These properties are useful in separation and transportation of the dehusked coconut.

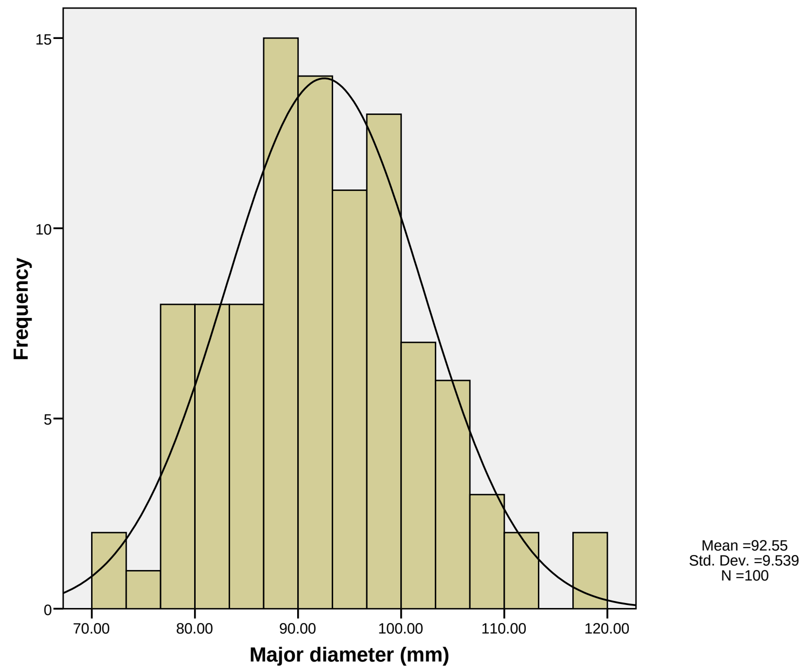

Fig. 4.1. (a) Frequency distribution of major diameter (mm) of 100 dehusked coconut

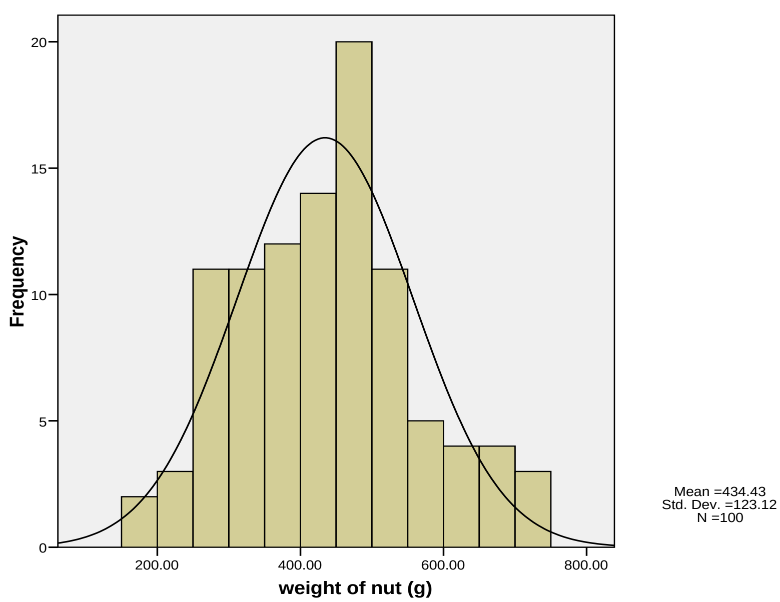

Fig. 4.1. (b) Frequency distribution of fruit mass (g) of 100 dehusked coconut

Table 4.1. Size parameters of dehusked coconut

Property	Mean ± SD	Number of observations
Length (mm)	99.2 ± 13.3	100
Major diameter (mm)	92.5 ± 9.5	100
Minor diameter (mm)	89.5 ± 8.7	100
Geometric mean diameter (mm)	92.9 ± 9.7	100
Sphericity	0.90±0.05	100
Surface area (cm^2)	274.2 ± 50.4	100
Bulk density ($kg.m^{-3}$)	483 ± 37.3	25
True density ($kg.m^{-3}$)	998 ± 68.8	25

The properties of dehusked coconut fruit are listed in the Table 4.2 (Appendix I). Fruits ranged widely in weight with these characteristics exhibiting 4.1-fold increase between the smallest and largest fruits. The fruits encompassed the full range of commercial grading classes. The fruit volume ranged between 714 cm^3 to 281 cm^3 exhibiting 2.6-fold increases between the smallest and the largest fruits. Fruit maturity could impact fruit size, and the same could also vary with the genotype (Hazel, 2011).

The weight of kernel, weight of shell, shell thickness and weight of copra per fruit exhibited 3.1-, 2.7-, 2.6- and 3.2- fold difference respectively, among all the fruit sampled. The percent of weight of kernel, weight of copra and shell weight exhibited 1.4-, 2.2- and 2-fold differences, respectively. It was found that the percentage of weight of kernel was relatively consistent, and varied up to 1.4 times difference among the fruits of all sizes.

Table 4.2. Characteristics of dehusked coconut

Parameter	Mean ± SD
Total fruit weight, g	434.43 ±123.12
Fruit volume, cm^3	505.26 ±147.49
Weight of kernel, g	225.26 ±53.42
Weight of shell, g	118.83 ±26.16
Thickness of shell, mm	3.79 ±0.70
Thickness of flesh, mm	11.67 ±1.08
Weight of copra, g	125.10 ±28.65
Weight of water, g	86.38 ±50.38
% of kernel to total weight of nut	53.18 ±4.55
% of copra to total weight of nut	29.82 ±4.49
% of shell to total weight of nut	28.25 ±3.51

n = 100

4.1.2. Frictional properties

Table 4.3 shows the coefficient of friction of dehusked coconut on cardboard, rubber, stainless steel, aluminium, and galvanised iron surfaces. It was found that the higher coefficient of friction was on rubber (0.43), followed by galvanised iron sheet (0.388), showing that these surfaces exerted more friction on dehusked coconut. Lower friction was experienced on aluminium (0.256) and it was clear that this behaviour was due to the properties of friction surfaces (Ozguven and Vursavus, 2005). Similar results were also observed in a study conducted by Zhiguo *et al.* (2011) for tomato fruit.

Table 4.3. Coefficient of friction of dehusked coconut

Surface	Mean ±SD
Card board	0.311 ± 0.07
Rubber	0.430 ± 0.09
Stainless steel	0.274 ± 0.07
Aluminium	0.256 ± 0.06
Galvanised iron sheet	0.388 ± 0.11

4.2. Fruit Grade Attributes

ANOVA of dehusked coconut attributes are presented in Table 4.4. Statistical analysis revealed that there was a significant difference in length, major diameter, minor diameter, mass, weight of kernel, shell weight and weight of copra among the four grades of dehusked coconut [>110mm (first grade), 101-110 mm (second grade), 91-100 mm (third grade), 80 – 90 mm (fourth grade)] at 1 % level of significance. Similar results were reported by Sharifi *et al*. (2007) for physical properties of orange (var. Tompson).

Table 4.4. Analysis of variance as related to graded dehusked coconut physical properties

Dependent Variables	Source	Sum of squares	Mean squares	F
Length		2165.704	721.901	14.168*
	Error	10801.951	50.953	
	Total	12967.656		
Major diameter		21771.408	7257.136	971.874*
	Error	1583.037	7.467	
	Total	23354.444		
Minor diameter		20476.291	6825.430	673.299*
	Error	2149.105	10.137	
	Total	22625.396		
Mass		54.4×10^5	18.1×10^5	474.180*
	Error	81.1×10^4	3827.305	
	Total	62.5×10^5		
Weight of kernel		33.1×10^4	11.0×10^4	140.892*
	Error	16.6×10^4	785.414	
	Total	49.8×10^4		
Weight of shell		20.8×10^4	69.5×10^3	165.664*
	Error	89.0×10^3	419.876	
	Total	29.7×10^4		
Weight of copra		16.8×10^4	56.0×10^3	100.937*
	Error	11.7×10^4	554.879	
	Total	28.5×10^4		
Shell thickness		3.893	1.298	3.740**
	Error	73.552	.347	
	Total	77.445		

**Significant at 1% level **Significant at 5% level*

4.3. Variability of Dehusked Coconut

To find the variability in the size and weight of dehusked coconut, a total of 600 nuts were selected randomly from the different fields in Sungaramadaku village, Pollachi. The variability in the size and weight of dehusked coconut obtained in this study are listed in Table 4.5. Dehusked coconut exhibited a wide range of sizes with smallest and largest fruit having 80 and 120mm diameter respectively. It was an interesting factor to note that the fruits with same size say 80 to 90mm have shown weight ranging from 250g to 550g. The same phenomena were observed with all categories of size. This shows that even though the nuts are with same size they vary in weight which may be due to the difference in weight of kernel, quantity of coconut water and shell weight.

Table 4.5. Variability between size and weight of dehusked coconut

Size (mm)	Weight(g)	Number of nuts
80-90	250-350	45
	350-450	89
	450-550	9
90-100	350-450	85
	450-550	127
	550-650	17
100-110	450-550	16
	550-650	75
	650-750	67
	750-850	12
>110	700-800	12
	800-900	18
	>900	7
	Total	**579**

4.4. Fruit Character Correlation

The correlation matrix relating the fruit characteristics of different dehusked coconut is presented in Table 4.6. Fruit characteristics as major diameter, weight of nut, shell weight, weight of mature coconut water and wet flesh weight were strongly correlated with fruit weight and total fresh kernel weight

Weight of nut and major diameter of nut indicated a strong positive relationships with weight of kernel (r = 0.96 and 0.91, respectively), indicating that larger fruit were heavier and had greater total fresh kernel weight (significant at 0.05 level). The weight of shell was highly correlated with weight of nut and also the weight of mature coconut water showed strong positive association with weight of nut. In contrast, the fruit length was poorly correlated with the weight of kernel, copra, shell, mature coconut water and shell thickness. Similarly, the shell thickness was also poorly correlated with all fruit characteristics, indicating that heavier and bigger coconut were not influenced by shell thickness. Similar results were obtained by Hazel (2011) for pomegranate fruit characteristic.

4.5. Principle Component Analysis (PCA)

As the section 4.4 clearly indicates that most of the measured variables were correlated each other and therefore to find the principal component in all the measured variables of dehusked coconut, PCA would be best suited. For that reason three different size range of dehusked coconut (80-90, 91-100 and 101-110mm diameter) 75 of each were taken for PCA (Appendix I). From the PCA results, two plots *viz.*, score plot and loading plot were obtained.

Principle components (PC) with high eigenvalues represent maximum variation among the variables. Most of the studies have assumed PCs with eigen value >1 (Ritika *et al.*, 2016; Atanu and Rattan, 2014) represents the supreme variations.

Table 4.6. Correlation between the properties of dehusked coconut

	Length, mm	**Major diameter, mm**	**Minor diameter, mm**	**Weight of nut, g**	**Shell weight, g**	**Weight of copra, g**	**Shell thickness, mm**	**Weight of mature coconut water, g**	**Weight of kernel, g**
Length, mm	1								
Major diameter, mm	0.2832	1							
Minor diameter, mm	0.3072	**0.9838**	1						
Weight of nut, g	0.4015	**0.9179**	**0.9189**	1					
Shell weight, g	0.4218	0.7897	0.7901	**0.8719**	1				
Weight of copra, g	0.3903	0.7020	0.7091	0.8219	0.8111	1			
Shell thickness, mm	0.0750	0.2744	0.2735	0.2616	0.2830	0.2704	1		
Weight of mature coconut water, g	0.3431	0.8247	0.8255	**0.9282**	0.6860	0.6788	0.1483	1	
Weight of kernel, g	0.3807	**0.9176**	**0.9191**	**0.9661**	**0.8411**	**0.8270**	0.3150	**0.8266**	1

Table 4.7, shows the PCs with eigenvalues greater than one which explains the total variations of 87.3 %.

Table 4.7. PCA for dehusked coconut size ranging from 80-90 mm

	PC1	**PC2**	**PC3**	**PC4**
Eigenvalue	4.4108	2.7481	1.4012	1.0435
Proportion	0.401	0.25	0.127	0.095
Cumulative variability (%)	40.1	65.1	77.8	87.3
Factor Loading				
Weight of nut	**0.43**	0.172	-0.102	-0.249
Major diameter	0.074	**0.5**	-0.296	0.221
Minor diameter	0.087	**0.519**	-0.247	0.151
Length	**0.408**	-0.236	0.05	-0.039
Weight of shell	0.302	-0.171	**-0.469**	0.198
Thickness of shell	0.091	-0.326	**-0.587**	0.05
Weight of copra	**0.41**	0.026	0.157	0.069
Weight of kernel	**0.421**	0.17	0.107	0.119
Weight of water	0.151	0.276	0.022	**-0.775**
Thickness of kernel	0.223	0.12	**0.468**	**0.442**
Spericity	-0.345	0.375	-0.133	0.09

Bold faces in each PC give the important variables

The results revealed that, PC1 with eigenvalue of 4.41 was able to explain 40% of the total variation and PC2 was also able to explain 25% of variation and both the PCs (PC1 and PC2) explained 65% of the total variation. Similarly PC3 and PC4 were able to explain 12 and 9% respectively. The factor loadings of respective variables are presented in Table 4.7 and it shows that the highest factor loading value gives the chief important variable under a certain PC and absolute factor loading value within 10% of the highest values under same PC. Thus PC1 explains more about the weight of nut, length, weight of copra and weight of kernel. Further, PC2 was influenced by major and minor diameter of the nut and PC3 explains about weight and thickness of the shell. Moreover, PC4 had the highest factor loadings for weight of water and thickness of the kernel.

The PCA loading plot drawn between PC1 and PC2 is presented in Fig. 4.2(a). It was observed that the spoke length of the weight of nut, weight of kernel and spericity was longest among all the characteristic of dehusked coconut of size 80-90 mm and therefore it was proved as a most interactive character of dehusked coconut. However, weight of fresh kernel and weight of nut had similar character as it had a small angle within them. Similarly, major diameter and minor diameter had similar character. However, minor diameter, weight of water, thickness of kernel, weight of copra, length and thickness of shell have different characters for the dehusked coconut size ranging from 80-90 mm, due to high angle between them.

In Fig 4.2 (b) the data obtained from the nut size 80-90 mm was grouped based on the weight of the nut as 300-400 and 401-500 g. The score plot obtained has revealed the variation between the two groups. The clear separation between the coconut samples pointed out the differences in weight of coconut of size 80 -90mm.

The PCA for dehusked coconut size ranging from 90-100 mm is presented in the Table. 4.8. From the table it was inferred the four PCs with eigenvalues greater than one had the cumulative variability of 85.5 %. As discussed in the previous section, PC1 explains more about the weight of the nut (0.455) followed by the weight of fresh kernel (0.391) whereas PC2 has highest factor loading for spericity. This depicts that all three dimensions such as major, minor diameter and length of the coconut have equal importance in PC2 whereas PC3 was influenced by weight and thickness of the shell. It is noticed that the PC4 was influenced by the thickness of the kernel. The loading plot of the dehusked coconut with size ranging from 90-100 mm are shown in Fig 4.3.(a). As similar to the results of coconut with size 80 -90 mm, weight of the nut and the weight of kernel have longest spoke length. The spoke length of thickness of shell and thickness of kernel are approximately same which indicate that these variables had similar characters. In Fig. 4.3 (a) three groups of weight of coconut viz., <400, 401-500 and >501 g can be clearly distinguished and this shows the variations in weight of coconut with size ranging from 90 to 100 mm.

Table 4.8. PCA for dehusked coconut size ranging from 90-100 mm

	PC1	**PC2**	**PC3**	**PC4**
Eigenvalue	4.4819	2.5607	1.346	1.0132
Proportion	0.407	0.233	0.122	0.092
Cumulative variability (%)	40.7	64.0	76.3	85.5
Factor loading				
Weight of nut	**0.455**	0.022	0.05	-0.096
Major diameter	0.353	0.342	-0.086	-0.019
Minor diameter	0.357	0.347	-0.096	-0.006
Length	0.249	**-0.481**	0.054	-0.259
Weight of shell	0.307	-0.132	**-0.425**	0.295
Thickness of shell	0.076	-0.179	**-0.744**	0.129
Weight of copra	0.325	-0.17	0.096	0.187
Weight of kernel	**0.391**	-0.16	0.186	-0.063
Weight of water	0.325	0.246	0.196	-0.298
Thickness of kernel	0.111	-0.118	0.391	**0.799**
Sphericity	-0.05	**0.594**	-0.097	0.231

Bold faces in each PC give the chief important variables

The PCA for dehusked coconut size ranging from 100-110 mm is shown in Table 4.9 and it was observed that 86.5 % of cumulative variability is from the first four PCs. As similar to the results of Table 4.7 and Table 4.8, the factor loading obtained from PC1 explained more about weight of nut and weight of kernel. In Fig.4.4(a) huge angle between the weight of nut and weight of kernel shows the different interactive character between them. The score plot presented in Fig. 4.4(b) visually infers that the differences in the weight of coconuts of size 100-110mm.

Table 4.9. PCA for dehusked coconut size ranging from 100-110 mm

	PC1	**PC2**	**PC3**	**PC4**
Eigenvalue	3.8365	2.5984	1.8648	1.2205
Proportion	0.349	0.236	0.17	0.111
Cumulative variability (%)	34.9	58.5	75.5	86.5
Factor Loading				
Weight of nut	**0.445**	0.196	-0.141	0.103
Major diameter	0.271	**0.403**	0.283	0.019
Minor diameter	0.26	**0.427**	0.273	-0.115
Length	0.375	-0.177	-0.374	0.105
Weight of shell	0.193	0.265	-0.337	**-0.513**
Thickness of shell	-0.162	0.247	-0.38	**-0.518**
Weight of copra	0.349	-0.238	0.213	-0.252
Weight of kernel	**0.444**	-0.18	0.137	-0.104
Weight of water	0.203	0.333	-0.167	**0.54**
Thickness of kernel	0.205	-0.363	0.335	-0.233
Spericity	-0.234	0.352	**0.473**	-0.114

Bold faces in each PC give the chief important variables

The PCA suggest that PCs weight of nut, weight of kernel, size of coconut, weight and thickness of the shell had explained much of the variation in size and weight attributes of the coconut. From the above results the grading standards for dehusked coconut were formulated and presented in Table 4.10

Table 4.10. Suggested grading standards for dehusked coconut

Size (mm)	Weight(g)	Grade designation
80-90	300-400	Grade - VIII
	401-500	Grade – VII
90-100	<400	Grade – VI
	400-500	Grade – V
	>500	Grade – IV
100-110	<600	Grade – III
	600-700	Grade – II
	>700	Grade – I

4.5.1. Performance evaluation of size grader

The influence of independent variables (belt speed and inclination angle) on the dependent variables (grading efficiency and contamination ratio) were analysed by a two factorial completely randomized block design. Three replications were made to statistically evaluate the efficiency of the sizing machine.

The effect of belt speed and inclination angle on grading efficiency of fully dehusked coconut is shown in the Fig.4.5. It was learned that the size grader recorded a highest grading efficiency of 85.26 percent at 1.7 m/s speed with belt inclination angle of 15^o for fully dehusked coconuts. Also it is understood that the increase in belt speed from 1.3 to 1.7 m/s leads to increase the grading efficiency at the inclination angle of 10^o and 15^o. Further increase in speed from 1.7 to 2.1 m/s, lead to decrease in grading efficiency. It may be due to that at higher velocity, some coconuts left the belt without making a contact with sizing rubber board. As a result the sizing error was increased with belt speed. Analogous results on the effect of velocity were observed by Treeamnuka *et al.,* (2010) for java apple fruit.

ANOVA obtained from the experimental design is given in the Table 4.11. The selected five different belt speed and three different inclination angle of the belt significantly influenced the grading efficiency at 1 percent level while considering the parameters individually. While considering the interactions, the effect of inclination angle of the belt and belt speed was found insignificant on the grading efficiency.

Table 4.11. Analysis of variance for grading efficiency (fully husked) of sizing machine of various belt speed and inclination angle

Source	Sum of Squares	df	Mean Square	F
Treatment	3005.644	14	214.689	30.381**
Intercept	231268.356	1	231268.356	32726.654**
Angle (a)	354.978	2	177.489	25.116**
Speed (s)	2520.756	4	630.189	89.178**
a * s	129.911	8	16.239	2.298 ^{NS}
Error	212.000	30	7.067	
Total	234486.000	45		

** Significant at 5 % level; **significant at 1 % level; NS-not significant*

4.5.2. Grading error (contamination ratio) during grading of fully dehusked coconut

The influence of belt speed and inclination angle on contamination ratio of fully dehusked coconut is presented in Fig.4.6. It was depicted that, the contamination ratio is low at the angles 10^{o} and 15^{o} when the speed of belt is 1.5 m/s. Further, increase in the speed increased the contamination ratio. This may be due to the low residence time given to the dehusked coconut to come in contact with the sizing rubber board. It was also noted that when the inclination angle increased from 15 to 20^{o} the contamination ratio also increased. This may be due to the rolling angle of fully dehusked coconut. When the inclination angle was increased, the fully dehusked coconut rolls faster and the bigger sized coconut may get chocked in the smaller aperture of sizing board.

The significant influence of independent variables viz., speed and inclination angle of the belt were interpreted with ANOVA and presented in Table 4.12.

Table 4.12. Analysis of variance for contamination ratio (fully husked) of sizing machine for various belt speed and inclination angle

Source	Sum of Squares	df	Mean Square	F
Treatment	1157.467	14	82.676	11.308**
Intercept	50200.200	1	50200.200	6866.289**
Angle (a)	886.800	4	221.700	30.324**
Speed (s)	213.733	2	106.867	14.617**
a * s	56.933	8	7.117	.973^{NS}
Error	219.333	30	7.311	
Total	51577.000	45		

** Significant at 5 % level; **significant at 1 % level; NS-not significant*

From the Table 4.11, it was understood that belt speed and inclination angle have significantly affected the contamination ratio at 1 percent level of significance. While considering the interactions, the effect of inclination angle of the belt and its speed was insignificant on the contamination ratio.

Mean values of grading efficiency and contamination ratio of fully dehusked coconut under different treatments are given in Table 4.13. The maximum mean value of the grading efficiency of fully dehusked coconut was 81.11 percent at belt speed of 1.7 m/s. It was also observed that there is no significant difference between the belt speed of 1.9 and 1.3 m/s. The minimum mean value of the contamination ratio of fully husked coconut was 27.66 percent, meanwhile there was no significant difference between the belt speed of 1.7 and 1.5 m/s as far as contamination ratio is concerned.

Table 4.13. Mean comparison by Duncan's multiple range tests (at 5% level) for fully husked coconuts

Dependent variable	Inclination angle (degree)	Subset 1	2	3	4
Grading efficiency (%)	20	68.133			
	10		71.933		
	15			75.000	
	Belt speed (rpm)				
	2.1	59.666			
	1.9		69.66		
	1.3		70.00		
	1.5			78.00	
	1.7				81.111
Contamination error (%)	**Inclination angle (degree)**				
	15	30.80			
	10		33.266		
	20			36.133	
	Belt speed (rpm)				
	1.7	27.66			
	1.5	29.88			
	1.3		33.22		
	1.9			36.00	
	2.1				40.22

4.5.3. Grading efficiency of partially dehusked coconut

The interaction between the belt speed and inclination angle is given in Fig 4.7. At 1.5 m/s the sizing machine recorded 77 percent grading efficiency at 15^o for partially dehusked coconut. However, increasing the belt speed from 1.5 m/s to 2.1 m/s, the grading efficiency is gradually reduced. This may be due to the fact that, the partially dehusked coconut rotates both axially and radially with the speed of the belt from the feeding trough towards the sizing rubber board, resulting in chocking the sizing gap and improper grading.

The influence of independent variables *i.e.* belt speed and inclination angle were interpreted with ANOVA as presented in Table 4.14.

Table 4.14. Analysis of variance for grading efficiency (partially husked) of sizing machine for various belt speed and inclination angle

Source	Sum of Squares	df	Mean Square	F
Treatment	3875.644	14	276.832	57.942**
Intercept	169771.022	1	169771.022	35533.470**
Angle (a)	3424.756	4	856.189	179.202**
Speed (s)	154.311	2	77.156	16.149**
a * s	296.578	8	37.072	7.759**
Error	143.333	30	4.778	
Total	173790.000	45		

It was understood from the table that the independent variables *i.e.* belt speed and inclination angle influenced the grading efficiency individually at 1 percent level of significance. While considering the interaction effect, the belt speed and inclination angle influenced the grading efficiency at 1 percent level of significance.

4.5.4. Grading error (contamination ratio) during grading of partially dehusked coconut

The effect of belt speed and inclination angle of the partially dehusked coconut on contamination ratio is presented in Figure 4.8. It was depicted that the contamination ratio observed was minimum at a belt speed of 1.7 m/s and inclination angle of 15^{o}. Whereas increasing trend was observed beyond belt speed of 1.7 m/s for all the tested inclination angle of the belt.

The contamination ratio was determined for all the treatments tested and statistically analysed to study the influencing factors. The analysis of variance for contamination ratio of partially dehusked coconut is given in the Table 4.15.

Table 4.15. Analysis of variance for contamination ratio (partially husked) of sizing machine for various belt speed and inclination angle

Source	Sum of Squares	df	Mean Square	F
Treatment	2532.800	14	180.914	43.770**
Intercept	54915.200	1	54915.200	13285.935 **
Angle (a)	2108.800	4	527.200	127.548**
Speed (s)	107.200	2	53.600	12.968**
a * s	316.800	8	39.600	9.581**
Error	124.000	30	4.133	
Total	57572.000	45		

It was noted that the selected five different belt speed and three different inclination angle influenced the contamination ratio at 1 percent level of significance. It was also found that the interaction of sizing belt speed and inclination angle significantly influenced the contamination ratio at 1 percent level of significance.

The mean values of belt speed and inclination angle on grading efficiency and contamination ratio are presented in the Table 4.16. The mean values of the best treatments are denoted with superscript 'a' in the Table 4.16. It was observed that the grading efficiency was maximum at a belt speed of 1.5 m/s with the combination of inclination angle 15°. From the table it was observed that the capacity of the size grader was higher with the higher belt speed on the other hand contamination ratio was much higher.

Table 4.16. Mean values of partially dehusked coconut at different treatments during grading

Belt speed, m/s	Inclination angle, (°)	Efficiency * (%)	Contamination ratio *	Capacity (kg/hr)
1.3	10	58.98 [de]	35 [ef]	1964
	15	61.58 [cd]	30 [bc]	2040
	20	60.55 [cd]	31 [bc]	2647
1.5	10	69.47 [b]	31 [c]	3353
	15	77.53 [a]	27 [ab]	3317
	20	71.61 [b]	29 [bc]	3986
1.7	10	69.77 [b]	32 [cd]	2598
	15	70.22 [b]	25 [a]	3767
	20	60.48 [c]	29 [bc]	3356
1.9	10	53.19 [fg]	35 [de]	4333
	15	55.43 [ef]	39 [fg]	4186
	20	62.03 [cd]	39 [fg]	4755
2.1	10	45.22 [hi]	51 [h]	5555
	15	50.76 [g]	50 [h]	4255
	20	49.13 [h]	40 [g]	5263

**means with different letter in the same column implies the statistical difference at P<0.05.*

4.6. Development of Weight Grader

4.6.1. Effect of tilting angles of carrier cups on free falling behaviour of coconuts

The effect of tilting angle of carrier cup on free falling behaviour of coconuts are presented in Fig 4.9. From the figure, it was observed that the highest percent of free falling behaviour of the coconut of 100 percent for MS carrier cup 2 (C_2) was with 10 ^{o} and 15 ^{o} tilt angle of the carrier cup mechanism. This may be due to the rolling angle and rolling resistance of the coconut that is the force resisting the motion of coconut when the carrier cup tilts. It was also found that Plastic carrier cup 1 (C_1) had 90 percent free falling behaviour at 15 ^{o} tilt angle whereas at 10 ^{o} tilt angle, the free falling behaviour was 60 percent. It is also noticed that the free falling behaviour of coconut was shown increasing trend with the increase in tilt angle for C1. This may be due to the bucket like shape of the plastic carrier cup (C_1) in which the coconuts was comfortably seated.

The influence of the tilting angle of the carrier cup on the free falling behaviour of coconuts were analysed statistically and the effect of different treatments were presented in Table 4.17. It was inferred from the table that the treatment individually have significant effect on the free falling behaviour of the dehusked coconut. While the interaction effects of tilting angle and carrier cups was insignificant.

Table 4.17. Analysis of variance for free falling behaviour of partially dehusked coconut

Source	Sum of Squares	df	Mean Square	F
Treatment	13644.444	5	2728.889	70.171 **
Intercept	93888.889	1	93888.889	2414.286 **
Tilt angle (t)	9077.778	2	4538.889	116.714 **
Carrier cup (c)	3755.556	1	3755.556	96.571 **
t * c	811.111	2	405.556	10.429 ns
Error	466.667	12	38.889	
Total	108000.000	18		

4.6.2. Effect of tilting angles of carrier cups return mechanism

Apart from free falling behaviour of the coconut, carrier cup return mechanism was also considered as one of the performance indices. The effect of tilting angle and carrier cup return is shown in Fig 4.10. From the Figure it was observed that, 5^{o} tilt angle had the highest percent of return back position of carrier cup (100 %) for both C1 and C2. Whereas at 10^{o} tilt angle C1 had 70 % and C2 had 100 % return back of carrier cup respectively.

The percent return back position was determined for all treatments tested and statistically analysed to study the influencing factors. The ANOVA is given in the Table 4.18.

Table 4.18. Analysis of variance for carrier cup return mechanism

Source	Sum of Squares	df	Mean Square	F
Treatment	9850.000	5	1970.000	39.40**
Intercept	110450.000	1	110450.000	2209.00**
Tilt angle (t)	7900.000	2	3950.000	79.00**
Carrier cup (c)	1250.000	1	1250.000	25.00**
t * c	700.000	2	350.000	7.00^{NS}
Error	600.000	12	50.000	
Total	120900.000	18		

It was observed that the individual variables *i.e.* tilting angle and type of carrier cup had significantly influenced the return back position of carrier cup. While the interaction effects of tilting angle and carrier cups was found insignificant.

Mean values of free falling behaviour of coconut and return back position of carrier cup under different treatments are given in Table 4.19. The maximum mean value of free falling behaviour of coconut was 95 % at 15 ^{o} tilt angle whereas the maximum mean value of return back position of carrier cup was 50 % at 15 ^{o} tilt angle. Though the percentage of free falling behaviour of coconut was high at a tilt angle 15 ^{o}, the return back position of carrier cup was less. It was also noted that at 10^o tilt angle, the free falling behaviour and return back position of carrier cup was 80 and 85 percent, respectively. From the figure 4.9 and 4.10 it was inferred that the performance of MS carrier cup was superior to Plastic carrier cup. Therefore tilt angle of 10^o and MS carrier cup was selected for the present study.

Table 4.19. Mean comparison by Duncan's multiple range tests (at 5% level) for carrier cup mechanism

Dependent variable	Inclination angle (degree)	Subset		
		1	2	3
Free falling behaviour of coconut (%)	5	41.6667		
	10		80.0000	
	15			95.0000
Return back position of carrier cup (%)	15	50.0000		
	10		85.0000	
	5			100.0000

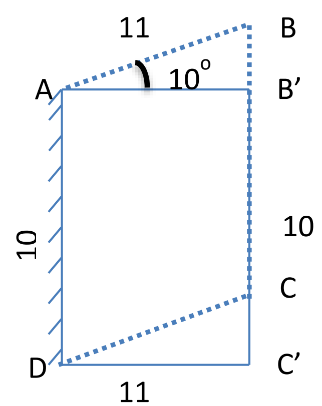

Fig. 4.11. Line Diagram of Carrier cup mechanism

To achieve 10^o tilt angle in carrier cup mechanism, the pointer attached with the carrier cup mechanism has to move down for 20 mm that is the distance of BB' (Fig. 4.11). To attain this, standard available pneumatic cylinder of piston rod with stroke length 25 mm was selected.

4.6.3. Performance of the load cell after the development of weight grader

The performance of the load cell was determined in the developed weight grading machine. The result of performance of load cell is shown in Fig. 4.12. The scatter plot between the measured and the actual weight of the dehusked coconut shows high correlation, with R^2 equal to 0.98. This shows that the prediction accuracy of the developed weight grader is higher. It can also be noted that at higher weight range the measured weight is accurate when compared to the lower weight.

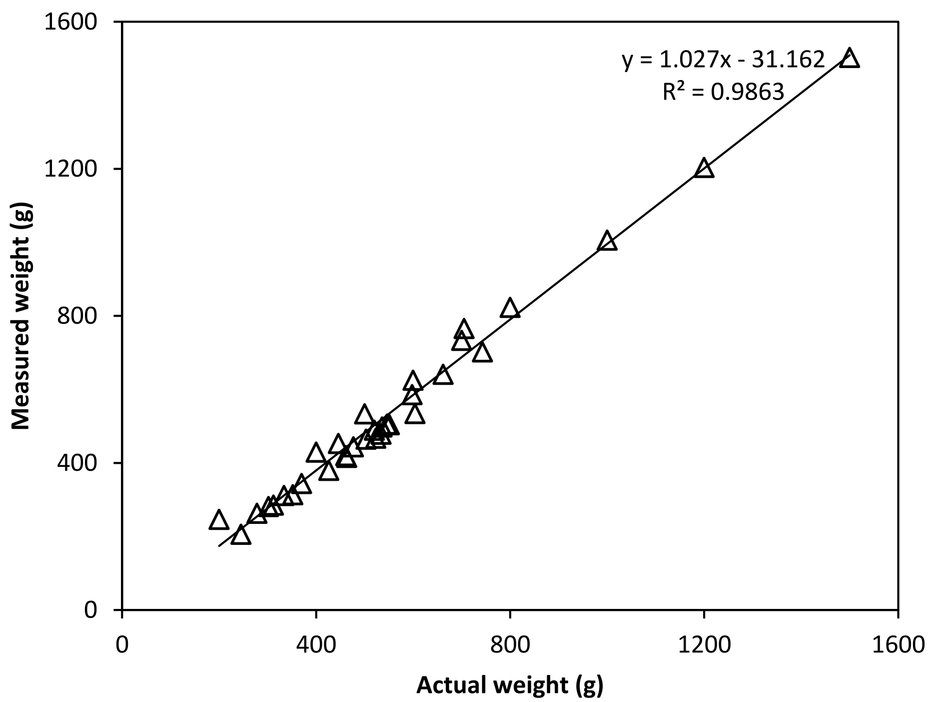

Fig. 4.12. Actual weight Vs Measured weight

4.6.4. Performance evaluation of the weight grader

The effect of angular velocity on the grading efficiency is given in Fig. 4.13 and it was observed that, the grading efficiency had an increasing trend with the increase in angular velocity. The highest grading efficiency of 84.6 percent was recorded at 16 rad/min. This is mainly due to the less travel time of carrier cup to reach the electronic weighing assembly; thereby it increases the capacity which ultimately leads to increase in efficiency.

From the Fig. 4.13 it was also observed that, the grading efficiency was found to be increased when the settling time was increased. In the settling time of 4 s the highest grading efficiency was found. This was mainly due to the load cell which requires a settling time for the signal to reach a constant value. Therefore, when the settling time of 2 s is given to the load cell constant value was not reached, so it may result in the deviation of the original weight of dehusked coconut which thereby affects the grading efficiency. Similarly Misra *et al.*, (2011) also measured settling time for calibration of load cell.

The influence of independent variable (angular velocity and settling time) on the dependent variable (grading efficiency and contamination ratio) was analysed by a factorial analysis. Three replications were made to statistically evaluate the grading efficiency of the weight grader. The analysis of varience obtained from the experimental design is given in Table 4.20

Table 4.20 Analysis of variance for grading efficiency of weight grader for various angular speed and settling time

Source	Sum of Squares	df	Mean Square	F
Treatment	2624.805	13	201.908	18.228 **
Intercept	185039.059	1	185039	16705.500**
Angular speed (a)	1467.691	2	733.845	66.252 **
Settling time (s)	993.170	3	331.057	29.88**
a * s	74.064	6	12.344	1.114 ^{NS}
Error	243.684	22	11.077	
Total	187907.549	36		

From the table it was inferred that the angular velocity and settling time influenced the grading efficiency significantly at 1 percent level individually. While considering the interaction of the angular velocity and settling time it was insignificant.

4.6.5. Grading error (contamination ratio) during grading of dehusked coconut

The effect of angular velocity on contamination ratio is shown in Fig. 4.14. At the angular velocity of 16 rad/min the minimum contamination ratio was found be 16.66. This might be due to high grading efficiency at angular velocity 16 rad/min.

From the Fig. 4.14, it was also understood that contamination ratio was minimum at settling time of 4 s. This might be due the higher settling time given to the load cell to give its constant values.

The results of analysis of variance obtained for the contamination ratio is presented in Table 4.21 and it was inferred that the angular velocity and settling time has influenced the contamination ratio significantly at 1 percent level individually. While considering the interaction, the two variable combinations were found to be insignificant.

Table 4.21. Analysis of variance for contamination ratio of weight grader for various angular speed and settling time

Source	Sum of Squares	df	Mean Square	F
Treatment	22.66.61	13	174.355	17.277 **
Intercept	31843.98	1	31843.98	3155.386 **
Angular speed (a)	1239.81	2	619.909	61.426 **
Settling time (s)	930.434	3	310.145	30.732 **
a * s	44.610	6	7.435	0.737 ^{NS}
Error	222.023	22	10.092	
Total	34332.625	36		

Mean values of grading efficiency and contamination ratio of the weight grader are presented in the Table 4.22. The maximum mean value for grading efficiency of weight grader was 79.63 percent at angular velocity of 16 rad/min. Moreover the grading efficiency was found to be 76.34 at a settling time of 4 s. Similarly the minimum mean value of contamination ratio was found to be 22.15 at angular velocity of 16 rad/min. However there was no significant difference between the settling time of 4 and 5 s.

Table 4.22. Mean comparison by Duncan's multiple range tests (at 5% level) for weight grader

Dependent variety	Angular Speed (rad/min)	Subset		
		1	2	3
Grading efficiency (%)	12	64.00		
	14		71.44	
	16			79.63
	Settling time (s)			
	2	63.57		
	3		70.52	
	5			76.33
	4			76.34
Contamination error (%)	**Angular Speed (rad/min)**			
	16	22.15		
	14		30.62	
	12			36.44
	Settling time (s)			
	5	24.77		
	4	25.28		
	3		31.75	
	2			37.14

Hence, it was observed that the treatments that include the angular velocity of 16 rad/min and settling time of 4 s resulted in the maximum grading efficiency of 84 percent and minimum contamination ratio of 16 was considered to be the best treatment.

4.7. Cost Economics

The cost of developed size and weight grader was estimated and found to be Rs. 60,000 and Rs. 90,000 respectively. The details of total cost and cost economics of size and weight grader are given in the Appendix IV. The The operation cost of the size and weight grader was found to be Rs. 64.73/h and Rs.76.95/h, respectively.