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Design and Evaluation of Portable Manually Operated Spawn Spreading Machine for Oyster Mushroom (*Pleurotus florida*) Cultivation

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Oyster mushroom (*Pleurotus florida*) is gaining demand owing to its benefits and taste. But, the prevailing manual method of cultivation is compromised with limited spawn spreading capacity and high chance of contamination which could be overcome by use of a spawn spreading machine. Currently no such machine is available which has prompted us to develop the same. The benefaction of the developed machine to the farmers is lightweight, portable, autoclavable, affordable, uncomplicated design, unskilled person can operate and minimize contamination chance that leads to increase in yield of mushroom. It constitutes the main frame, truncated conical hopper and ball valve metering mechanism. The machine evaluated in the lab shown that a highest spawn spreading capacity of 288 bags/h as compared to manual spreading operation of 110 bags/h for rice straw substrate at spawning rate of 50 g. In this context, the result clearly indicate that, the spawn spreading machine is very cost effective, save time and reduce labour requirement as compared to manual operation.

Keywords: Ball valve, Cost economics, Hopper, Spreading capacity, Total yield

Introduction

Mushrooms have been recognizing as one of the important food items since ancient times. In the current scenario, it is also considered as one of the main horticultural crop because of its high nutritional and medicinal properties. Across the globe China is the major prevalent mushroom producing and supplying country to the world market followed by USA, Netherlands, Poland and Spain.[1] The most popular varieties being grown all over the world are European or white button mushroom (*Agaricus bisporus*), Oyster mushrooms or Dhingri (*Pleurotus* species), Chinese or Paddy straw mushroom (*Volvariella volvacea*), Shiitake mushrooms (*Lentinus edodes*) and Black Ear mushroom (*Auricus laria*).[2]

Among those varieties oyster mushrooms are predominantly cultivated worldwide especially in South East Asia, India, Europe and Africa. Especially, in India button mushrooms are widely cultivated followed by oyster mushroom. Several oyster mushrooms can be commercially cultivated during summer season, which includes *Pleurotus flabelltus, Sajor cajo, Sapidus, Membranaceous, Citrinopileatus, Eous etc.* Similarly, *Pleurotus ostreatus, Florida, Cornucopiae, Fossulatus* and *Eryngii* are being cultivated during winter season.[3] Among these, *Pleurotus florida* is well-known day by day due to its culinary taste and flavor and which has been considering as an better alternative to button mushroom. Therefore, in this study *Pleurotus florida* mushroom variety was opted for mushroom cultivation. The different lignocellulosic substrates such as cotton seed hulls, cassava peels, corncobs, crushed bagasse, water hyacinth, water lily, bean, wheat straw, oil-palm fiber, paper and cardboard can be used for *Pleurotus florida* mushroom cultivation.[4,5] But, in this study, the substrates such as rice straw, rice straw powder and sawdust were mainly utilized for *Pleurotus florida* cultivation because of their copious availability in the states of Karnataka and Andhra Pradesh (rice is the major staple food) and also due to their highest biological yield.[6]

The variation of spawning rate for rice straw substrate has significant influence on the growth and yield of *Pleurotus florida* mushroom as compared to any other mushroom species.[7] Presently, in *Pleurotus florida* mushroom cultivation practice followed by

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farmers the substrates are filled in 1 kg polypropylene bags and autoclaved. Later, approximately 50 g (about 5% of 1 kg weight of wet substrate) of mushroom spawn is inoculated and randomly spread on the top surface of substrates in each bag manually. Based on this practice, in this study, an attempt was made to know the best and accurate spawning rate by varying the spawning rate from 40, 50 and 60 g. Their effect on spawn spreading capacity was also determined.

In the *Pleurotus florida* mushroom cultivation the manual spawn inoculation and random spreading process are very laborious and there may be chances of severe contamination and also less spawn spreading capacity. Although, there is huge demand for spawn spreading machines from the farmers to the best of our knowledge, no machine is available to perform these operations so far. So, an attempt was made with an objective to design and develop portable manually operated spawn spreading machine and evaluate its performance with respect to spawn spreading capacity.

Materials and Methods

A portable manually operated spawn spreading machine was designed and fabricated at Division of Post-Harvest Technology and Agricultural Engineering, ICAR-Indian Institute of Horticultural Research, Bengaluru, Karnataka. The evaluation was carried out in Mushroom Research Laboratory.

Determination of Physical and Engineering Properties of the Mushroom Spawn

The determination of physical and engineering properties of the mushroom spawn viz., moisture content (w.b.), bulk density(kg/m^3), angle of repose (°) and coefficient of static friction are very much important before initiating design and development of spawn spreading machine because they affects the designing of spawn spreading machine.

The determination of moisture content of mushroom spawn was found crucial, because, if the moisture content of spawn is increased or decreased, there may be chances of clogging inside hopper and it may reduce spawn spreading capacity (bags/h). So, the moisture content of spawn was determined by following AOAC method (Method No. 925.10).[8] The procedure used for conducting experiment was as follows. Ten gram of spawn samples were filled in moisture bottles. The initial weight of the samples was recorded as W_1. The moisture bottles with samples were placed in hot air oven maintained at 105°C for 24 h. After drying, moisture bottles with samples were placed in the desiccator and then final weight of dried samples were noted as W_2. All the measurement was replicated thrice and the average moisture content was computed. The moisture content (w.b.) of the samples was calculated by using the following equation.

$$MC = \frac{(W_1 - W_2)}{W_1} \times 100 \quad \ldots (1)$$

where, MC = Moisture content of sample on wet basis, %; W_1 = Initial mass of samples before drying, g and W_2 = Dried final mass of samples, g.

Bulk density (kg/m^3) of the mushroom spawn was determined to find out the quantity of spawn filled per unit volume especially for correct design of hopper of the machine. The mean bulk density values of mushroom spawn found by taking five replications and using the following relation (Fig. 1a).[9]

$$\rho_b = \frac{\text{Weight of samples, kg}}{\text{Volume of the container, m}^3} \quad \ldots (2)$$

Angle of repose (°) is necessary to design conveying machine and hoppers.[10] Angle of repose of mushroom spawn was studied to understand the drillability (ease of flow without clogging) of the spawn inside the hopper of the machine. The angle of repose spawn was determined by using an apparatus having a hollow metal box of 130 × 130 × 200 mm size (L × W × H) and mounted on rectangular platform having size of 300 × 170 × 185 mm and discharge gate was provided at one side of the box (Fig. 1a). The box was filled with spawn and the gate was lifted slowly until it formed a cone on the circular base. The diameter (D_C, mm) and height (Hc, mm) of the spawn cone formed was measured and the angle of repose was computed by using the given below equation.[9]

$$\theta = \tan^{-1} \frac{2H_c}{D_c} \quad \ldots (3)$$

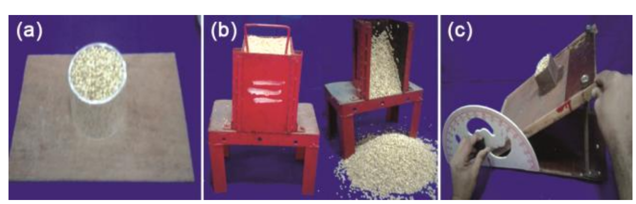

Fig. 1 — Determination of physical and engineering properties of mushroom spawn: (a) bulk density of spawn, (b) angle of repose of spawn, (c) coefficient of static friction of spawn

where, θ = Angle of repose (°); H_C = Height of spawn, mm and Dc= Diameter of spawn, mm.

Coefficient of static friction is used to confirm the angle at which hopper positioned to achieve consistent flow of the biomass or granular biomass materials through the hopper with less friction.[10] The mild steel surface material was selected for finding coefficient of static friction of spawn and the procedure followed is given below. The spawn poured into a hollow square box having dimensions of 50 × 50 × 50 mm (Fig. 1c). The spawn put in a position parallel to the direction of motion and the table was raised gently by a screw device, the angle at which the spawn start to slide (the angle of inclination) was read from a graduated scale on a tilting plate, this process repeated thrice. The coefficient of static friction (μ) was calculated as the tangent of the angle using the below equation.[11,12]

$$\mu = \tan\alpha \qquad \dots (4)$$

where, α is the tilting surface angle.

Design and Development of Portable Manually Operated Spawn Spreading Machine

Design Criteria

After measurement of physical properties of spawn, design criteria was established for the portable manually operated spawn spreading machine based on the following requirements. The machine should:

i) Have spawn spreading capacity at least in the range of 250–300 bags/h above than manual operation of 110 bags/h
ii) Design should be simple and user friendly.
iii) It should be light in weight and total cost of machine should be such that an individual can afford it.
iv) It should reduce chances of contamination and should not require any skilled person to operate

Fabrication of Portable Manually Operated Spawn Spreading Machine

The orthographic view of spawn spreading machine designed in solid work software 2014 version are shown in Fig. 2 (dimension in mm). The developed machine fulfils the above design requirement with least ignorance and it mainly consists of main frame, truncated conical hopper and ball valve metering mechanism. The detailed information of various components is hereunder.

Main frame

For supporting truncated conical hopper and ball valve metering mechanism a circular frame was made of stainless steel flat and L angle. Correspondingly,

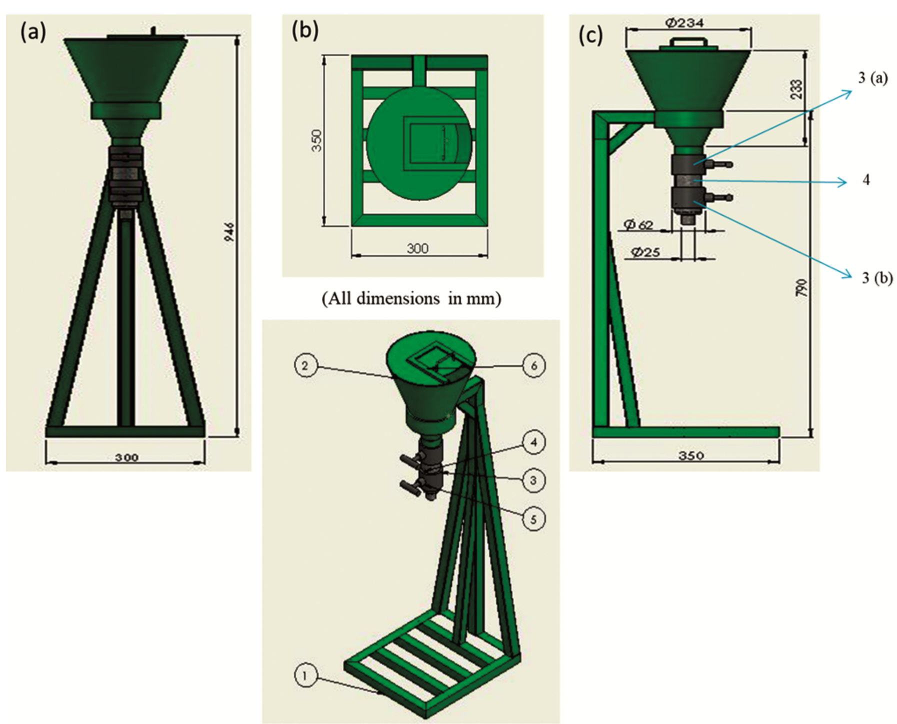

Fig. 2 — Orthographic view of spawn spreading machine: (a) front view, (b) top view; (c) right side view; Captions—(1) base Frame, (2) conical hoper, (3a) ball valve-1, (3b) ball valve-2, (4) measuring jar/cylinder, (5) ball valve handle/knob, (6) lid

the main frame length, width and height were 350 × 300 × 790 mm, respectively. Same size of MS L angle was welded across all the members of frame to make it as rigid frame. The specification of spawn spreading machine is presented in Table 1.

Truncated Conical Hopper

The truncated conical hopper or frustum is the component of spawn spreading machine, which receives, store and feed mushroom spawn to the ball valve metering mechanism. The mushroom spawn is manually fed into the hopper. It was fabricated using 2 mm thick stainless steel sheet having top diameter of 230 mm, bottom diameter of 50 mm and height of 240 mm. The volume of mushroom spawn occupied inside the truncated conical hopper with extended cylinder was computed by using the equation as follows

$$\text{Volume of frustum (V)} = \frac{\pi \times h}{3} \times \left(r^2 + R^2 + rR\right) \quad \dots (5)$$

where, V = Volume of frustum, m^3 ; h = Height of hopper, m; R = Top radius of hopper, m and r = Bottom radius of hopper, m.

$$V = \frac{\pi \times 0.12}{3} \times \left(0.175^2 + 0.05^2 + 0.175 \times 0.05\right)$$

$V = 0.12\ (0.030 + 0.0025 + 0.00875)$

$V = 0.00492\ m^3$

[

The weight of the mushroom spawn occupied inside the hopper was theoretically computed by using the equation as follow

$$\text{Weight of mushroom spawn (w)} = V \times \rho_b \quad \dots (6)$$

where, ρ_b = Bulk density of spawn, kg/m^3.

$w = 0.00492 \times 620.43$

$w = 3.05\ kg \approx 3\ kg$

In ball valve metering mechanism, the volume of mushroom spawn occupied inside the cylindrical tube or measuring jar in between two ball valves were computed by using the equation as follows

$$V = \pi \times r^2 \times h \quad \dots (7)$$

where, V = Volume of cylindrical tube or measuring jar volume in between two ball valves; r = Radius of cylindrical tube or jar, m and h = Height of cylindrical tube or jar, m.

Ball Valve Metering Mechanism

The ball valves metering mechanism was used for metering the spawn and discharges it at the outlet end. During the operation, in this mechanism, two ball valves were connected by using stainless steel jar in between them. The metered quantity of spawn was filled in between two valves initially by opening first valve which was being connected to the bottom of hopper and at the same time another valve was closed. After filling metered quantity of spawn inside the jar in between valves, first valve closed and second valve outlet end inserted through the PP ring and the valve was opened to spread the spawn on the top surface of sterilized substrates inside the bag.

In ball valve metering mechanism, the volume of spawn occupied inside the first valve was computed as follows:

The inside diameter and height of first portion of first ball valve

$d_1 = 31.20$ mm $h_1 = 16.50$ mm

$V_1 = 3.142 \times 0.0155^2 \times 0.0165$

$V_1 = 0.0000124\ m^3$

The volume of mushroom spawn occupied inside first portion of first ball valve and its weight was determined by using below equation

$$\text{Weight of spawn } (w_1) = V_1 \times \rho_b \quad \dots (8)$$

$w_1 = 0.0000124 \times 620.43$

$w_1 = 0.007727\ kg \approx 7.72\ g$

The inside diameter and height of second portion of first ball valve

Table 1 — Specifications of portable manually operated spawn spreading machine

Components	Material	Shape/dimensions (mm)
Main frame (Length × width × height)	Stainless steel	350 × 300 × 790
Truncated conical hopper(top diameter × bottom diameter × height)	Stainless steel	234 × 50 × 233
Shape		Truncated cone/frustum
Ball valve metering mechanism: Number of ball valve	Stainless steel	2
Ball valve top portion (inside diameter × height), mm		31.2 × 16.50
Ball valve bottom portion (inside diameter × height), mm		24.5 × 10.50
Measuring jar (diameter × height), mm		50 × 26
Power source		Manual

$d_2 = 24.50$ mm $h_2 = 10.50$ mm
$V_2 = 3.142 \times 0.01225^2 \times 0.00525$
$V_2 = 0.00000247\ m^3$

The weight of the mushroom spawn occupied inside second portion of first ball valve was determined by using equation as follows:

Weight of spawn (w_2) = $V_2 \times \rho_b$ … (9)
$w_2 = 0.00000247 \times 620.43$
$w_2 = 0.00153$ kg ≈ 1.535 g

If it is considered approximately 50 g of metered quantity of spawn should be spread inside the PP bag then,

The weight of spawn occupied inside first ball valve = $w_{1+}\ w_2$ … (10)
= 7.72 +1.535 = 9.256 g

Similarly for second ball valve the same weight of spawn was also found. It means total quantity of 18.51 g of spawn occupied inside first and second ball valve and the remaining quantity of 31.50 g need to be filled inside the stainless steel jar. The volume of jar required to fill the 31.50 g of spawn was determined by using the equation 7 by assuming the diameter of jar 50 mm and height of 26 mm.

The inside diameter and height of stainless steel jar

$d_3 = 50$ mm $h_3 = 26$ mm
$V_3 = 3.142 \times 0.025^2 \times 0.026$
$V_3 = 0.000051\ m^3$

The weight of the mushroom spawn occupied inside the jar was determined by using equation as follows:

Weight of spawn (w_3) = $V_3 \times \rho_b$ … (11)
$w_3 = 0.000053 \times 620.43$
$w_3 = 0.03167$ kg ≈ 31.67 g

Total weight of mushroom spawn,

$w = 2\ (w_1 + w_{2)} + w_3)$ … (12)
w = 2 (7.72+ 1.535) +31.67
w = 50.18 g

Testing and Evaluation of Portable Manually Operated Spawn Spreading Machine

The performance of spawn spreading machine was evaluated under laboratory conditions. The Design-Expert software version 7.7.0 was utilized for analyzing statistical effect of operational parameter. A two factor completely randomized block design was used to analyze the effect of spawning rate (40 g, 50 g and 60 g) and different types of substrate (such as rice straw, rice straw powder and sawdust) on spawn spreading capacity (Table 2). The sequence of traditional manual spawn spreading operation and manual spawn spreading operation by using the machine are shown in Fig. 3 & 4. The procedure used for evaluating spawn spreading machine is given below.

Evaluation of Spawn Spreading Capacity of Spawn Spreading Machine

Spreading capacity of spawn spreading machine is measured by counting the number of 1 kg polypropylene bags inoculated (randomly spreading at the surface of the substrate with mushroom spawn) per unit time and expressed as bags/h.

Results and Discussion

Physical and Engineering Properties of Spawn

The results of physical and engineering properties were obtained after conducting experiments and it

Table 2 — Research plan

Variables	Levels	
Independent variable		
Spawning rate (SR), g	3	40, 50 and 60
Types of substrate (ST)	3	rice straw, rice straw powder and sawdust
Dependent variable		
Spawn spreading capacity, bags/h		

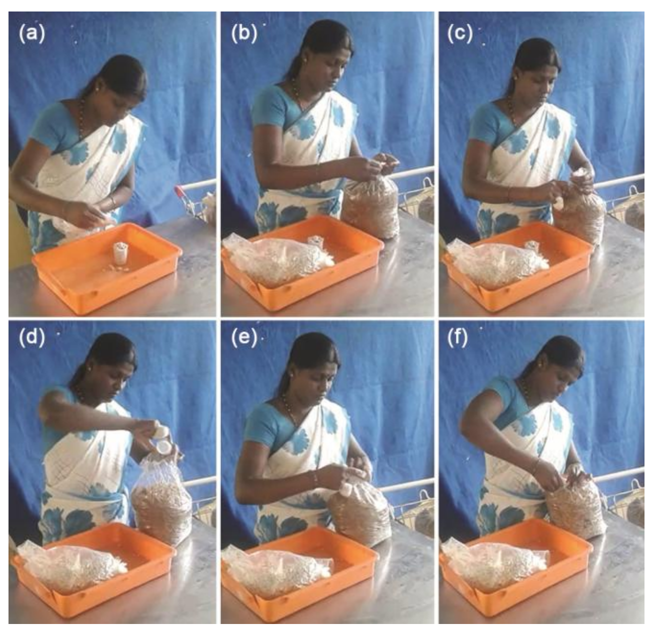

Fig. 3 — Sequence of traditional manual spawn spreading operation: (a) feeding of mushroom spawn inside 50 g beaker, (b) removing of cotton plug of the PP bag, (c) Removing of PP ring, (d) inoculation and random spreading of the spawn on top of the substrate surface, (e) Inserting the PP ring, (f) inserting the cotton plug after inoculation

Table 3 — Physical properties of mushroom spawn

Properties	Mean ± SEM value of Mushroom spawn
Moisture content, (w.b) (%)	48.80 ± 2.47**
Bulk density(kg/m^3)	620.43 ± 17.41**
Angle of repose (°)	24.04 ± 0.49**
Coefficient of static friction Mild steel sheet	0.56 ± 0.02**

**= significant at 5% level

Fig. 4 — Sequence of manual operation of spawn spreading machine: (a) feeding of mushroom spawn inside hopper, (b) removing of cotton plug of the PP bag, (c) turn on and off the first valve for filling the spawn inside measuring jar, (d) inserting bag on the outlet end of machine, (e) turn on and off the second valve for inoculation and random spreading of the spawn on top of the substrate surface, (f) inserting cotton plug after inoculation

statistically analysed by using single factor ANOVA design in AGRES Software. The mean value of moisture content of spawn on wet basis, bulk density of spawn, angle of repose and coefficient of static friction were determined and shown in Table 3.

Effect of Design and Operational Parameters on Spawn Spreading Capacity

The spawn spreading machine obtained a spawn spreading capacity of up to 292 bags/h, ranging from 201 to 292 bags/h depending on the spawning rate and types of substrate (Table 4). It is observed that the maximum spreading capacity found at a spawning rate of 40 g but after conducting statistical analysis, it was found that 50 g is the best spawning rate for rice straw substrate. The individual effect of spawning rate and types of substrate on spreading capacity was found significantly influenced at 1% level of significance. It was also revealed that, the spreading capacity of machine slightly increased with the decreased spawning rate, the reason might be due to less time taken for filling measuring jar in between ball valves at lower spawning rate. The rice straw gave highest bag spreading capacity as compared to rice straw powder and sawdust. This could probably because the whole volume of bag was filled with substrate due to lower bulk density of rice straw, resulting into very less headspace in between substrate and polypropylene ring. Hence, an inoculated spawn get directly placed on the top surface of substrate inside the polypropylene (PP) bag. Whereas, in latter cases more headspace was found in between substrate and PP ring due to the higher bulk density of rice straw powder and sawdust. Consequently, less quantity of substrate filled as compared to rice straw (lower bulk density) inside the PP bag which caused the obstruction in between substrate and PP ring to directly inoculate and randomly spread mushroom spawn inside PP bag. In order to solve this problem gentle shaking of PP bag was done. Therefore, the time taken for shaking and inoculation in rice straw powder and sawdust were more as compared to rice straw substrate.

Table 4 — Effect of spawning rate and type of substrates on spawn spreading capacity of spawn spreading machine

Types of substrate (ST)	Spawning rate (SR), g	Spawn spreading capacity (bags/h)
Rice straw (RS)	40	292
	50	288
	60	283
Rice straw powder (RSP)	40	216
	50	210
	60	206
Sawdust (SD)	40	212
	50	207
	60	201

Reports regarding spawn spreading capacity of spawn spreading machine on different substrate were scarce and to the best of our knowledge this was the first extensive study on this research area.

Analysis of variance (ANOVA) and estimated coefficient values for the spawn spreading capacity of spawn spreading machine is presented in Table 5. The model F-value of 71.13 implies that the model was significant ($p<0.0001$) and the values of "Prob >F" less than 0.05 indicate that the model terms were significant. In this case, A and B were significant model terms and the values greater

Table 5 — Analysis of variance table for spawn spreading capacity of spawn spreading machine

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F		Term	Coefficient Estimate	df	Standard Error
Model	36734.65	8	4591.83	71.13	< 0.0001	Significant	Intercept	235.78	1	1.55
A - SR (g)	417.4	2	208.7	3.23	0.0632		A [1]	4.18	1	2.19
B - ST	36265.83	2	18132.91	280.9	< 0.0001		A [2]	1.08	1	2.19
AB	51.42	4	12.86	0.2	0.9355		B [1]	51.82	1	2.19
Pure Error	1161.93	18	64.55				B [2]	−24.84	1	2.19
Cor Total	37896.58	26					A [1] B [1]	−0.32	1	3.09
							A [2] B [1]	−0.66	1	3.09
Std. Dev.	8.03		R-Squared		0.9693		A [1] B [2]	1.05	1	3.09
Mean	235.78		Adj R-Squared		0.9557		A [2] B [2]	−1.88	1	3.09
C.V. %	3.41		Pred R-Squared		0.931					
PRESS	2614.35		Adeq Precision		19.344					

than 0.1 indicate that the model term was not significant. The statistical analysis indicated that the proposed model fitted the experimental data with R^2 value of 0.96, whereas the optimized predictive model had an R^2 value of 0.93 and was in reasonable agreement with the “Adj R-Squared” of 0.95. Adeq Precision ratio of more than 4 was desirable. The Adeq Precision ratio of 19.34 indicated an adequate signal.

Conclusions

With the optimized spawn spreading capacity of 288 bags/h at 50 g spawning rate for rice straw substrate as compared to rice straw powder and sawdust, the developed spawn spreading machine could be used by farmers in rural areas as well as small scale mushroom industries. It has light weight, simple design, reduced chances of contamination, low cost (Rs. 8,882/-) and higher spawn spreading capacity. The spreading capacity of the machine could be improved by providing automatic spawn feeding system and spawn metering mechanism. Finally, this study has inferred that, inoculation and random spreading of spawn at the top surface of substrate inside the polypropylene bag by utilizing spawn spreading machine is more economical to the farmers in terms of saving time, cost and labor in comparison with manual spreading operation.

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