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Mechanization Of Oyster Mushroom (*Pleurotus Ostreatus*) Production With Mango Saw Dust

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ABSTRACT

Preparation of saw dust as the growing substrate and filling into poly bags are the most difficult aspects of Oyster mushroom cultivation in Sri Lanka as the process is still not mechanized. The purpose of this research is to find an appropriate mechanical solution to prepare the saw dust growing media and fill it into transparent poly bags. As the first step of media preparation, saw dust should be sieved well to get separated the fine particles and then it should be mixed properly with other essential nutrient ingredients and water. A motorized machine with three separate units as saw dust sieving unit, ingredient mixing unit and mixture filling unit were designed and fabricated to replace the manual operations. The integrated filing and compaction of the mixture filling unit is the most salient feature of this machine. The performance of the machine was evaluated compare to manual operation with well dried mango saw dust and other recommended ingredient. The theoretical and actual machine capacities of the sieving unit were 252 kg/hr and 212 kg/hr respectively with 84% sieving efficiency while it was 190 kg/hr and 145 kg/hr respectively in manual sieving with 76% efficiency. The theoretical and actual capacities of the mixing unit were 480 kg/hr and 323 kg/hr respectively with 67% mixing efficiency while it was 230 kg/hr and 162 kg/hr respectively in manual mixing with 70 % efficiency. The theoretical and actual capacities of the mixture filling unit were 97 bags/hr and 81 bags/hr respectively with 83% filling efficiency while it was 44 bags/hr and 32 bags/hr respectively in manual filling with 72 % efficiency. According to the results, this machine can effectively replace the manual methods.

Keywords: *integrated filling and compaction, mechanical sieving, mechanical filling, mechanical mixing*

1 . Introduction

Farming of varies kind of mushroom has become popular tremendously in Sri Lanka as profitable self employments. This has become a the main income source of majority of the people who have been engaged in mushroom industry (*Ranathunge et al* (2010)). According to the mushroom growers, low production cost and high productivity per unit area are the reasons for being this as a profitable enterprise in Sri Lanka. High nutritional value, good flavor and texture, low in fat and calories, rich in vitamin B and C, good source of mineral nutrients, comparatively high protein content and low price can be considered as the reasons for the blooming demand for mushroom as a food. In Sri Lanka, lot of government and non government organizations are involved to promote mushroom cultivation as a self employment.

Oyster mushroom (*Pleurotus sp.*), Abelone mushroom (*Pleurotus sp.*), Paddy straw mushroom (*Volvariellavovacea*), milky mushroom and button mushroom (*Agaricusbisporus*) are the most common cultivated mushroom types in Sri Lanka. Out of these types, Oyester mushroom has a significant demand among mushroom cultivators in Sri Lanka due to the high growth rate, high yield, less attentiveness and low initial cost. Saw dust and paddy straw with nutrient ingredients are the most common artificial media for mushroom industry in Sri Lanka.

Saw dust is a byproduct of wood cutting industry and it is low cost and readily available in Sri Lanka. Paddy straw is also readily available at paddy harvesting season and both these saw dust and paddy straw have a big demand from other industries as an energy source.

Saw dust should be sieved well to get fine particles and then sieved particles should be mixed properly with other essential nutrient ingredients and water. After filling this prepared mixture into transparent poly bags, it should be sterilized well with steam for about 3 hours. After that, mushroom seeds should be inoculated under sterilized conditions and allow them for running the spawn under shaded conditions. After about one month incubation period, poly bags should be open and kept in a properly constructed mushroom shed and humid conditions should be provided. At a disease and pest free conditions, yield can be harvested for two or three months. In spite of being a profitable and popular industry in Sri Lanka, still almost all these activities of mushroom cultivation are done manually.

In some developed countries, mushroom cultivation has been properly mechanized according to their practicing methods. Most of those machineries are not compatible with growing methods and substrates available in Sri Lanka. Therefore, a properly designed study should be carried out to appropriately mechanize the mushroom industry in Sri Lanka. As most of the Sri Lankan mushroom farmers are living in rural areas and sustaining a marginal profit, affordability of the machine should be highly considered. As well as, carrying out a village level maintenance and repairs should be facilitated. In addition to that, high efficiency of operation, safety of the operator, reduction of drudgery, convenient directions of force application, low labor requirement and durability should be considered.

Therefore this study was aimed to introduce a mechanical method for growing media preparation and poly bag filling in oyster mushroom cultivation in order to increase the profitability by reducing the labor cost.

2. Research Problem

Most of the mushroom growers in Sri Lanka use sawdust media filled into poly bags in oyster mushroom cultivation. Preparation of saw dust as the growing media and filling into poly bags are the most difficult aspects of the cultivation process and quality of the filled bags are highly effected by the skillness of the person. Therefore, the production has been limited to a certain extent as family members can managed. Due to all these problems, most of the mushroom enterprises of Sri Lanka have been categorized as small scale enterprises. In spite of bringing lot of problems by the manual techniques, there is no any designed device in Sri Lanka for growing media preparation and filling.

3. Justification

Unemployment is one of the national problems, which is very difficult to solve in Sri Lanka due to majority of unemployed youths are educated and they are not satisfied with a low salary. Despite the mushroom cultivation is one of the profitable self employment, most of the people do not like to engage it due to several reasons such as difficulties in hiring labor, lack of proper machineries, pest and diseases. Therefore by appropriately mechanizing the mushroom cultivation, young people can be attracted and mushroom industry can be popularized as a suitable and profitable self employment for educated people.

4. Objectives

General objective
To introduce a mechanical method for media preparation and poly bag filling in oyster mushroom cultivation in order to increase the profitability by reducing the labor cost
Specific objectives

01) Designing and fabrication of a saw dust sieving unit, ingredient mixing unit and growing media filling unit.

02) Evaluation of the performance of the saw dust sieving unit ingredient mixing unit and growing media filling unit with mango saw dust, compare to manual methods.

5. Methodology

Designing, fabrication and evaluation of the machine performance were carried out in the engineering workshop of the Faculty of Agriculture, Rajarata University of Sri Lanka, Puliyankulama, Anuradhapura. The growth and yield parameters of prepared poly bags were tested at a properly constructed mushroom shed in the Faculty premises.

5.1Designing and fabrication of the machine

Converting the saw dust into a culture media for edible mushroom, takes several steps as sieving saw dust to get fine particles in order to facilitate the decaying by target fungi, mixing the sieved saw dust with essential nutrient ingredient to provide favorable conditions for a optimum growth and filling them into transparent poly bags to facilitate the sterilization process and provide light. Therefore, it was decided to mechanize this process as three separated units such as saw dust sieving unit, ingredient mixing unit and poly bag filling unit.

5.2 Factors considered in designing

Since, the target group of this innovation was Sri Lankan mushroom growers who have a very low purchasing power, several special factors were considered. Affordability of the technology for Sri Lankan small and medium scale farmers was highly considered. Therefore, it paid the attention to keep the production cost of the machine at a low level. The capacity and efficiency of the machine was also taken into account as one of the major objectives of this machine is increasing the mushroom production by reducing the production cost. At the selection of the materials for the fabrication, standard and durable materials were selected whenever possible in order to facilitate the repairs and maintenance at village level (Khurmi and Gupta, 2006). As all the family members are engaged in most of the mushroom enterprises of Sri Lanka, operating the machine by female operators and child were facilitated by reducing the required forces to operate levers and pedals by taking their capabilities and limitations into account. As well as, all the moving and heating up parts were covered and convenient directions for force application were considered to provide a safe working environment. On the other hand, load capacity of some containers have been limited to low values such as maximum 25 kg to ease the handling. It was highly considered to apply Ergonomics principles wherever possible for productive, safe, comfortable and effective human use.

5.3 Saw dust sieving unit

The designed capacity of the container of the sieve is 5 kg of saw dust and as the sieving can be continuously done, unsieved saw dust can be loaded when the sieve is operating. According to the average specific volume of saw dust (0.007 m^3/kg), the dimensions of the container were decided as 80 cm in length, 51 cm in width and 17 cm in height. It was assumed that, only half of the container should be filled for better operation without any dispersion. A collector with a slight sloped bottom towards the outlet has been designed to fit underneath of the sieve in order to collect the sieved saw dust. Continuous forward and backward movement of the saw dust container of the sieve cause to move the fine particles through the wire mesh. This continuous reciprocating movement is given by the crank shaft of the sieve. This crank shaft converts the angular motion of the electric motor into linear motion of the saw dust container. At one rotation of the crank shaft, 20 cm linear movement into forward and backward can be obtained as the radius of the crank is 10 cm. Six caster wheels are attached to the bottom of the container to facilitate the forward and backward motion. In addition to that, two rails are fitted to the frame of the sieve in order to guide the container on a linear pathway. Sieved saw dust is collected by the collector underneath the sieving mesh and collected saw dust is guided towards the outlet of the saw dust collector under the gravity force. In addition to that, it has provided facilities to remove the unsieved particles from the saw dust container of the sieve. The wire mesh of the container is fitted to a separate frame and connected with the container with hinges and locks as it can be open when it is needed. An electric switch is fitted to the frame of the sieve in order to connect and disconnect the electric power supply to the motor. The drawing of the sawdust sieving unit is given in the figure 1.

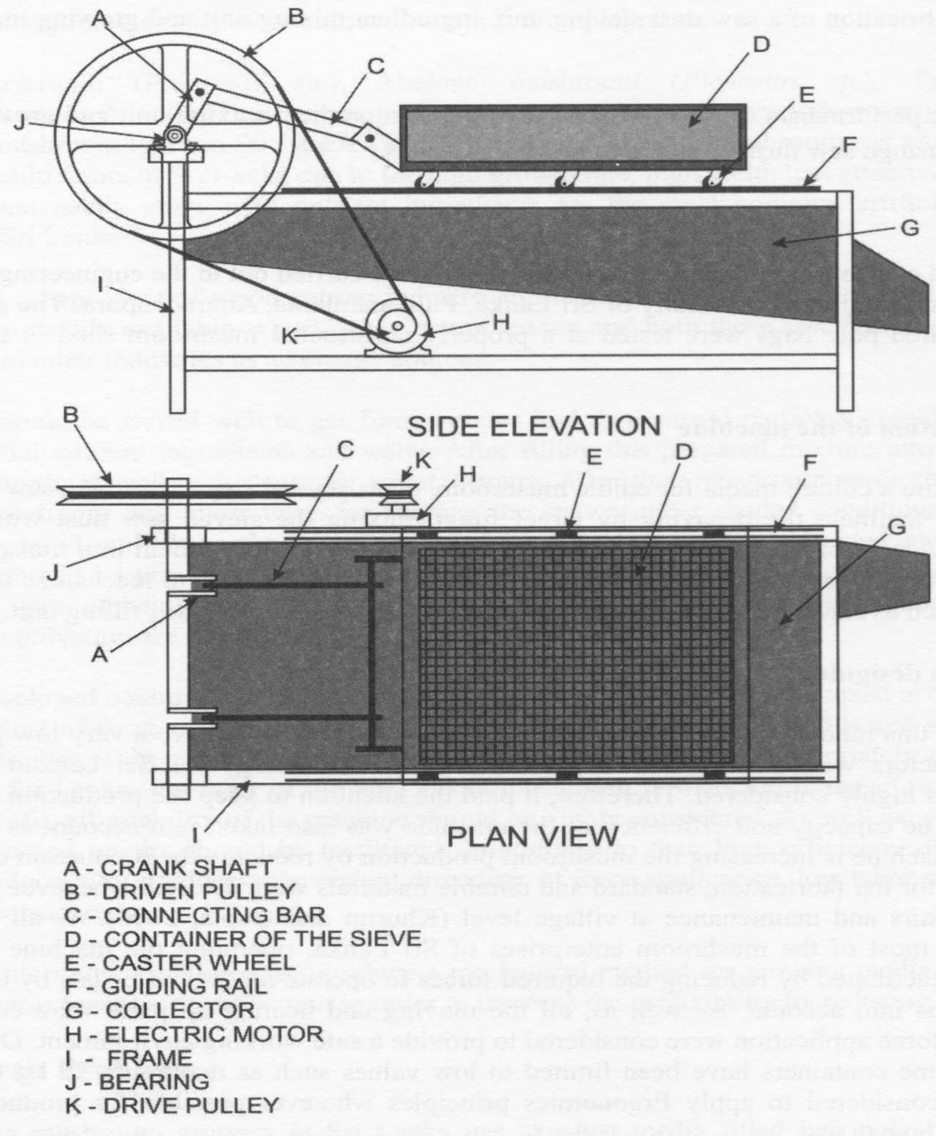


Figure 1: Sawdust sieving unit

5.4 Ingredient mixing unit

Designed capacity of the ingredients mixing unit was 15 kg of saw dust (Figure 2). Since, this is a drum type mixing tank; four mixing plates were fitted inside the tank in order to increase the mixing ability when rotating the tank. An iron shaft with 2.5 cm diameter was used as the main shaft of the mixing tank and tank was connected with the shaft using two connectors as shown in the figure 2. The mixing tank, connectors and the shaft were connected together using nuts and bolts, which is one of the non permanent fastening methods, in order to facilitate the maintenance and repairs. The tank with the shaft is connected to the frame with the support of two bearings. At the one end of the main shaft, a pulley with 50 cm in diameter is connected as the driven pulley of this unit. Belt and pulley was selected as the power transmission method, because then the electrical motor is protected by the unfavorable loads. Two openings were made on the tank in order to use as inlet and outlet. Top opening is used as the ingredient inlet and a door with two locks is connected to it with the support of two hinges. A handle is also fitted to the door for opening and closing. Bottom opening is used as the mixture outlet and three sliding doors which can be open and closed independently are connected with this in order to ease the mixture taking out with a control. All these three doors are covered by another single door to provide a sealed condition. All the edges of the doors and openings have been lined with rubber to tightly seal the tank. The frame of the unit was fabricated with 2" x 2" x 5 mm L angled iron bars.

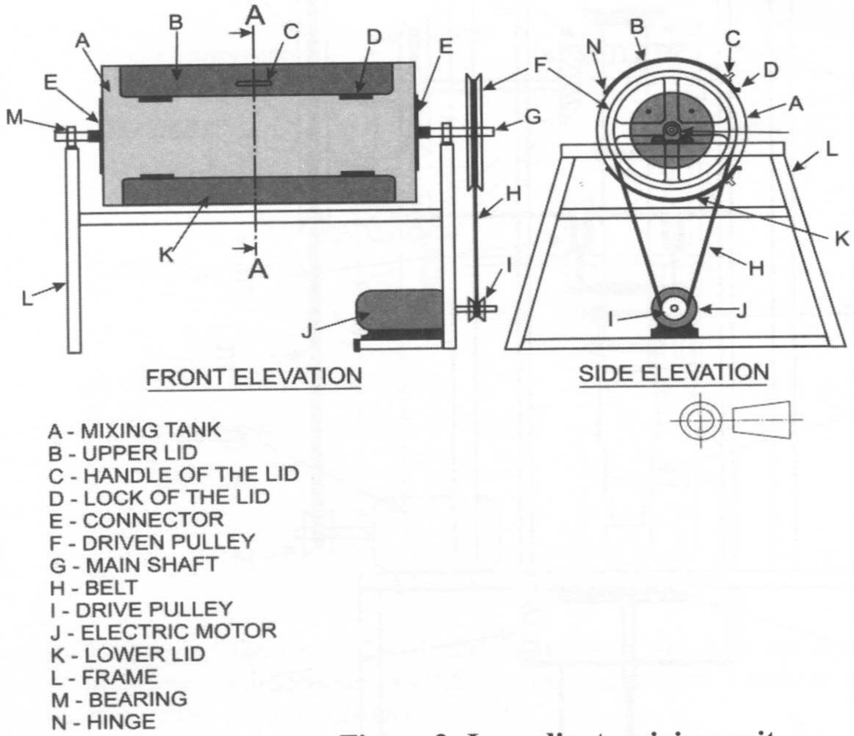
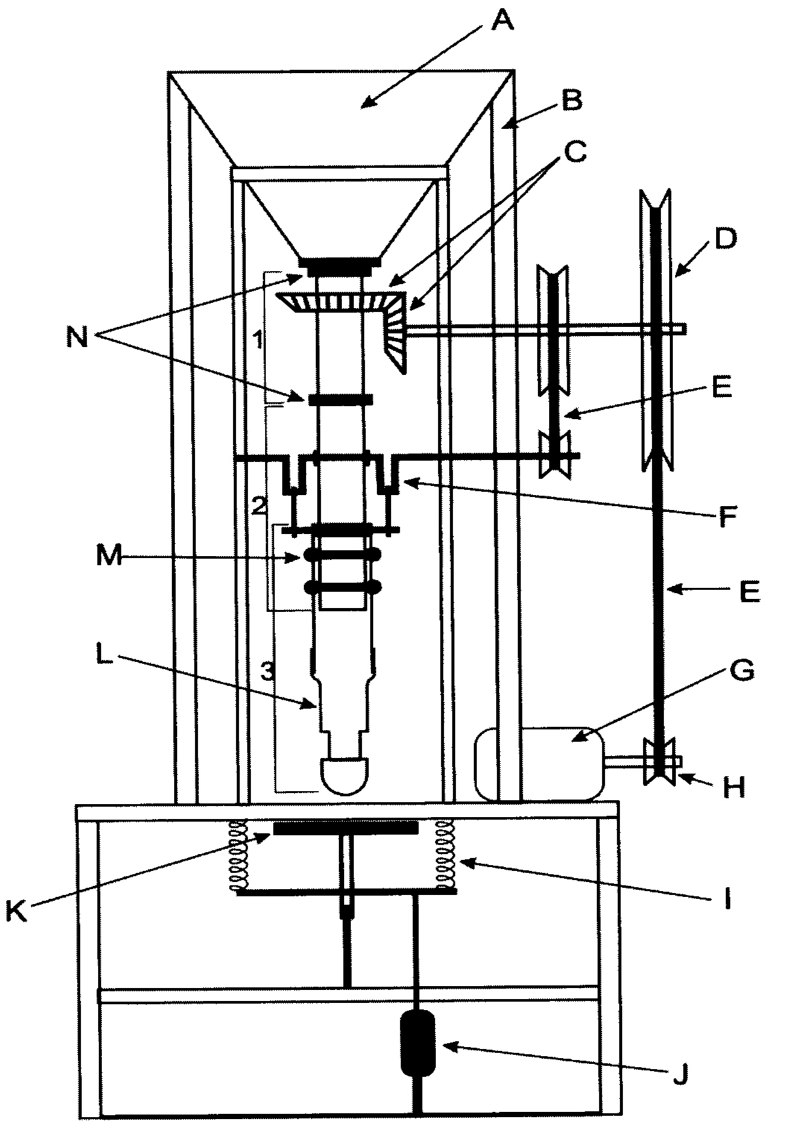


Figure 2: Ingredients mixing unit

The specific volume of saw dust, calcium carbonate, magnesium sulfate, rice brand and powdered soya bean were used to determine the capacity of the tank. A preliminary study was carried out to find the above mentioned physical properties of ingredients. The size of the mixing tank is 110 cm length with 25 cm radius.
The 45 gallon barrel is used with modification as it is approximately fitted with the designed dimensions. In addition to facilitate the fabrication, it will help to easily replace and maintain at village level.
Four mixing plates with an equal gap were fitted inside the barrel in order to increase the mixing rate. According to the designed mixing ratio, one fifth of the total mixture is subjected to mix at one rotation of the mixing tank. In addition to the mixing plates, three holes were made on each and every mixing plate in order to increase the mixing efficiency further.

5.5 Growing media filling unit

After preparing the saw dust media, it should be filled and compacted into transparent poly bags and a piece of PVC pipe should be fitted to the top of the bag to operate as the opening of the bag to place the mushroom seeds. This process ease the steaming and transparent bag allows lighting for optimum growth. When it consider to the whole media preparation process, this is the most labor and time consuming step. The skillness of the labor is highly effect for the condition of filled bags. Low compaction of saw dust leads to reduce the economical lifetime of the bag and high compaction reduce the growth of fungi. At this process, 200 gauge, 15.2 cm width and 33 cm height polythene bags should be filled only up to 25.4 cm.
Although, growing media filling unit is somewhat complicated assembly with lot of parts, it can be divided into six main components as Hopper, Conveying unit, Compacting unit, Adjustable stage, Power transmission system and Frame. Following figure 3 shows all the parts of the Growing media filling unit.
Hopper was designed to contain a bulk of growing media to convey to the hammer. The capacity of the hopper was decided by considering the specific weight of the saw dust mixture. Since this unit is batch type, once a batch of the mixture should be filled into the hopper and hammer should be operated to fill it into poly bags. The designed capacity of the hopper is 100 liters. It was decided to have the shape of the hopper as a frustum of a square pyramid in order to improve the flowing of mixture to the conveying screw under the gravity.



A - HOPPER
B - FRAME
C - BEVEL GEARS
D - DRIVEN PULLEY
E - BELT
F - CRANK SHAFT OF THE HAMMER
G - ELECTRIC MOTOR
H - DRIVE PULLEY
I - SPRINGS
J - PADDLE
K - SPRING LOADED TABLE TOP
L - FEEDER AND HAMMER
M - GUIDING WHEELS
N - BEARINGS

Figure 3: Parts of growing media filling unit

The dimensions of the hopper were decided according to the capacity of the machine. The equation 1 shows the relationship among volume, areas of the upper and lower bases and perpendicular height of the frustum (Anon1 (2015).

$$V = (h/3)\,[A_1 + A_2 + A_1 \sqrt{A_2}] \qquad (1)$$

Where, V – Volume of the frustum
h - Perpendicular height of the frustum
A_1 – Area of the upper base
A_2 – Area of the lower base

The dimensions of the upper base and lower base were decided as 60 cm x 60 cm and 20 cm x 20 cm square shape respectively to provide enough space to connect with the conveying unit. Volume of the frustum is equal to 100 liters. Based on all these measurements, the perpendicular height and the slanted height of the frustum were calculated as 58 cm and 61.4 cm respectively.

Conveying unit (figure 4) is one of the most important assembly of this machine and it consist of two level gears, rotating pipe with a conveying screw, two mounting bearings, agitator and two pulleys. This section is represented by number 1 and 2 of the figure 05. Bevel gears have been used to transmit the power of the motor to the rotating pipe, so that rotating pipe can be rotated on a perpendicular plane (horizontal) to the power transmission plane (vertical).

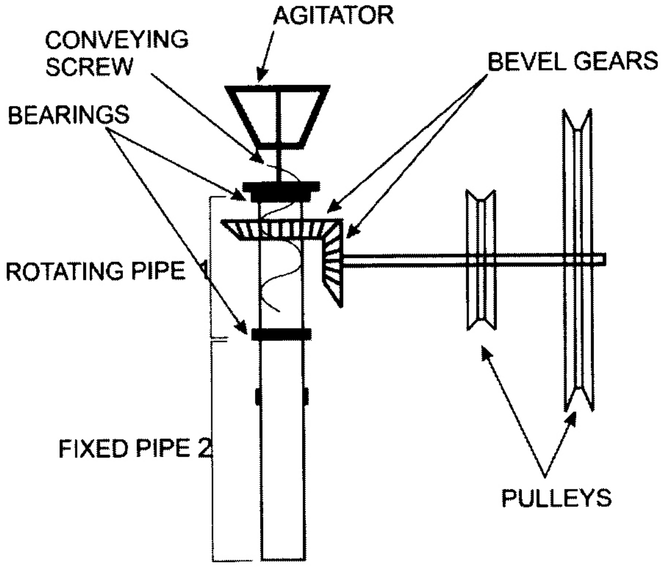


Figure 4: Conveying unit

As the expected capacity of the screw is 50 cm^3 of mixture which is conveyed to hammer per one rotation, suitable pitch of the screw was calculated as 2.5 cm using equation 2 and the trough loading percentage of the screw was assumed as 100% (Anon2 (2015).

$$C = 0.7854\,(A_S^2 - A_P^2) \times P \quad (2)$$

Where, P- pitch of the screw

A_S – Cross sectional area of the screw

A_P – Cross sectional area of the pipe

Compaction unit is fitted to the fixed pipe of the conveying unit. When the growing media mixture is filled into poly bags, it should be compacted properly. In manual bag filling methods, farmers use their hands or empty glass bottles to compact the mixture. In this machine, a reciprocating hammer, which is connected with a crank shaft and guided by wheels on a groove, is used. As, filling the mixture into poly bags and compacting should be simultaneously happen, both filling and compaction actions are synchronized using belts and pulleys. The crank has been designed to give a 6 cm stroke for the hammer.

The degree of the compactness of the mixture is a very important factor that effect to the growth performance of fungi. The hammer itself cannot control the degree of compactness. An adjustable, spring loaded table top was designed to control the degree of compactness by pressing the paddle and to place the filled poly bags.

5.6 Designing of the power transmission system of the media filling unit

An electric motor (3 hp) was used as the power source of the growing media filling unit. The power transmission system of this unit is comprised of bevel gears, belt and pulleys to protect the motor from unfavorable loads. As the power should be supplied to the conveying unit to be rotated on a horizontal plane, bevel gears were used with a suitable speed ratio (Tata, 2012). The shaft of the main driven pulley 01 in figure 5 is connected with the vertical bevel gear and driven pulley 02. Driven pulley 02 supply the power to the driven pulley 03 (crank shaft) in order to synchronize the filling and compacting actions. The specification of the power transmission system is given in table 1

Table 1: Specifications of the power transmission system

Components	Dimensions
Diameter of the drive pulley	5 cm
Diameter of the driven pulley 01	50 cm
Speed of the motor	1400 rpm
Therefore, speed of the bevel gear 01	140 rpm
Number of teeth of bevel gear 01	10
Number of teeth of bevel gear 02	20
speed of the bevel gear 02 (conveying unit)	70 rpm
Diameter of the Driven pulley 02	24 cm
Speed of the driven pulley 02	140 rpm
Diameter of the driven pulley 03	6 cm
Speed of the hammer	35 rpm

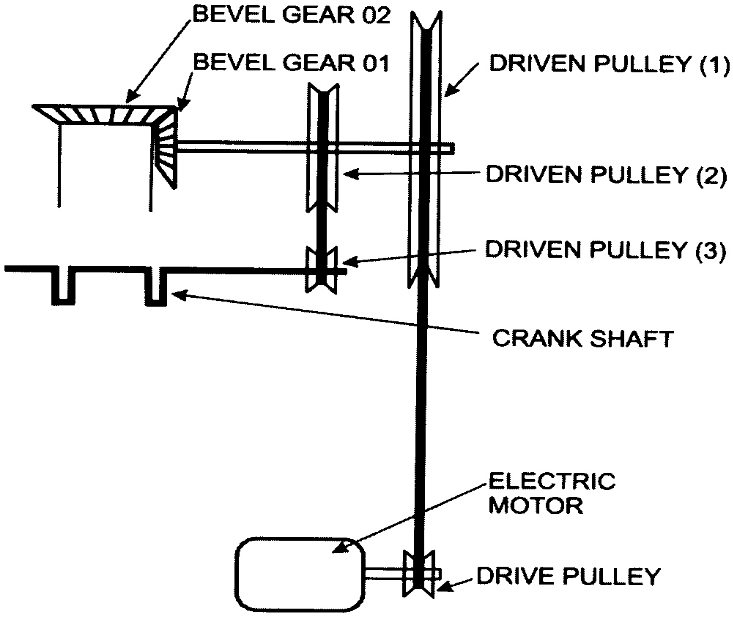


Figure 5: Power transmission system

5.7 Evaluation of the performance

Evaluation of the performance of three units was done compare to the existing manual methods with the properly dried mango saw dust.

5.8 Evaluation of the performance of saw dust sieving unit

Performance of the saw dust sieving unit was evaluated compared to the manual saw dust sieving method. Manual saw dust sieve with 80 cm in length, 51 cm in width and 17 cm in height was made using a wooden frame and No. 16 wire mesh to compare the performance of the mechanical sieve with same dimensions. Three replicates of each treatment with 5 kg of saw dust were carried out and total time taken to finish 5 kg of saw dust, time taken to unload unsieved particles, time wastage for adjustments and injuries happened during the trails were recorded. Another three replicates of all the treatments were carried out to calculate the amount of saw dust for 60 minutes duration.

Theoretical sieving capacity using equation 3, actual sieving capacity and sieving efficiencies using equation 4 of both methods were calculated (Roth, 1975).

$$SC_T = (5/t_1) \times 60 \qquad (3)$$

Where, SC_T – Theoretical sieving capacity (kg/ hr)

t_l – Time taken to sieve 5 kg of saw dust (min)

$$E_S = (SC_A/SC_T) \times 100 \qquad (4)$$

Where; E_S – Sieving efficiency

SC_A – Actual sieving capacity (kg/hr)

SC_T – Theoretical sieving capacity (kg/hr)

5.9 Evaluation of the Ingredient mixing unit

The performance of the mechanical ingredient mixing unit was compared with the most practicing manual mixing method. For the mechanical mixing method, 20 kg of sieved saw-dust, rice bran, calcium carbonate and grain powder were put into the mixing tank. Then 20g of magnesium sulphatewas dissolved in a cup of water and sprinkled on to the mixture and lid of the mixing tank was closed tightly. Then, the mixing unit was operated until the ingredients got mixed well. Then, adequate amount of water was added and operate unit again. Three persons were used as three replicate to check the condition of the mixture by squeezing of handful mixture as done in the manual method. The time was recorded to complete the work.
Theoretical and Actual mixing capacities and mixing efficiencies for both methods were calculated using following equations 5 and 6 (Roth, 1975).

$$\mathbf{MC_T = (20/t) \times 60} \qquad (5)$$

Where; MC_T - mixing capacity (Kg/ hr)
t - timetaken to mixed 20 kg of saw dust with other ingredients(min)

$$\mathbf{E_M = (MC_A/MC_T) \times 100} \qquad (6)$$

Where; E_M – Mixing efficiency (%)
MC_A – Actual mixing capacity (kg/ hr)
MC_T – Theoretical Mixing capacity (kg/hr)

5.10 Evaluation of the mixture filling unit

Evaluation of the mixture filling unit was carried out with the mixtures prepared by the manual and machine mixing methods which used for the comparison of the ingredient mixing methods. Filling the mixture into poly bags by both manual and machine were tested.
Theoretical and Actual filling capacities and filling efficiencies for both methods were calculated using following equations 7 and 8 (Roth, 1975).

$$\mathbf{MC_T = (1/t) \times 60} \qquad (7)$$

Where; MC_T - filling capacity (No. of bags/ hr)
t - timetaken to fill one poly bag (min)

$$\mathbf{E_M = (FC_A/FC_T) \times 100} \qquad (8)$$

Where; E_M – Filling efficiency (%)
MC_A – Actual filling capacity (No. of bags/ hr)
MC_T – Theoretical filling capacity (No. of bags /hr)

5.11 Calculation the cost of mushroom bag filling machine

The production cost and operating cost of the newly designed machine was estimated.

6. Results and Discussion

Although, the machine comprise of three separate units, each unit can be coupled with the same power source when it required. Belt and pulley power transmission system support to connect with the electric motor easily and protect the motor from adverse loadings. The working principle of the sieving unit is converting angular motion of motor into linear motion of the sieve by a crank shaft. Mixing unit is equipped with a rotating drum comprised with mixing plates and it is coupled with the electric motor. Mixture filling unit is working with a hammer moving up and down which help to convey the mixture from hopper to poly bags and apply required force to compact the mixture. A spring loaded stage provide a stage to place the poly bag while filling and it help to control the degree of compaction. The production cost of the machine without labor cost was LKR 75000. The performance parameters during the machine evaluation of both mechanical and manual methods were given in table 02.

Table 02: Comparison of mechanical and manual methods of growing media preparation

	Mechanical method	Manual method
Theoretical sieving capacity (SC_T)	252 kg/hr	190 kg/hr
Actual sieving capacity (SC_A)	212 kg/hr	145 kg/hr
Sieving efficiency (E_S)	84%	76%
Theoretical mixing capacity (MC_T)	480 kg/hr	230 kg/hr
Actual mixing capacity (MC_A)	323 kg/hr	162 kg/hr
Mixing efficiency (E_M)	67%	70%
Theoretical filling capacity (FC_T)	97 bags/hr	44 bags/hr
Actual filling capacity (FC_A)	81 bags/hr	32 bags/hr
Filling efficiency (E_F)	83%	72%

Because of the sieving process is continuous process, operator has only to fill the unsieved saw dust on to the mesh. But in manual method, operator has to fill, agitate and unload the residual particles. Therefore, the capacity and efficiency of manual sieving is much more lower than mechanical sieving due to time wastage for unproductive work in manual sieving. But mechanical mixing is a batch type process and only 20 kg of saw dust can be mixed in a one batch. After every batch, mixture should be unloaded and ingredients should be filled again into the container. Therefore, in spite of having higher mixing capacity, the efficiency is somewhat lower than the manual mixing due to higher unproductive work in mechanical mixing. Filling the mixture into poly bags by mechanical method has shown higher capacity and efficiency. According to the actual capacities of both methods, the labor and electricity cost for preparation of 1000 filled bags were calculated to find the most economical method. In mechanical method, it takes only 19 hours while manual method takes 42 hours to complete the task. Based on the capacity of the motor (3 hp) and present electricity charges, the electricity cost to operate the motor was calculated as 335 LKR. Including the labor cost (assuming 800 LKR for 8 hour work), the total cost in mechanical and manual methods were 2235 LKR and 4200 LKR respectively.

7. Conclusions

According to the results of this study, it can be concluded that, mechanical method can be used efficiently with higher working capacities and efficiencies as a solution for the scarcity of skilled labor in mushroom industry. It gives 55% time saving and 47% money saving compared to the manual method. As, the required forces to loading, unloading and operating the machine is very low, the machine can be used by adults as well as by children. Safety of the operator can be assured as 100%, as no injuries recorded during evaluation and the machine is ergonomically well suited.

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