Design, Fabrication, and Performance Evaluation of Village-Type Coconut Coir Dust Compacting Machine

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Abstract: *This study was conducted to design, fabricate, and evaluate the performance of the village-type coconut coir dust compacting machine. Coconut coir dust (CCD) was compacted to form coconut coir dust bricks (CCDBs) suitable for storage and transportation to be used as a potting medium. Two different initial heights of CCD have been tested with three different levels of cassava starch binder (CSB) mixture notably 10%, 20%, and 30% of the initial weight of the CCD. The result showed that at 6" initial height with 30% CSB, the compressed density and relaxed density was highest at 4.49 g/cm^3 and 2.16 g/cm^3 respectively. In terms of production capacity, CCDBs at 6" initial height with 30% CSB got the highest compacting rate of 3.09 kg/hr with an output rate of approximately 21 CCDBs/hr. Results implied that the CCDBs at 6" initial height with 30% CSB were more suitable for storage and transportation purposes.*

Keywords: Coconut coir dust compacting machine (CCDCM); Coconut coir dust bricks (CCDBs); Cassava starch binder (CSB) levels; Compressed density; Relaxed density;

1. INTRODUCTION

In the Philippines, the coconut tree (*Cocos nucifera*) is dubbed the "tree of life" because of the varied uses and the variety of products and livelihoods it can produce [1]. Some farmers cut down their coconut trees to sell as lumber for its beneficial usage as a construction material for timber houses [1] [2]. Coconut is one of the most important crops for the Filipinos, hence, 6 million metric tons of coconut husks per year (about 732,750 metric tons of coco fiber per year) were produced in the Philippines [1].

In coconut husk processing, industrially valuable long fibers (coir) are removed (used in the manufacture of ropes) leaving a considerate quantity of both pith tissue (Coir dust/coir pith) and short to medium-length fibers [3]. The coconut husk is 35 % fiber and 65 % dust [1]. These materials remain available as waste product (coir waste) which is accumulated and formed in hillocks in the vicinities of coir fiber extraction units for which until now have been burned or dumped without control and is considered one of the largest agro-wastes in tropical countries [3] [4].

1.1 Coconut Coir Dust

Coconut coir dust (CCD) is the spongy, peat like residue made from the fiber found between the husk and the outer shell of a coconut. CCD also known as coco peat, consists of short fibers (<2cm) around 2%-13% of the total and cork like particles ranging in size from granules to fine dust [3] [5]. CCD has a very high moisture retention capacity of 600- 800% and can be as high as 1100% of dry weight and slowly releases water to the plant through its feeding roots. A coconut farm producing 10,000 nuts/year has the potential of 3,600 kg of husks and 2,300 kg of CCD, with a storage capacity of about 18,000 liters of water if incorporated into the soil. These conditions could help minimize the crop water deficit during the El Nino period [4].

It has a high potassium concentration and a low bulk density (0.18g/cc) and particle density (0.8g/cc). Its high CEC, which ranges from 20 to 30 meq/100 g, allows it to retain a lot of nutrients, and the absorption complex contains a lot of exchangeable K, Na, Ca, and Mg in it. These qualities make it perfect for use as a mulch and soil amendment, especially in dry, sandy locations with poor water retention [4]. When used as potting medium or soil conditioner, CCD accordingly will not only revitalize the plants it also induces uniformity in growth by enhancing water retention and microbial activity. CCD enhances the nutrient carrying capacity of the plants and helps maintain moisture that reconditions the soil [5].

1.2 Binder

Some factors to be considered in selecting binders are the binding properties, cost, and environmental friendliness. The use of inorganic binders like polyvinylpyrrolidone proves to be a good binding material [6]. However, some are avoided for their possibility to affect plant once mixed or present in CCD such as carbon methylcellulose sodium silicate and pretreated starch [7].

Starch has been used in the compaction of sorghum residue and corn cobs as a binder in some densification processes [8] [9]. It has been reported that the mixture of starch has improved briquette characteristics. Starch is a polysaccharide with a high energy content which is good as a binding agent due to its chemical and structural properties [10]. The addition of water and heat to starch powder will lead to the formation of a viscous solution that undergoes gelling which in turn increases its shear and tensile strengths. The fluidity and viscoelasticity of the produced solution is an ability of the starch gel to occupy the void spaces present within and between biomass particles which later become stronger upon air-drying [11]. Among the most used starches available and accessible within the area, corn starch and cassava starch were considered and studied. However, according to the study, wherein extracted starch was compared with the commercially available corn (maize) starch, the results showed that lactose granulations prepared with cassava starch acquired higher physical properties than with corn starch. The binding efficiency is said to be higher in cassava starch [12]. Aside from the high price of corn starch when bought from the local market, cassava starch is preferred as the binding agent for CCD compaction due to its binding efficiency over corn starch.

1.3 Coconut Coir Compacting Machine

The introduction of a coconut coir dust compacting machine (CCDCM) to the farmers will not only help in disposing of the hillocks of CCD accumulated and dumped outside of coir fiber mills but also help the environment, in general, by minimizing the pollution caused by wrong or improper practice of disposing of it. Aside from that, farmers will also gain benefits and will even earn money from selling the coconut coir dust bricks (CCDBs) produced by the Coconut coir dust compacting machine (CCDCM) as a potting medium or soil amendments because accordingly, nowadays high-quality dust has an economic value almost equal to fiber. This study aims to design and fabricate a village-type CCDCM. Its production capacity is measured through its output rate in CCDBs/hr. Furthermore, the CCD to be used will be tested at a different level of thickness (initial height) at varying CSB levels to evaluate which level of treatment will make the CCDBs more suitable for storage and transportation.

2. METHODOLOGY

2.1 Methodological Framework

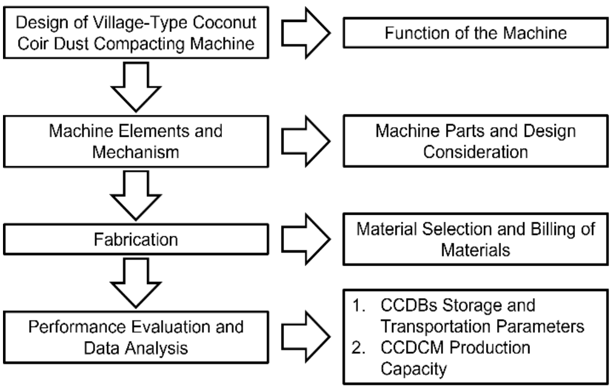

Fig. 1. General Methodology

Figure 1 showed the general methodology involved in this study. The design of the village-type coconut coir dust compacting machine (CCDCM) took into consideration, its capacity can compress composted coconut coir dust (CCD) as well as its efficiency in terms of operation. Machine elements and mechanisms were also considered. Material costing was done by selection and canvassing. The selection of the materials was strictly implemented to secure safety standards and the quality of the machine to operate.

The fabrication process involved materials and fabricator selection. It was necessary to select the best fabricators in the fabrication process in obtaining the quality of the machine. The adjustments of the machine were followed by testing and observing some defects, discrepancies, and errors during fabrication.

In the performance evaluation, the methods involved were measured by evaluating the two major parameters. First is the storage and transportation parameters which include the compressed density, relaxed density, relaxation ratio, and water retention test. The second is the production capacity which includes the input capacity, compacting rate, and output rate.

2.2 Machine Elements and Mechanism

The design of the Coconut coir dust compacting machine (CCDCM) is shown in Figure 2. The CCDCM is composed of the following parts namely: the molder, pistons, hydraulic jack, frame, and flat plate (catching plate). The machine was designed in such a way that even an ordinary farmer can operate it. It also requires minimum labor and is made of cost-efficient materials.

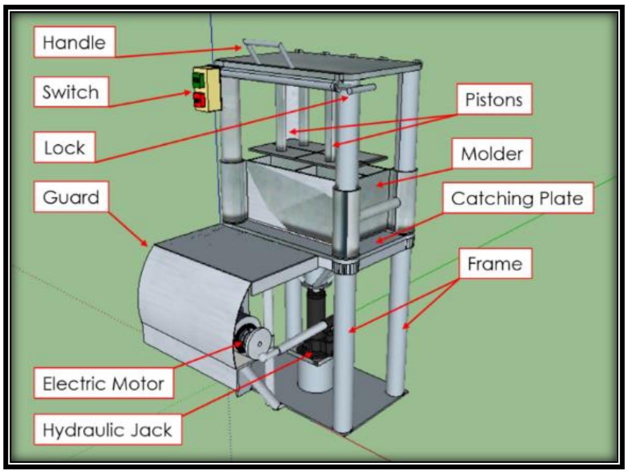

Fig. 2. Design of Village Type Coconut Coir Dust Compacting Machine

The catching plate must be properly positioned under the molders and the composted coconut coir dust must be evenly placed inside the molders. Using the hydraulic jack, one can start compacting the CCD to the desired size. When CCD reaches the desired height and while the hydraulic jack is still locked, pull upward the molders so that the compacted coir dust (coconut coir dust brick, CCDB) will fall onto the catching plate. Afterward, one can get CCDB from the catching plate and then return the molders by pulling it downward and at the same time the hydraulic jack upward to start another set of CCDs to be compacted.

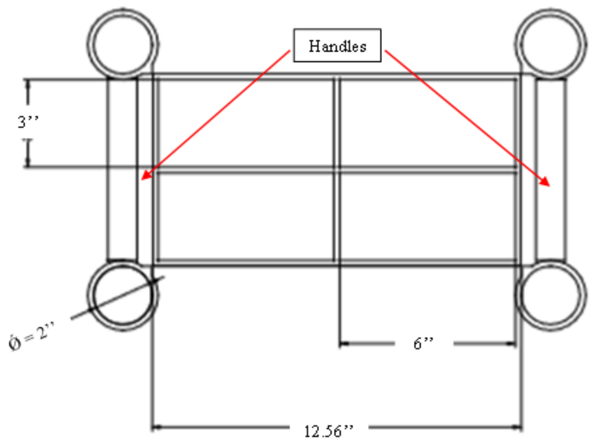

Fig. 3. Working Design of the Molder

2.2.1 The Molder

The molder is situated at the upper portion of the catching plate. It has a dimension of 12.56 inches in length, 6.56 inches in width, and 6 inches in height. It has 4 compartments with 6 inches x 3 inches dimensions each. It was made up of a 6 mm MS steel plate.

2.2.2 The Hydraulic Jack

The use of a suitable prime mover is crucial, hence, two available prime movers: the pneumatic system and hydraulic jack were considered in this study. The two were under a thorough research to compare which system will suit the designed machine. However, the hydraulic jack was considered in the final design since it uses hydraulic oil to lift heavier loads higher and smoothly because of the oil incompressibility while the pneumatic system have a lower pneumatic pressure due to compressor design limitations [13] [14].

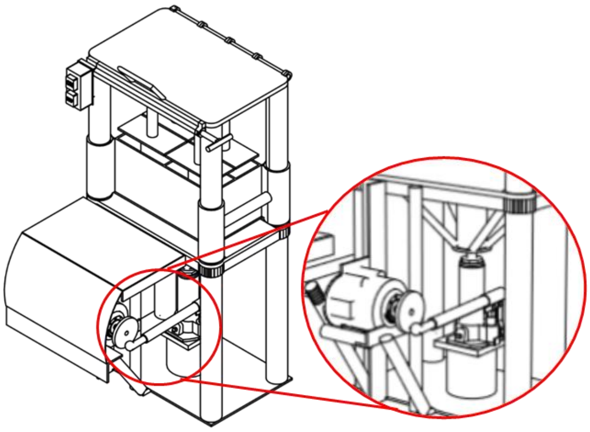

Fig. 4. Zoom-in view of the Hydraulic Jack and Electric Motor Connection

The Hydraulic Jack is located at the lower portion of the machine design and is connected to the catching plate. It has a capacity of 6 tons. For the operation to go with ease, the researchers opted to connect the hydraulic jack to the electric motor. Therefore, instead of operating the jack manually it will now be electric motor driven.

2.3 Experimental Set-up

The Coconut Coir Dust (CCD) was sun-dried for 7 days to reduce its moisture content. After drying, the coconut coir was sieved and separated from the fibers greater than 2 cm in length. Cassava starch, bought from a local market, was also prepared as a binding agent mainly to initiate compaction of the samples. Thereafter, CCD and Cassava Starch Binder (CSB) were thoroughly mixed at ratios of 100:10, 100:20, and 100:30.

2.4 Data Gathering

During the process of compaction, the time for loading CCD samples into molders (t_1), time for compressing the CCD samples (t_2), and time for ejecting the CCDBs (t_3), were observed and recorded as the total operating time of the compacting machine. Upon ejection of the CCDBs (with 30 minutes of creep) from the molders and after the CCDBs were air dried, the mass and the dimensions were taken to determine the density in g/cm^3. A water retention test was also conducted to determine the suitability of CCDBs for storage and transportation. The output rate of CCDCM in CCDBs/hr was also recorded. The evaluation of the performance of CCDCM were determined in accordance with the different test parameters presented in the following part of this paper.

2.5 Storage and Transportation Parameters

To determine which of the CCDBs at specific level of treatment is more suitable for storage and transportation the parameters used are the following:

2.5.1 Determination of Compressed Density

The compressed density of CCDBs is determined immediately after ejection from the molders. It is the ratio of the measured weight to the calculated volume. It is calculated using Equation 1.

$$\rho c = \frac{W}{V} \qquad (1)$$

Where:

ρc = Compressed density, g/cm^3
W = Weight of CCDBs, g
V = Volume, cm^3

2.5.2 Determination of Relaxed Density

The relaxed density of CCDBs is the ratio of the weight of its dried weight over its new volume. This will give an indication of the relative stability of the CCDBs after compression. It is calculated using Equation 2.

$$\rho r = \frac{W}{Vn} \qquad (2)$$

Where:

ρr = Relaxed density, g/cm^3
W = Weight of CCDBs, g
Vn = New volume, cm^3

2.5.3 Determination of Relaxation Ratio

It is the ratio of compressed density to the relaxed density of the coconut coir dust bricks (CCDBs). It is calculated using Equation 3.

$$RR = \frac{\rho c}{\rho r} \qquad (3)$$

Where:

RR = Relaxation ratio
ρc = Compressed density, g/cm3
ρr = Relaxed density, g/cm3

2.5.4 Determination of CCDBs' Surface Expansion

CCDBs surface expansion is performed through a water retention test, where each of the CCDB produced is fully soaked into 1 L of water within 1 hour. This is also done to determine how CCDBs are likely to expand their surface once exposed to an area with high relative humidity.

2.6 Production Capacity Parameters

To determine the production capacity of the CCDCM the following parameters are used.

2.6.1 Determination of Input Capacity

It is measured by the ratio of the total weight of input material to the total operating time. It is calculated using Equation 4.

$$Ci = \frac{Wt}{Tt} \tag{4}$$

Where:

C_i = Input Capacity, kg/h
W_t = Total weight of input material, kg
T_t = Total operating time, hr

2.6.2 Determination of Compacting Rate

The compacting rate of CCDCM is the ratio of the weight of CCDBs collected to the total operating time. It is calculated using Equation (5).

$$Cr = \frac{Wf}{Tt} \tag{5}$$

Where:

C_r = Compacting rate, kg/hr.
W_f = Weight of CCDBs collected kg
T_t = Total operating time, hr.

2.6.3 Determination of Output Rate of CCDCM

Production capacity is determined through the output rate of CCDCM in CCDBs/hr. It is calculated using Equation 6.

$$\text{No. of CCDBs} = \frac{N_{CCDB}}{T_{operation}} \tag{6}$$

Where:

No. of CCDBs = Number of CCDBs produced per hour, CCDBs/hr
N_{CCDB} = Number of CCDBs in one compaction
$T_{operation}$ = Total operating time per compaction, hr

3. RESULTS AND DISCUSSION

3.1 Fabrication of the Village-Type Coconut Coir Dust Compacting Machine

Fig. 5. Actual photo of the fabricated CCDCM

Figure 5 shows the actual photo of the fabricated CCDCM. The dimensions and specifications of the designed machine were made sure to coincide with the actual fabrication of the machine.

3.2 Performance Evaluation and Data Analysis

For the performance evaluation, the set-up for testing the CCD was directed and operated through four 3" x 6" x 6" molders and compacted by 6 tons electric motor driven hydraulic jack. The use of an electric motor-driven hydraulic jack to perform the compaction instead of using a manually operated hydraulic jack was initiated for constant and quicker operation time and production of CCDBs. Subsequently, the compressed density, relaxed density, and surface expansion of CCDBs were analyzed to determine the suitability of the CCDBs for storage and transportation. While compacting rate and output rate were calculated to determine the production capacity of CCDCM.

3.3 Storage and Transportation Parameters

To determine the suitability of the CCDBs for storage and transportation, the following parameters' results are presented and analyzed.

3.3.1 Compressed Density of CCDBs

The compressed density of the CCDBs was determined immediately after ejection from the molder. Each trial will remain in the molder for thirty (30) minutes which will serve as its creep before ejecting in the molder.

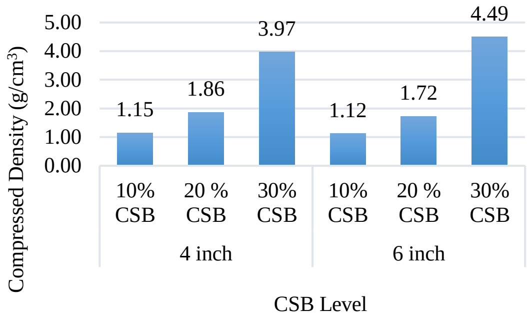

Fig. 6. Graphical Representation of the Compressed Density of CCDB at Different Binder Levels

Figure 6 shows that the highest compressed density were CCDBs at 6" initial height with 30% cassava starch binder (CSB) which has a mean value of 4.49 g/cm3 and the lowest were CCDBs at 6" initial height with 10% CSB which has a mean value of 1.12 g/cm3. This means that the initial weight of the coconut coir dust (CCD) does affect its density after compression given that it is the basis of the weight of the binder to be mixed following the 1:5 cassava starch to water ratio. In addition, the level of CSB. In addition, the level of CSB affects the compaction the most. The higher the binder the lesser the relaxation of CCDBs after compaction. Also, the contact of thirty (30) minutes of creep helps the binder to hold the CCD better and prevent instantaneously expansion of CCDBs from its original state after ejection from the molders. Since the instantaneously recovered elastic strain is equal to the initial instantaneous strain [15].

3.3.2 Relaxed Density of CCDBs

Relaxed density is the ratio of the weight of the CCDBs when dried over the new volume. This will give an indication of the relative stability of the CCDBs after compression. In this experiment, the researchers dried the

CCDBs through air drying for seven (7) days. The CCDBs were then weighed, and the dimensions were then measured and recorded as their new volume.

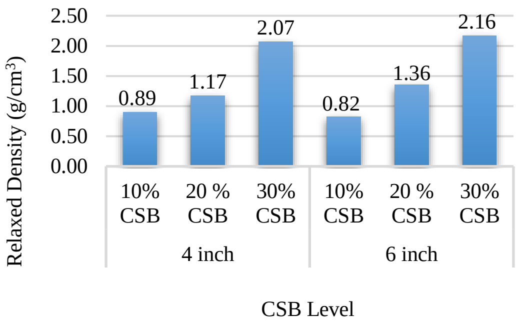

Fig. 7. Graphical Representation of the Relaxed Density of CCDBs at Different Binder Levels

Figure 7 shows a graphical representation of the relaxed density of CCDBs at a different level of the binder. Results show that the highest mean relaxed density was the CCDBs at 6" initial height with 30% cassava starch binder (CSB) and the lowest mean relaxed density was the CCDBs at 6" initial height with 10% CSB. This means that CCDBs at 6" initial height with 30% CSB expand lesser compared to the others, while CCDBs at 6" initial height with 10% CSB expands the most compared to the others. In the book of N. Mohsenin [15], he stated that relaxation time is a measure of the rate at which a material dissipates stress after receiving a sudden force. Meaning, that CCDBs with 10% CSB tend to dissipate the stress more over time compared to CCDBs with 30% CSB. Also, results show that the relaxed density increases as the level of binder increases.

3.3.3 Relaxation Ratio

The relaxation ratio is the ratio of compressed density to the relaxed density of the coconut coir dust bricks (CCDBs). The data were gathered following the seven (7) – day – drying of CCDBs.

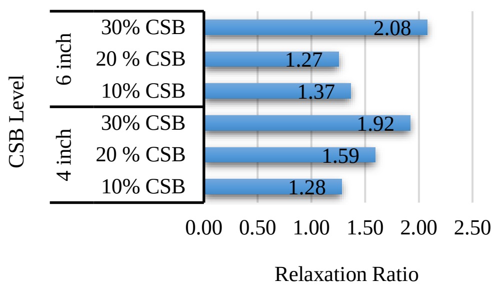

Fig. 8. Graphical Representation of the Relaxation Ratio of CCDBs

Figure 8 shows the graphical representation of the relaxation ratio of the CCDBs. The results show that the highest mean relaxation ratio were the CCDBs at 6" initial height with 30% cassava starch binder (CSB) which has a mean value of 2.08 which means that the CCDBs at 6" initial height was more compressed than the others and expands lesser compared to the other treatments after drying. On the other hand, the lowest relaxation ratio was the CCDBs at 6" initial height with 20% CSB with a mean value of 1.27.

3.3.4 Water Retention Test (Surface Expansion of CCDBs)

A water retention test is performed to determine the water resistance of the coconut coir dust bricks (CCDBs) before storage and transportation. During the test procedures, one (1) CCDB is fully soaked with 1 L of water. Hence, 4 L of water is used for the CCDBs produced in one compression.

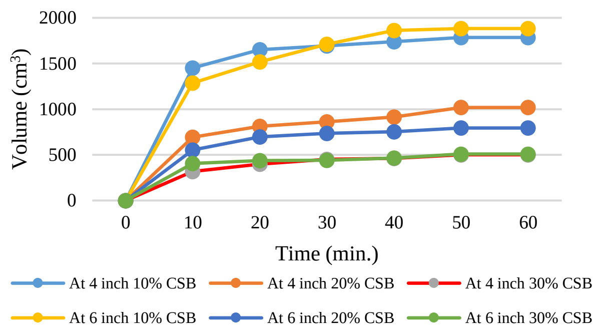

Fig. 9. Surface Expansion at Different Levels of Binder across Treatment

Figure 9 shows the results of the surface expansion of CCDBs across the levels of treatments. CCDBs at 6 inches thick with 10% CSB attained the highest surface expansion. The results are not only due to the particle size of the samples in which accordingly, at smaller particle size, the expansion and water absorption is higher [16] but also due to the percentage of CSB mixed. Since coir dust has a cylindrically opened cells with foam-like structure, these specifications when mixed with lower CSB made fewer particles held together such that many of its pores will be coated weakly, hence, fast absorption and higher expansion on its surface was observed. On the other hand, the results also shows that the level of initial height has a relative effect on surface expansion and water absorption. CCDBs at 4 inches thick with 30% CSB attained the lowest surface expansion among the other treatment used. This is mainly because the particles at 4 inches at 30 minutes creep, are more compacted than the particles at 6 inches thick. The compaction of samples in which accordingly, bond more the particles together [17] influences the expansion and absorption properties of the CCDBs samples with the combination of binder. As observed, the surface expansion of CCDBs is evident in their initial volume and their physical structure.

3.3.5 Water Absorbed by CCDBs

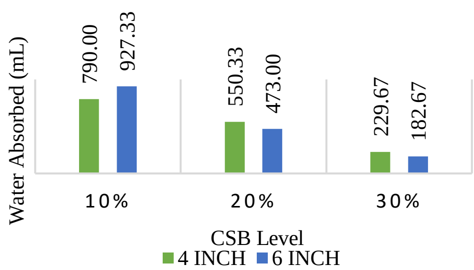

Fig. 10. Water Absorbed by CCDBs across a level of treatments

Figure 10 shows the water absorbed by CCDBs across a level of treatments after 1 hour. The CCDBs at 6 inches thick with 10% CSB attained the highest mean amount of water absorbed of 927.33 mL while CCDBs at 6 inches thick with 30% CSB attained the lowest mean amount of water absorbed of 182.67 mL. Hence, CCDBs with 30% CSB is good for storage and transportation, since they were observed to resist more water. With this, there will be less surface expansion on its surface once it is exposed to an area with high relative humidity. Overall, as can be seen in figure 9 and 10, relative results are observed as the surface expansion and water absorption goes with the trend across levels of treatments.

3.4 Production Capacity Parameters

3.4.1 Input Capacity

Input capacity is measured by the ratio of the total weight of input material to the total operating time. The weight of the input material refers to the initial weight of CCD plus cassava starch binder (CSB) at different levels specifically at 10%, 20%, and 30%.

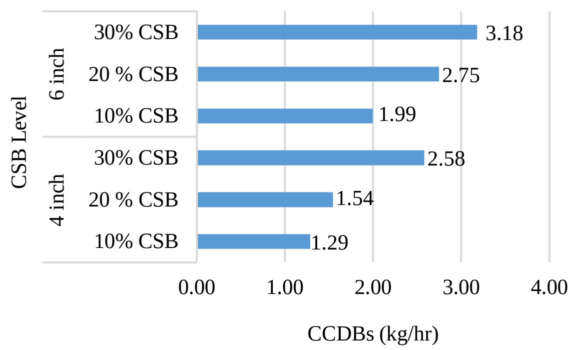

Fig. 11. Graphical Representation of the Input Capacity of the CCDCM

Figure 11 shows the graphical representation of the input capacity of the CCDCM. Input capacity is the ratio of the total weight of the CCD to be compacted (concerning the height: 4" and 6") to the total operating time including the creep which is thirty (30) minutes.

Results show that the highest input capacity was the CCD at a 6”-inch initial height with 30% CSB and the lowest is the CCD at a 4" initial height with 10% CSB. This is because the initial weight of the CCD at 6" initial height is heavier compared to the others assuming they all have the same initial moisture content.

3.4.2 Compacting Rate of CCDBs

Compacting rate is the ratio of the weight of coconut coir dust bricks (CCDB) collected to the total operating time. Three trials were done at each initial height corresponding to the level of the cassava starch binder (CSB) applied at 10%, 20%, and 30% of the weight of the coconut coir dust.

Figure 12 shows the graphical representation of the data gathered on the compacting rate of the CCDCM. Results show that the highest compacting rate is the CCDBs at 6-inch initial height with 30% CSB and the lowest is the CCDBs at 4-inch initial height with 10% CSB.

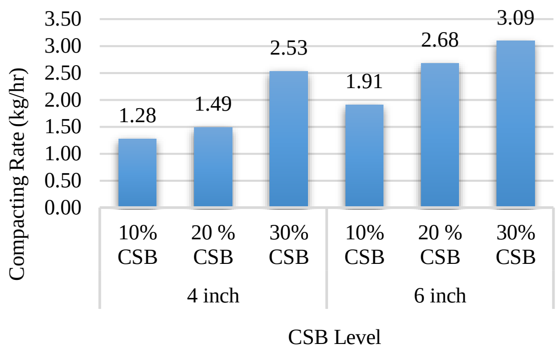

Fig. 12. Graphical Representation of the Compacting Rate of the CCDCM

Since the ratio of the cassava starch to water is 1:5, the weight of the CCD at 6” initial height which has the highest initial weight plus 30% CSB will become heavier than the other treatments.

3.4.3 Output Rate of CCDCM

The output rate of the CCDCM in CCDBs/hr is determined and calculated through the mean weight of the CCDBs across a level of treatments.

Table 1. Output Rate of CCDCM

Initial Height	Level of CSB	Output Rate (CCDBs/Hr)
4 inches	10%	21
	20%	
	30%	
6 inches	10%	
	20%	
	30%	

With the assumption of 10 minutes of creep which can make the operation longer but can assure the quality of compacted CCD considerably, the calculation was carried out. The calculated output rate is almost the same across each level of treatment and was approximated at 21 CCDBs/hr.

4. CONCLUSIONS

The study revealed that in terms of the storage and transportation parameters, the CCDBs at 6-inch initial height with 30% CSB got the highest mean values from compressed density and relaxed density which implies that it is more compressed compared to the other treatment and dissipates the stress less over time. This was also supported with the results of the water absorption test in which the CCDBs at a 6-inch initial height with 30% CSB got the lowest absorbed volume of water within 1 hour. These characteristics of CCDBs makes them more suitable for storage and transportation purposes since they are compact enough to withstand shattering and relaxation/expansion over time. They also absorb lesser ambient moisture which makes them suitable to store for a long period.

In terms of production capacity, the results revealed that the highest mean value of compacting rate of CCDCM was achieved at a 6-inch initial height with 30% CSB of 3.09 kg/hr with an output rate of approximately 21 CCDBs/hr across all levels of treatment. This result denotes that across a level of treatments, the CCDCM achieves higher compaction at CCD with a higher initial height and level of CSB.

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