

# Development of weight grader for dehusked coconut

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**Abstract:** Grading of dehusked coconut is an important postharvest mechanization needed in the marketing of the dehusked coconut. In India, farmers grade the dehusked coconut manually which is in lack of objectivity, accuracy and lower efficiency. This work aims to design, develop and evaluate the performance of an efficient weight grading machine for dehusked coconut. The developed grader characterized by an electronic weighing assembly, carrier cups with four bar linkage mechanism, proximity sensor, pneumatic actuators, and drive mechanism. Mild steel carrier cups with the tilt angle of 10° was optimised to ensure a free falling behaviour of dehusked coconut as well as return back position of carrier cups. The performance tests indicated that the design parameters viz angular velocity of carrier cup and the signal settling time of the load cell influenced the grading performance at 5% level of significance. An acceptable grading efficiency of 84% was obtained at an angular velocity of 16 rad min<sup>-1</sup> and load cell settling time of 4 s. The error found in the weight prediction using load cell was ±10 percent suggesting a higher grading efficiency. Further there was no mechanical damage to the graded coconuts. The local vendors and wholesalers can be benefitted with the developed weight grader as it is user friendly, compact and have reasonable grading accuracy.

**Keywords:** weight grader, dehusked coconut, four-bar linkage, grading efficiency, performance evaluation

**Citation:** Asha Monicka, A., T. Pandiarajan, A. Brusly Solomon and S. Ganapathy. 2021. Development of weight grader for dehusked coconut. *Agricultural Engineering International: CIGR Journal*, 23 (3):220-231.

## 1 Introduction

Coconut is one of the important horticultural crop and the most valuable gift to mankind. It gains its importance as it provides food, oil, beverage, medicine and raw material for the variety of industrial productions. It is also meant for food security for a large number of the population especially in India more than 10 million people depend on the coconut for their livelihood and the major contribution is from the small and marginal farmers. Being the tropical crop coconut survives well in the hot climate (Marife et al., 2020). According to coconut development board, India has earned around Rs. 17929 lakh in the year 2018-19 from the export of fresh

coconuts. Coconut is grown in more than 86 countries worldwide, with a total production of 54 billion nuts per annum. In world scenario, Indonesia occupies 29.59 % world area; Philippines occupies 28.71 % world area and India occupies 17.58 % world area in coconut production (CDB, 2018). However overtaking Indonesia and the Philippines, India occupies the premier position in the world with an annual production of 13 billion nuts. It is reported that in India, the area and production of coconut are in increasing trend (Nehru, 2017).

The competitive coconut market is getting highly discerning, requiring the sellers to give the products according to high-quality standards. In India more than 70 % of the farmers sell their coconuts to the traders just by manual inspection. It is known that the hand sorting of coconut is labor intensive, time consuming and suffers from the problem of inconsistency and inaccuracy in judgment by different men and also causes eye fatigue.

**Received date:** 2020-04-29      **Accepted date:** 2020-09-23

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To enter into the high value global supply chain it lacks to efficiently utilize the increase in the production as well as the marketing strategies (Jayasekhar et al., 2019). Therefore fruit sorting is greatly needed in postharvest handling as it fetches the higher value, attracts buyers and facilitates packaging designs (Peleg, 1985; Jarimopas et al., 2007), and brings an overall improvement in the marketing system. In recent years, there is large number of grading systems have emerged for the need for the food processing industry. The electronic sorting system not only reduces labor but also improve quality by eliminating human error. Sorting according to the color, size, and weight has recently been applied to most of the fruits. The color-based automatic grading system development is quite expensive and complex in nature.

Ryall and Lipton (1972) reported that many fruits like apples, pears, citrus and vegetables like potatoes, carrots and onions were graded by weight. Omre and Saxena (2003) designed a weight grader and the performance of the grader was evaluated on four types of fruits namely, apple, orange, mosambi and pomegranate. The performance was satisfactory at the carrier speed between 12 to 15 rpm with a capacity of 150 to 200 kg h<sup>-1</sup>. Brennan et al. (1976) reported that generally, eggs are sorted on the basis of weight. Stroshine et al. (1994) recommended grading by weighing mechanism for the irregular shape product. Ali et al. (2011) developed an electronic weight grading machine for sapota. Golpira (2012) developed an electronic apple sorting machine employing a load cell with rated capacity of 2 kg and 1 mv v<sup>-1</sup> sensitivity. In another study, (Golpira, 2013) developed a machine to sort an apple and it comprised of conveyor which works with the assistance of gravity, measuring device and control system along with pneumatic cylinders as actuators. Gaikwad et al. (2014) developed an electronic weight grading machine which could sort oranges in four commercial weight-grades of less than 100 g, 100-150 g, 150-200 g and greater than 200 g.

Historically, the coconut has been sorted manually by different diameter iron rings, however, the coconut with the same size differs in weight. Therefore grading

dehusked coconut based on weight can fetch better profit to the coconut growers. The literature study suggests there is no specific grading machine available in India for dehusked coconut. Hence, the present investigation carried out to develop an electronic weight grading machine for dehusked coconut.

## 2 Materials and methods

### 2.1 Design concept

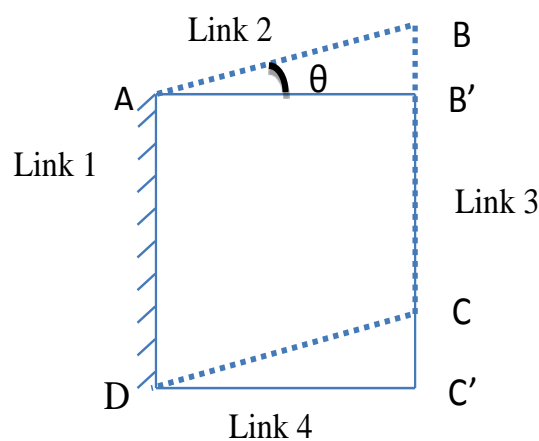
The design concept of weight grader involves two criteria a) the electronic weighing machine had to offer mechanisms to consistently measure the weight of each fruit and correctly release the measured fruit to the corresponding tray and b) the machine should be simple and compact which is affordable to farmers.

The developed machine has a mechanical and electronic system

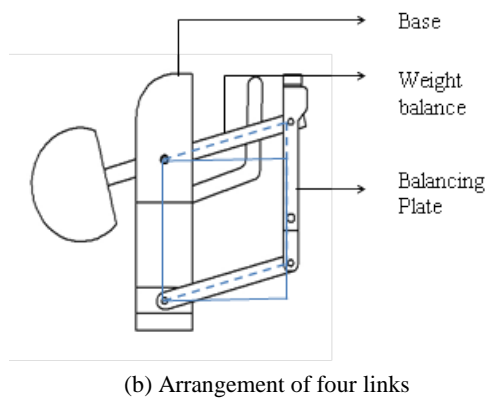
#### 2.1.1 Design of the mechanical system

The main part of the mechanical system is carrier cup which was developed based on parallel four bar linkage mechanism. The binary joints in four bar linkage mechanism are shown in Figure 1(a); A. top of the base with the weight balance constitute one link; B. weight balance with balancing plate constitute second link; C. balancing plate with connecting rod constitute third link D. balancing plate with the bottom of the base constitute the fourth link.

The initial position of the mechanism is shown in Figure 1(b) by dotted lines whereas the full lines show the position of mechanism when the cup is tilted.



(a) Binary joints



(b) Arrangement of four links

Figure 1 Four bar linkage mechanism

In the design, one of the most important concern is that the number of degrees of freedom (also called movability) of the mechanism. The number of degrees of freedom of a mechanism ( $n$ ) is given by:

$$n = 3(l - 1) - 2j \quad (1)$$

where  $l$  is the number of links and  $j$  is the number of binary joints.

The degree of freedom for this mechanism is one ( $l=j=4$ ), *i.e.* by independently controlling anyone parameter in this mechanism desired output can be achieved. When the opposite links are at same length, a parallel linkage formed, and it is a special case of Grashof's criteria, for parallel linkage mechanism given as follows (Khurmi and Gupta, 2005).

$$s + l = p + q \quad (2)$$

where,  $s$  is the length of shortest link (mm),  $l$  is the length of longest link (mm),  $p$  is the length of one remaining link (mm),  $q$  is the length of other remaining link(mm).

Therefore in this study the following length of links were used  $s=100$  mm,  $l=110$  mm,  $p=100$  mm and  $q=110$  mm, Thus satisfies the Grashof's condition for parallel linkage mechanism.

Figure 2 shows the developed carrier cup mechanism and it consists of a base, weight balance, and a balancing plate. The base was made of 5 mm thick mild steel flat plate. A tongue like structure with 60 mm length and 60 mm height was attached to the centre of the base to tilt the carrier cup. The weight balance consists of a known weight of 1500 g to balance the weight on both sides. This helps to bring back the carrier cup to the original position after it discharged the dehusked coconut. The balancing plate is a part of carrier cup mechanism which

slides over the guiding rail. The carrier cups were fitted on the iron steel rods of the balancing plate such a way that when the cup is poked at the bottom it tilts freely.

In general, the parallel linkage mechanism can rotate  $360^\circ$  around its axis. However, the desired output is the angle required to tilt the carrier cup. Hence an experiment was conducted to find the tilting angle of the carrier cup. The base of the carrier cup was fixed in a bench vice. Using the protractor the selected angles ( $5^\circ$ ,  $10^\circ$  and  $15^\circ$ ) were marked. The carrier cup was operated manually for different angles and observed the free falling behaviour and return back position of carrier cup with coconut. At each tilt angle, two different carrier cups (C1- Plastic, and C2- Mild Steel) were tested. Plastic and Mild steel was selected for the present study because of availability and low cost.

Figure 3 shows the isometric view of the weight grader which consist of feed hopper and carrier cup mechanism attached in the main frame. The feed hopper dimension was 520 mm  $\times$  500 mm  $\times$  120mm. The hopper was extended to 600 mm length with the opening of 150 mm diameter at the periphery. The mainframe is the basic structure on which the whole grading assembly was mounted. The height of the frame from the ground level is fixed as 1000 mm. The mainframe supports rotating frame, electronic weighing assembly, guiding rail, pneumatic actuators, carrier cup mechanism, and coconut ejection points. The rotating frame comprised of rim, arm and a hub with the center hollow shaft. The inner diameter of the hub was equal to the outer diameter of the central hollow shaft. The length of the hub was equal to the width of the rim. The guiding rail with 115 cm diameter was attached with the mainframe by the supporting legs. The supporting frames were then welded with guiding rail in three positions at  $60^\circ$  interval for ejection points. The pneumatic actuators were then fixed at supporting frame by reversing the roles of the ports so that the piston rod extends outside. The guiding rail at these three ejection positions was cut and connected with pneumatic actuators. The base of the carrier cup mechanism was then attached with rotating frame. The circumference of the rotating frame was divided into six equal divisions and six carrier cups was attached. It was

fixed in such a way that the balancing plate in the carrier

cup mechanism moves freely on the guiding rail.

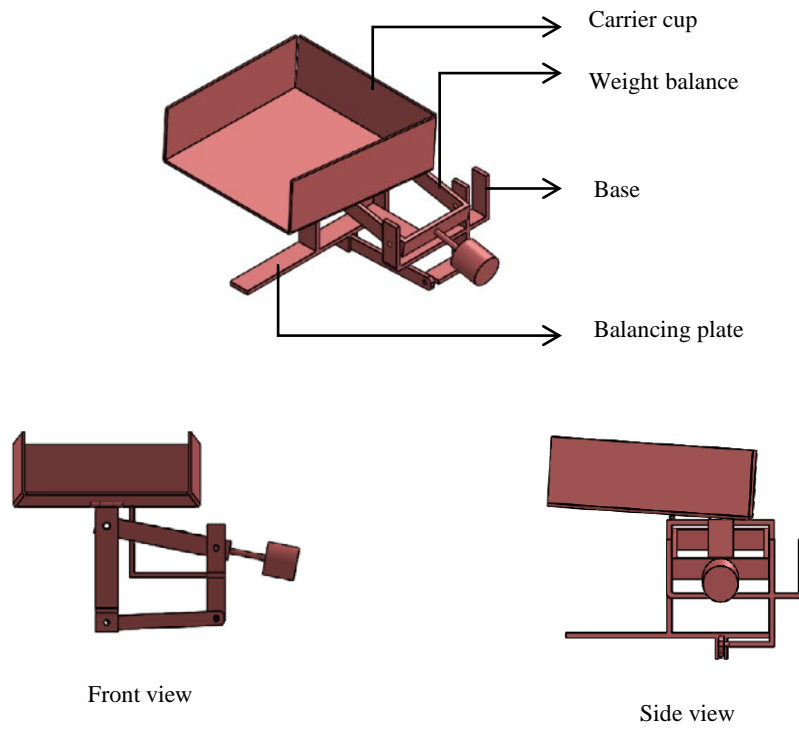


Figure 2 Carrier cup mechanism

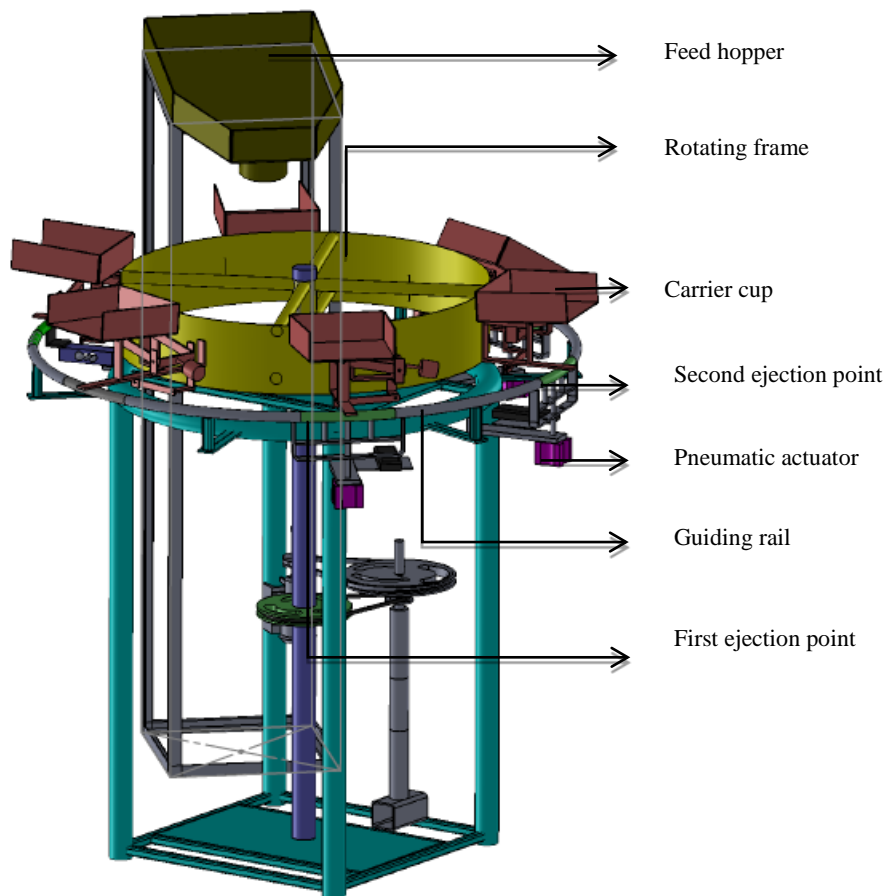


Figure 3 Isometric view of weight grader

### 2.1.2 The electronic part

The electronic part of the weight grader consists of a weighing scale assembly with beam type load cell of 20 kg capacity, proximity sensor, and direction control valve (DCV), microcontroller and DC motor connected with regulated power supply (RPS) unit. A piece of 15 cm length was cut from the guiding rail and fixed on the top of load cell. It was then placed in such a way that it does not touch with the end-to-end of guide rail. This arrangement would help the load cell to sense the individual weight of cups passing on it. A proximity sensor was fitted over mainframe across the weighing scale assembly to sense the presence of carrier cup. The direction control valve was used to operate the pneumatic actuators with the support of compressor. The microcontroller was programmed, to get the signal from the proximity sensor, to start and stop the DC motor, to receive data from the weighing scale, to take decision based on the weight and to send commands to open and close the DCV. The microcontroller also had a provision to enter the weight of nut to be graded and settling time needed by the load cell.

### 2.2 Sensitivity of load cell to the operating environment

The load cell selected for this study had the non-linearity, hysteresis and repeatability as 0.010%, 0.017% and 0.011% F.S (full scale), respectively. After the development of the electronic hardware and fabrication of the weight grader, experiment was conducted to examine the performance of the load cell by keeping a known weight in the carrier cup mechanism at different orientations/positions and noted the weight displayed.

### 2.3 Factors affecting the grading efficiency of the weight grader

The carrier cup used to carry the dehusked coconut comes in contact with the load cell at a specified location. As soon as the carrier cup comes in contact with the load cell, it starts to measure the weight of the coconut till the cup crosses the load cell. Meanwhile the microcontroller stores all the data send by load cell in which there was a significant variation from the original weight of the coconut. This may be due to the slight vibration of the machine during the operation. Hence it

was decided to stop the carrier cup at the centre point of the load cell and give a settling time of 2, 3, 4 and 5 s to the load cell to get the constant value and reduce the error.

Based on the preliminary study it was decided to operate the carrier cup at the angular velocity of 12, 14 and 16 rad min<sup>-1</sup>.

#### 2.3.1 Determination of optimum settling time of the load cell and the angular velocity of the carrier cup

Collection of data from load cell requires the acceptability to maintain a consistent performance. Misra et al. (2011) noted that a bridge measurement that includes switched voltage excitation, requires a settling time for the signal in the load cell to reach its stable value. Keeping these points in mind, three levels of the settling time viz., 2, 3, 4 seconds and three levels of angular velocity of carrier cup viz., 12, 14 and 16 rad min<sup>-1</sup> were considered for the experiment. Three replications were carried out for the combination of the control factors. The mean contamination ratio or error ( $\bar{C}_R$ ), grading efficiency % ( $E_W$ ) and throughput capacity kg hr<sup>-1</sup> ( $Q$ ) was analyzed using the following equations (Peleg, 1985). To determine the influence of the control factors by SPSS 15 software analysis of variance (ANOVA) and Duncan Multiple Range Test (DMRT) was applied.

$$\text{Contamination ratio } (\bar{C}_R) = \frac{\sum N_{ij}}{\sum N_i} \quad (3)$$

$$\text{Grading Efficiency } (E_W) = \frac{\sum (P_{gi} W_i G_i)}{Q P_i} \quad (4)$$

$$\text{Capacity } (Q) = \frac{w_t}{t} \quad (5)$$

$$P_{gi} = \frac{N_{gi}}{N_{ti}} \quad (6)$$

$$W_i = \frac{K_i P_i}{\sum K_i P_i} \quad (7)$$

$$G_i = \frac{w_i}{t} \quad (8)$$

$$P_i = \frac{N_i}{\sum N_i} \quad (9)$$

$$N_{ti} = N_{gi} + N_{ij} \quad (10)$$

where,  $E_W$  is the grading efficiency (%);  $Q$  is the inflow rate of dehusked coconut (kg h<sup>-1</sup>);  $N_{ij}$  is the number of weight  $i$  dropping into receiving tray size  $j$ ;  $N_i$  is the number of dehusked coconut weight  $i$  inputting to the grading machine;  $\sum N_i$  is the total number of

dehusked coconut inputting to the grading machine;  $P_{gi}$  is the fraction of fruit weight  $i$  to total fruit dropping into receiving tray size  $i$ ;  $N_{gi}$  is the number of weight  $i$  dropping correctly into receiving tray size  $i$ ;  $N_{ti}$  is the total number of fruit dropping into receiving tray size  $i$ ;  $W_i$  is the weighted function;  $K_i$  is the relative value fraction of grade  $i$ ;  $P_i$  is the fraction of size  $i$  to total fruit at the beginning of the grading;  $G_i$  is the outflow rate of dehusked coconut size  $i$  ( $\text{kg h}^{-1}$ );  $w_i$  is the total weight of dehusked coconut fruit in receiving tray size  $i$  (kg);  $w_t$  is the total weight of dehusked coconut corresponding to  $\sum N_i$  (kg);  $t$  is the grading time (hr).

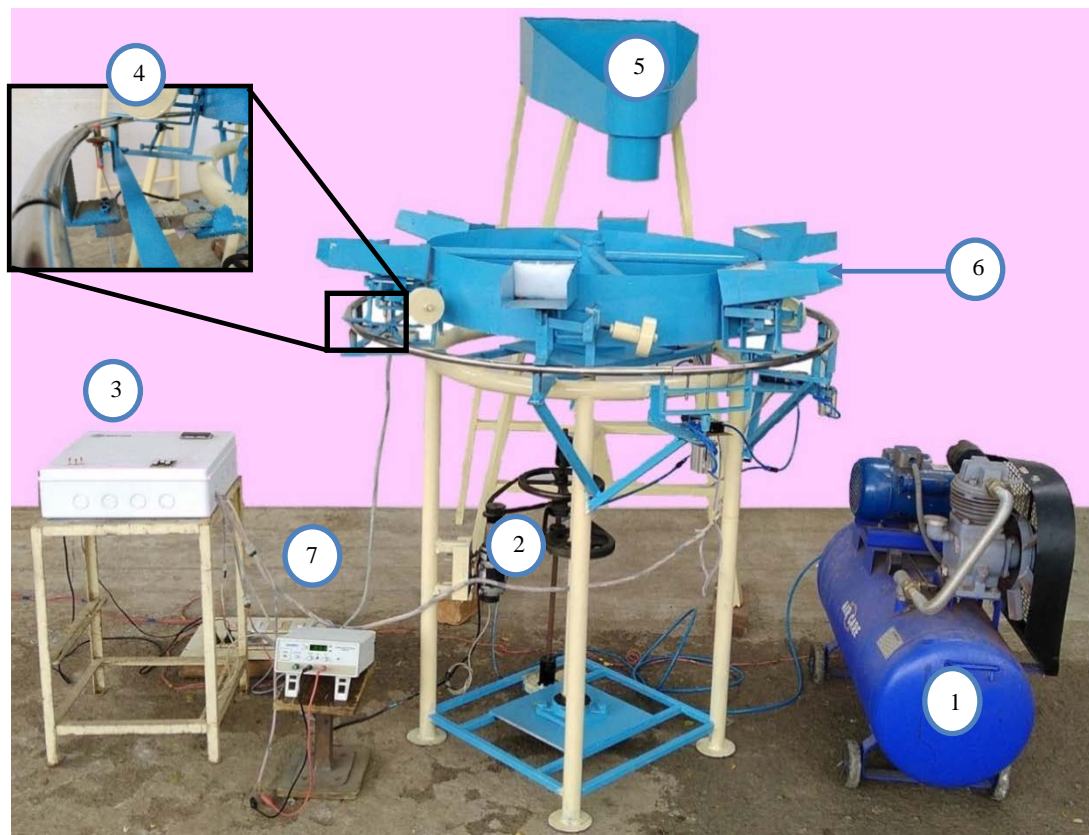
#### 2.4 Principle of operation of the machine

Initially, the ranges of weight in which dehusked coconut to be graded and the settling time of the load cell are given as inputs as mentioned in the Appendix 1. After the values are entered, the DC motor starts and the carrier cups moves over the guiding rail. As the cup moves, dehusked coconuts were fed one by one in the

carrier cup through a feed hopper, at the same time the proximity sensor detects the presence of carrier cup. The motor stops when the sensor detects the carrier cup till the given setting time of the load cell. Meanwhile load cell measures the weight of dehusked coconut. After the settling time over, the motor starts again. Based on weight, microcontroller decides to trigger the appropriate pneumatic actuators by sending control signals to the DCV. As the DCV gets the command it opens up the pneumatic actuators which results in tilting of carrier cup at the appropriate box.

##### 2.4.1 Performance test

The performance test was conducted for the developed weight grader (Figure 4). To evaluate the machine performance, well matured coconuts of weight ranging from  $\geq 300$ , 301-500 and  $< 500$ g was selected. There were twenty samples of dehusked coconut of each weight was taken and the weight of each coconut was measured using the electronic weighing balance.



1. Compressor 2. DC Motor 3. Electronic circuits & hardware 4. Load cell and sensor assembly 5. Feed hopper 6. Carrier cup mechanism 7. RPS unit

Figure 4 Front view of developed electronic weight grader



### 3 Results and discussion

#### 3.1 Effect of tilting angles of carrier cups on the free falling behaviour of coconuts and return mechanism

Figure 5 represents the effect of tilting angles of carrier cups on the free falling behaviour of coconut. It was noted that the free falling behaviour of coconut was increased for both plastic and mild steel, when the tilting angle increased from 5 to 15° and it was also observed that the highest percent of free falling behaviour of the coconut of 100 percent for MS carrier cup 2 (C2) was with 10° and 15° tilt angle of the carrier cup mechanism whereas at tilting angle of 5° the free falling behaviour of coconut was found to be only 60%. Moreover, the maximum angle of stability in rolling of coconut was between the tilting angles 5-10° and as a result above 10° tilting angle the free falling behaviour reaches 100% for MS carrier cup. It was also found that Plastic carrier cup 1 (C1) had 90 percent free falling behaviour at 15° tilting angle whereas, at 10° tilt angle, the free falling behaviour was 60 percent. Though the coefficient of friction of plastic is lesser than mild steel, the free falling behaviour of coconut with mild steel was found to be higher at 15° tilt angle. This may be due to the bucket like the shape of the plastic carrier cup (C1). The above cup was investigated since it was readily available in market which is meant for bucket elevators.

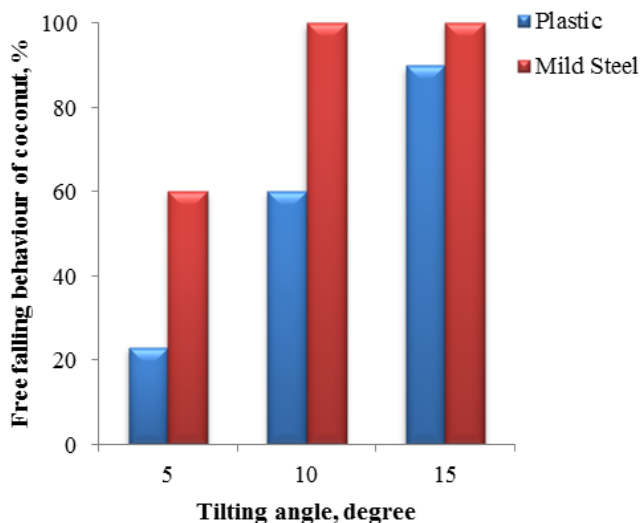


Figure 5 Effect of tilting angles of carrier cups on the free falling behaviour of coconut

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 of carrier cup on carrier cup return mechanism is shown in Figure 6. It was noted that when the tilting angle increased from 5 to 15°, the return back position of carrier cup decreased and it was also observed that 5° tilt angle has the highest percentage of return back position of carrier cup (100%) for both C1 and C2 whereas at 10° tilt angle C1 has 70% and C2 has 100% return back of carrier cup, respectively.

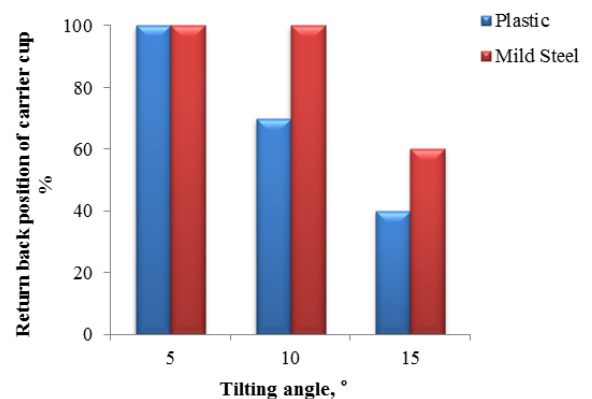


Figure 6 Effect of tilting angles of carrier cups in carrier cup return mechanism

From Figures 5 and 6, it was inferred that the performance of MS carrier cup was superior to Plastic carrier cup. Therefore, tilt angle of 10° and MS carrier cup was selected for the present study. To achieve 10° tilt angle in carrier cup mechanism, the balancing plate attached with the carrier cup mechanism should move down to 20 mm. To attain this, standard available pneumatic actuators of piston rod with stroke length of 25 mm was selected.

#### 3.2 Performance of the load cell

The performance of the load cell was verified before testing the mechanism and is shown in Figure 7. The scatter plot between the measured and the known weight of the de-husked coconut shows a high correlation, with  $R^2$  equal to 0.98. This shows that the prediction accuracy of the developed weight grader is higher and reasonable. It can also be noted that at higher weight range the measured weight is accurate when compared to the lower weight. The error was found to be within  $\pm 10\%$ .

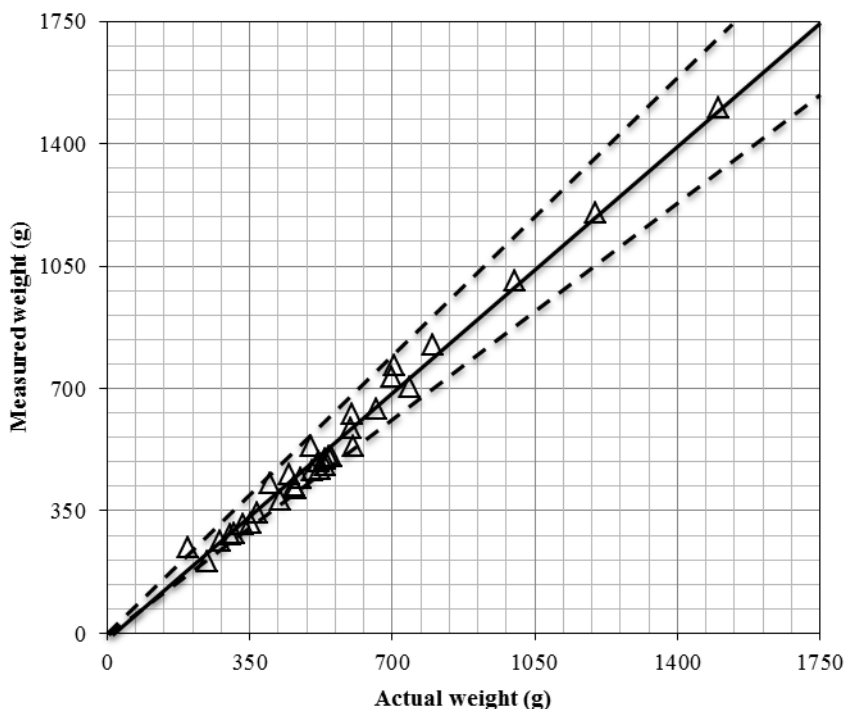


Figure 7 Actual weight Vs measured weight

**3.3 Optimum angular velocity of carrier cup and settling time of the load cell on the grading efficiency and contamination ratio of weight grader**

The effect of angular velocity on the grading efficiency was obtained and presented in Table 1. It was observed that the grading efficiency have an increasing trend with the increase in angular velocity whereas contamination ratio has a decreasing trend with the increase in angular velocity. The highest grading efficiency of 84.6 percent was recorded at 16 rad min<sup>-1</sup>. From the table it was also observed that the grading efficiency was found to be increased when the settling time was increased. At the settling time of 4 s the grading efficiency was higher for all the angular velocities (12, 14 and 16 rad min<sup>-1</sup>). It was calculated that at the angular velocity of 16 rad min<sup>-1</sup> the minimum contamination ratio was 16.66. It was also understood that contamination ratio was minimum at settling time of 4 s.

The load cell required settling time for a signal to reach a constant value (Misra et al., 2011). Therefore, when the settling time of 2 s was given to the load cell constant value was not reached, so it resulted in the deviation of the original weight of dehusked coconut which thereby affects the grading efficiency and

contamination ratio. When the higher settling time of 4 to 5 s was given, the load cell showed a constant value thereby increasing the grading efficiency. Moreover, when the angular velocity was increased, the travel time of carrier cup to reach the electronic weighing assembly was less; thereby it increases the capacity which ultimately leads to increase in grading efficiency.

**Table 1 Effect of angular velocity and settling time on the grading efficiency and contamination ratio of weight grader**

| Angular velocity (rad min <sup>-1</sup> ) | Settling time (seconds) | Grading efficiency (%) | Contamination n ratio |
|---|-------------------------|------------------------|-----------------------|
| 12  | 2                       | 56.8±2.4               | 42.3±3.1              |
|   | 3                       | 59.2±5.3               | 40±1.6                |
|   | 4                       | 69.6±2.1               | 32±2.5                |
|   | 5                       | 71±1.5                 | 30±2.0                |
| 14  | 2                       | 62.26±8.0              | 38.3±4.75             |
|   | 3                       | 71.1±1.0               | 31.03±2.6             |
|   | 4                       | 75±6.3                 | 26.6±3.5              |
|   | 5                       | 76±1.5                 | 25±1.1                |
| 16  | 2                       | 71.4±1.5               | 30±2.0                |
|   | 3                       | 80.8±1.5               | 23.33±2.0             |
|   | 4                       | 84.69±1.06             | 16.66±7.7             |
|   | 5                       | 83±3.5                 | 18±1.1                |

**3.4 Continuous performance of weight grader**

The mean grading efficiency and contamination ratio of the weight grader were presented in Table 2.

The weight grading machine was tested continuously with dehusked coconut. The contamination ratio and capacity were found to be 18.43 and 255 kg hr<sup>-1</sup> respectively. There were no noticeable mechanical



damages such as cracking. The maximum mean value for grading efficiency of weight grader was 79.63 percent at an angular velocity of 16 rad min<sup>-1</sup>. 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<sup>-1</sup>. However there was no significant difference between the settling time of 4 and 5 s.

**Table 2 Mean comparison by Duncan's multiple range tests (at 5% level) for weight grader**

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

## 4 Conclusion

To replace the manual grading of coconut an electronic weight grader was designed, developed and tested for its performance. A parallel four bar linkage mechanism was used for the development of the carrier cup in the weight grader. A 10° tilt angle of a carrier cup mechanism gave a 100% free falling behaviour of coconut. The scatter plot shows the performance of the load cell with a high correlation between the known and the predicted weight which indicates the grading accuracy. The design parameters such as the angular velocity and settling time of the load cell influence the grading efficiency at 5% level of significance. The optimum performance was characterized by the contamination ratio of 16% with a settling time of 4s and a capacity of 255 kg hr<sup>-1</sup>. Nevertheless during the continuous performance test the contamination ratio increased slightly to 18.43. Further there was no

significant change in the grading efficiency when the settling time was more than 4s. The operational cost of the grader was found to be Rs.76.95 h which is much lesser than the manual grading. Moreover, by using a high precision load cell the machine capacity can be enhanced by reducing the settling time. Further the developed weight grader can also be used to grade the fruits and vegetables such as mango, pomegranate, muskmelon etc which has the weight more than 150 g.

## Acknowledgment

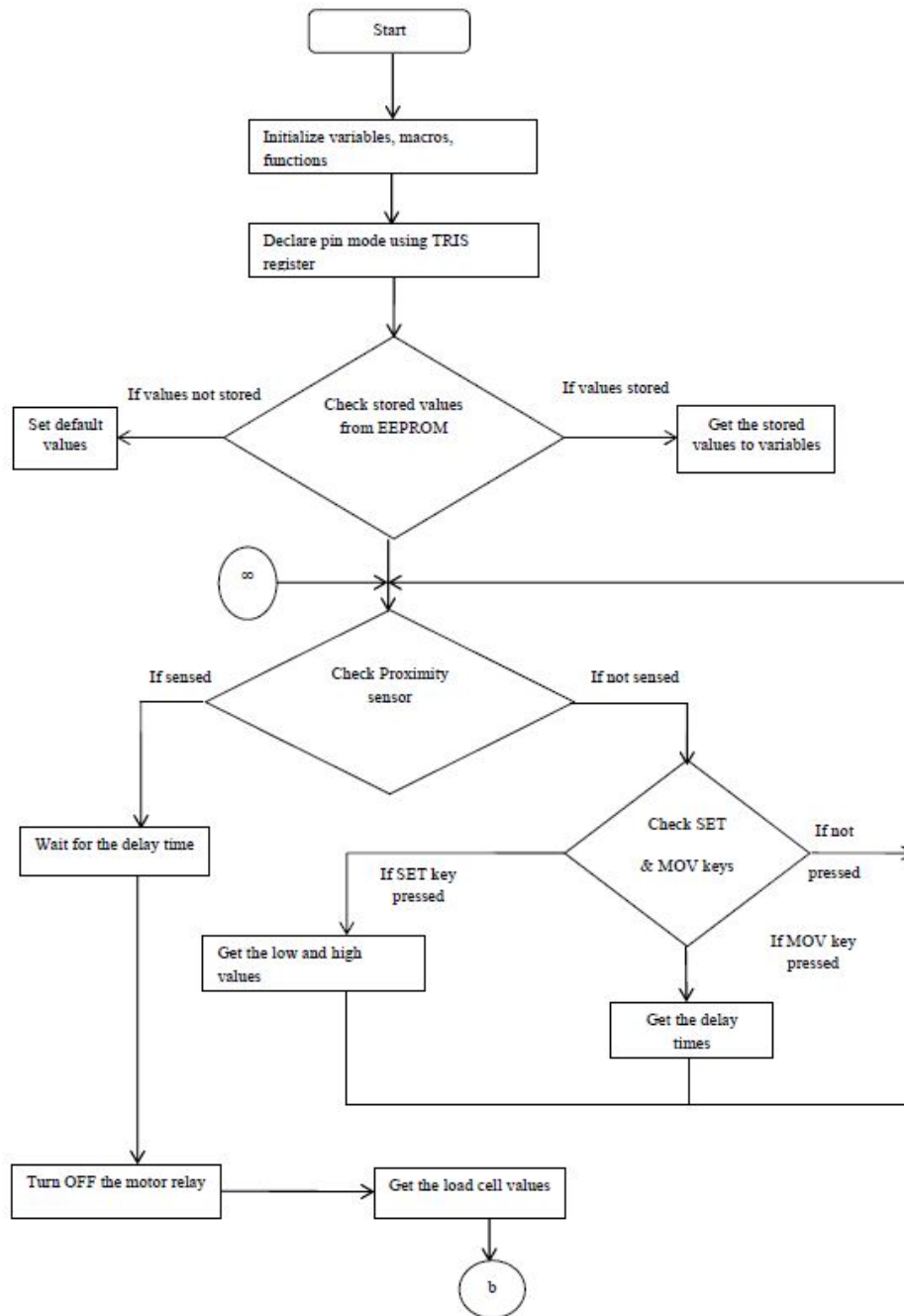
The authors would like to acknowledge the UGC- University Grants Commission for funding this research work.

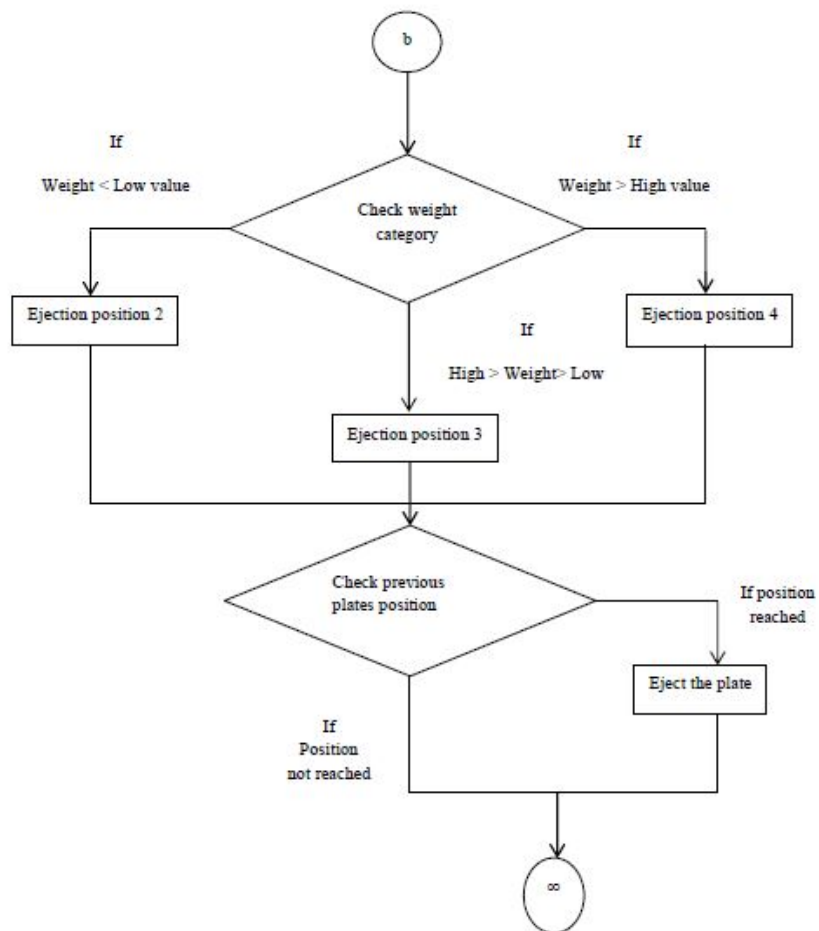
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### Appendix 1





Appendix 1 Flowchart for the development of the software program