Zero energy polytunnel: A rapid composting method for Agaricus bisporus cultivation

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Zero energy polytunnel: A rapid composting method for *Agaricus bisporus* cultivation

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ABSTRACT

The zero energy polytunnel, a novel composting method was developed for rapid substrate preparation for *Agaricus bisporus* cultivation using perforated HDPE pipes (10% perforations), iron frame and HDPE sheet (100-150 GSM). The ingredients mixture wheat straw (60%), wheat bran (5.5%), chicken manure (31%), urea (0.5%) and gypsum (3%) with initial moisture 75% (wb) used for composting. The process of composting was evaluated and standardized in terms of compost quality, numbers of turning, composting period and button mushroom yield. The method was also tested at seasonal/commercial grower's farms. The design of the polytunnel was based on basic ingredients/compost bioengineering characteristics, principle of natural passive aeration and heat-mass transfer of composted substrate. This is natural environment friendly 14-16 days composting process, which requires only two manual turning without additional infrastructure i.e. tunnel, boiler, blowers and compost yard. Zero energy polytunnel method reduced composting period by 60%, 40% and compost production cost by 37%, 50% as compared to long and short methods, respectively. The current study suggested the possibility to cultivate *A. bisporus* on a lingo-cellulosic, naturally pasteurized and conditioned composted substrate and significantly improved compost production (3-3.5 times of compost ingredients) and mushroom yield upto 22-27% with minimum energy, labor and infrastructure.

Key words: *Agaricus bisporus*, composting, zero energy polytunnel, bioengineering characteristics, HDPE pipes/sheet, heat-mass transfer, passive aeration

White button mushroom (*Agaricus bisporus*) farming is highly scientific and engineering based activity involving four steps; composting, conditioning, spawning and casing (Kariaga, 2012). This mushroom is cultivated on compost, a specially prepared selective medium produced by bioconversion of agro-industrial, forestry and household organic/inorganic matters that favours growth of the mushrooms by practical exclusion of other microorganisms (Femor *et al.,* 1985). Thus, the process of composting for button mushroom production is a solid-state fermentation process based on succession of thermophilic microbes and self-heating of substrate (Van Lier *et al.,* 1994).

In India, at present most commonly long (traditional) and short (tunnel) methods of composting are used for preparing the *Agaricus bisporus* compost (Vijay, 2010). The traditional composting method (Atkins, 1966) used in India (Mental *et al.*, 1972) for mushroom cultivation takes four to six weeks to complete the process in seven to eight turnings with an interval of three–four days to avoid anaerobic condition of substrate (Suman and Sharma, 2007). The long method had problems of non maintenance of efficient temperature control, moisture levels, and requirement of huge manpower to oxygenate the pile (Hernandez *et al.*, 2003). The two-phase short method of composting involves outdoor aerobic degradation for 10–12 days (Phase-I) followed by pasteurization (57 °C for 6–8 h) and conditioning (45-48 °C for 7–8 days) of compost inside an insulated room by free circulation of air under definite set of conditions (Phase-II) (Beyer, 2005; Sinden and Hauser, 1950; 1953). In both the methods, ammonia is reduced to the levels that are non-toxic to *A. bisporus.* Also long and short methods of composting are highly laborious and time intensive. Additional cost is involved in tunnel, boiler and blower for pasteurization and conditioning of compost in short method and is also an energy consuming process. Similarly, other alternative environment friendly non-polluting (Sanchez *et al*., 2002; Garcia *et al*., 2005) and complete indoor compost methods like INRA (Laborde, 1991) and Anglo Dutch (Gerrits *et al*., 1993) were studied successfully and employed in profitable button mushroom cultivation in some developed countries viz., France, Italy, Holland, Belgium and Australia (Sanchez *et al*., 2008). These methods operate at high temperature (68–80°C) using passive/forced ventilation and involve re-inoculation of thermophilic microbes for rapid compost preparation in 9-13 days (Perrin and Gaze, 1987). However, major disadvantages of these methods are the use of costly ingredients, infrastructure and high energy input for maintaining higher temperatures to pasteurize/condition the substrate. As a result of it, presently these methods are not found commercially economical for Indian marginal/seasonal growers. The traditional long method of composting is prevelent in 75–85% of Indian seasonal mushroom growers. Thus use of passive aeration principal in long composting can be a good alternative for minimizing energy and labour inputs, composting period and foul odour responsible for environment pollution. Aeration helps to release trapped ammonia and maintaining the appropriate conditions in compost in terms of temperature patterns, moisture content, pH, compost gas composition i.e.CO_2/O_2 levels for growth of thermophilic fungi and other micro flora responsible for the early maturity of compost (Collins, 2009; Parati *et al*., 2011; Sanchez *et al*., 2008, Savoie, 1995; Randle and Flegg, 1985; Yue *et al*., 2008).

In this study effort has been done to reduce anaerobic conditions responsible for longer and faulty composting process, and also numbers of labour intensive turning in long method of composting by inserting the perforated HDPE pipe inside the compost piles. The prime aim of this study was to develop a reliable environment friendly low cost, short duration composting method/technique based on natural self-heating and passive aeration process to improve the yield and profitability of button mushroom farming in all agro climatic regions. The objectives of present work were (i) to develop zero energy low cost polytunnel (ii) evaluation and standardization of composting process for *A. bisporus* compost production and (iii) comparison of zero energy polytunnel method with existing long and short methods of composting.

MATERIALS AND METHODS

Selection of compost ingredients and their bioengineering characteristics

The selection of ingredients depend on the availability and cost. The most commonly available compost ingredients viz., wheat straw (60% weight basis), chicken manure (31%), wheat bran (5%), urea (0.5%) and gypsum (3%) used for composting were procured from local market of Solan. The formulation was based on the optimum initial nitrogen level of compost ingredients mixture i.e. 1.6% for rapid initiation of compost process and minimizing the attack of yellow mould and other cellulose loving fungi (Vijay, 2011). The bioengineering characteristics of basic ingredients and compost viz., moisture content, bulk density and porosity, pH and EC, average particle size, angle of repose. C:N ratio were measured using standard methods of hot air oven at 60°C, mass volume cylinder methods, glass electrode pH meter and conductivity bridge, screen analysis, natural free fall method, muffle furnace and rapid titration method, respectively. For this purpose, three different samples of 250 g substrate were randomly taken from the center of pile. The design of zero energy polytunnel was based on some of the bioengineering characteristics of ingredients/composted substrate.

Design of zero energy polytunnel

The major considerations for design of the zero energy poly-tunnel involved were size and shape of compost pile, optimization of passive ventilation, materials for pipe/stands, spacing between the adjoining pipes and stands, frame design and selection of polythene sheet cover.

Size and shape of compost pile and polytunnel

The size and shape of the compost pile mainly depends upon the particle size and angle of repose of compost prepared from the various ingredients. The angle of repose of compost varies with composting period and bioengineering properties viz., moisture content, bulk density and particle size of compost ingredients. For determining the angle of repose, compost was made using above formulation by short and long methods separately and data was measured at an interval of five days. The minimum angle of repose (42-45°) was used to ascertain the suitable size and shape of compost pile so that the compost pile remains stable during composting. For determining the appropriate shape, compost piles of different possible shapes viz., semicircular, triangular, rectangular, square and trapezoidal etc. were made based on the minimum angle of repose with ground surface. Among all, trapezoidal shape pile was found most stable and hence used for designing the present tunnel. Based on series of experimentation with consideration of minimum angle of repose (42-45 °C), best size i.e. 6 m length × (2.7 m bottom + 0.6 m top) width × 1.40 m height of the pile was confirmed. Size of the compost pile and tunnel depends upon the compost required. Thus trapezoidal compost tunnel (4-5 tones capacity) of slightly higher size 6 m length × (2.7 m bottom + 0.70 m top) width × 1.6 m height was designed.

Optimization of passive aeration and standardization of materials for pipes, stands, frame and polythene sheet

For uniform passive aeration, three different perforated pipe arrangements like parallel, triangular and perpendicular with 10% perforations were inserted longitudinally inside the compost pile. In parallel adjustments, pipes (0.10 m diameter and 6 m length) arranged in staggered manner with 0.5 m pipe spacing performed best for passive aeration. Among different tested materials viz., PVC, SRS, GI; HDPE pipes with 6-10 mm thickness was found to be corrosion free and capable to withstand the temperature (70-80 °C) inside the compost pile during composting. The numbers of pipes required were calculated based on the cross-section area of the trapezoidal shape pile and spacing between the pipes. Thus out of six lines of HDPE pipes three were arranged at the bottom zone, two were at middle zone and one was at the top zone of compost pile (Fig.1). However, for easy handling and transportation during the turning of compost, each HDPE pipe was cut into 1.8-2 m pieces and joined with the help of collars. The corrosion and heat resistant GI pipes were used for designing of polytunnel frame and stands for supporting poly cover and HDPE pipes. The frame was flexible and could be dismantled easily for handling and transportation. The black HDPE sheet (6.2 m x 4.5 m) with enough thickness (50-150 GSM) was selected for covering the compost pile.

Composting process and comparison with existing methods

For making compost, 1100 kg (60% of total compost ingredients) of dry wheat straw was wetted with water properly for 1-2 days upto moisture level 75-80% (wb). Then various ingredient viz., wheat bran (5.5%), chicken manure (31%) and urea (0.5%) were mixed thoroughly. The trapezoidal compost pile was formed by inserting the perforated HDPE pipes in parallel zigzag arrangement from the properly mixed pre-wetted compost ingredients. Thereafter, every fourth day compost pile was turned manually and turning was repeated till the compost gets matured. For evaluation of compost quality and standardization of compost process and appropriate time for adding gypsum was determined by series of experimental combination separately. The quality of matured compost in terms of maturity index viz., pH (7.2-7.7), moisture content (60-66%, w.b.) and ammonia (< 7ppm) was measured. Also bioengineering characteristics for best compost combination prepared with use of the zero energy polytunnel was compared with compost made from long and short methods. Matured compost prepared from all three methods were used for growing two button mushroom strains, namely, S-11 and U-3 in seasonal bamboo hut made with paddy straw in three different bed replications. Around 500 kg of compost was spread uniformly with 0.075 m compost thickness in 1.2 m × 15 m bamboo bed. The polythene sheet was used to maintain the spawn run temperature (22 ± 3 °C) for a period of 8–12 days. After spawn run, the compost beds were covered with 0.025 m casing material (1: 0.6: 0.4, spent mushroom substrate: cow dung: rice husk fly ash). The favourable conditions required for *A. bisporus* fruiting like temperature (18 ± 2 °C) and relative humidity (85–90%) were maintained. The yield was recorded as percentage fresh weight of button mushroom obtained during first three harvests against wet weight of the compost used. The mushroom yield from compost prepared from the zero energy polytunnel method was also tested at seasonal/commercial grower's farms.

Statistical analysis

For all experiments one way ANOVA was applied to determine the significance between different treatments using SPSS 16.0 statistical software (SPSS, Inc., Chicago, IL, USA). Critical difference (P d″ 0.05) and standard error of means (SEM) were tabulated. Mean separations were calculated based on the mean rankings at P d″ 0.05 using Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

Ingredients/compost bioengineering characteristics, design specification and working principle of zero energy polytunnel

It is clear from the Table 1 that bioengineering characteristics of basic ingredients viz., wheat straw, wheat bran, chicken manure, urea and gypsum varied widely and caused variation in composted substrate characteristics. Various bioengineering properties of basic ingredients viz., initial moisture content (w.b.), bulk density and porosity, pH and EC, particle size and angle of repose were determined as they directly affect the bioengineering properties of compost and mushroom yields.

The Table 2 shows compost bioengineering characteristics viz., angle of repose, moisture content and bulk density prepared by both long and short methods and are used for determining the best size and shape of compost pile. It was observed that initial angle of repose 42.5° increased with increase in composting period and became constant at about 52° after 20 days in both the methods. The moisture content and bulk density of the compost decreased with increase in composting period, however, bulk density increases slightly after addition of gypsum on 10th days for both the methods (Table 2). Compost as compressible material exhibits both elastic and plastic behavior causing variation in moisture content, bulk densities and angle of repose due to occurrence of subsidence of substrate during composting with respect to height and time of pile. The previous studies also revealed the variations in the bioengineering characteristics of compost during composting (Randle and Flegg, 1985). Highly significant relationship

Table 1. Ingredients bioengineering characteristics

Ingredients	M.C. % (w.b.)	Bulk density (kg/m^3)	Porosity (%)	pH	E.C.	Particle size mm	Angle of repose (deg.)
Wheat straw	13.46	100.49	75.45	6.40	3.92	0.5-30	-
Wheat bran	9.89	344.14	71.54	6.14	2.00	0.550	44.00
Urea	0.78	714.29	46.67	8.32	0.62	0.741	30.00
Gypsum	3.39	782.73	66.08	8.01	5.44	0.019	33.72
Chicken manure	26.69	513.86	60.27	8.28	9.77	0.662	10.67

M.C. = Moisture content, E.C. = Electrical conductivity

Table 2. Compost bioengineering characteristics for short and long methods

	Long method			Short method		
Compost Period	Angle of repose (degree.)	M.C.% (w.b.)	Bulk density (kg/m^3)	Angle of repose (degree.)	M.C.% (w.b.)	Bulk density (kg/m^3)
0 days	42.51	74.78	438.66	42.46	75.21	446.07
5 days	43.51	74.14	416.66	43.62	72.09	415.78
10 days	45.59	71.07	420.03	45.64	71.00	437.54
15 days	48.60	68.22	412.00	48.58	69.04	398.06
20 days	52.12	67.95	390.20	51.91	68.12	359.84
25 days	52.25	67.30	378.70			
30 days	52.31	66.96	357.14			

between the moisture content, organic matters of compost and mushroom yield are also reported (Sanchez *et al.*, 2008). Determined bioengineering characteristics of compost ingredients were utilized to design polytunnel and standardization of composting process for *A. bisporus*.

The design specifications for zero energy polytunnel viz., size and shape of compost pile, optimization of ventilation and materials for pipe/stands, spacing between the adjoining pipes and stands, frame design and selection of polythene sheet cover are given Table 3.

The working of designed zero energy tunnel shown in Fig.1 is based on the principles of natural passive aeration and heat & mass transfer. Because of temperature difference between atmosphere and compost pile, the bottom three perforated HDPE pipes suck the air from the outside atmosphere. As a result of rise in temperature of compost pile due to microbial activity, air inside the compost gets heated and moves upward by convection. This heated air finds its way to go out through middle two and top perforated HDPE pipes. However, two middle HDPE pipes also suck the outside air as well as releases the hot air from the pile. Thus natural flow of the hot air was maintained during the entire composting process. Also heated air carrying the ammonia/ moisture are released during composting and was trapped in surrounded polythene cover of tunnel. This helps to raise temperature of the surface layer of the pile for proper pasteurization and conditioning of compost. Thus, all composting operation like uniform aeration, pasteurization and conditioning were maintained naturally by HDPE perforated pipes and polyethylene cover. Hence this is named as zero-energy polytunnel for button mushroom composting.

Table 3. Design specification of zero energy polytunnel

S. No.	Specifications details	
1.	Polytunnel capacity	4-5 tones
2.	Shape and size	Trapezoidal shape tunnel of size 6.0 m length × (2.7 m bottom + 0.7 m top) width × 1.6 m height
3.	Material details	
	Pipe material	Perforated HDPE pipe, Pipe diameter, 100 mmPipe thickness, 10 mm, Pipe piece length, 1.2 m Perforation diameter, 30 mm, Perforation, 10% of cross section area
	Frame and stands	GI rod with 12.7mm diameter
	Poly cover	HDPE sheet (100-250 GSM), Size 6.2 m × 4.5 m with trapezoidal side flaps
4.	Pipe arrangement details	Parallel zigzag longitudinal arrangement6 pipe lines(top –1, middle-2, bottom –3)Pipe spacing, 0.45 to 0.60 m

Fig. 1. Low cost zero energy polytunnel

In the present method, appropriate pasteurization/conditioning temperature is maintaining naturally by aeration and accelerates thermophilic microbial activities for rapid preparation of compost in short duration. Previous studies reports that process of composting was governed by a succession of thermophilic microorganisms and their growth was highly influenced by moisture content and oxygen availability in the compost pile (Collins, 2009, Parati et al., 2011).

Standardized composting process and evaluation of compost quality

After various composting trails, the time for addition of gypsum and optimization of number turnings in four days interval, the process of composting was evaluated and standardized. The standard process involved, the mixing of pre-wetted compost ingredients including gypsum, natural pasteurization by covering of compost pile with polythene sheet for three days at 66-70°C and conditioning of compost at 50-60°C for another two days. The first turning of compost pile was done on sixth days. Again second natural pasteurization of compost was done after two days at 60-65°C and conditioned the compost for next two days at 50-54°C. The pile was turned secondly on 11th days and covered with polythene cover for next three days and conditioned at 48-52°C. The desirable quality of matured compost (moisture content 62-66%, pH 7-7.7, ammonia < 7-10 ppm) was obtained after 14-16 days. The pile was broken and spread overnight for cooling. Spawning and filling of compost bags/ beds was done immediately. The natural environment friendly 14-16 days compost process requires only two manual turning without additional infrastructure i.e. tunnel, boiler, blowers and compost yard

The desirable values of moisture content, bulk densities, pH and C:N ration i.e. 66% (w.b.), 410.23 kg/m^3, 7.3, 16.15:1, respectively for matured compost were achieved within 14 days (Table 4). The statistical analysis reveals that results were significantly different for all bioengineering characteristics, compost period and their interaction at 5% level of significance (P d" 0.05). An increasing trend in population of thermophiles was observed up to sixth day of composting with highest population 23 × 10^{-4} CFU g^{-1} and a slightly decreasing trend was observed after this point (Table 4).The dominant groups identified were *Scytalidium thermophilium, Humicola insolens, Humicola grisea and Thermomyces lanuginosus.* The desirable levels of ammonia for matured compost (< 7 ppm) were observed after 14 days and oxygen and carbon dioxide were found to be 17.40% O_2 and 4.7% CO_2, respectively. Thus desirable quality of matured compost prepared by zero energy polytunnel for spawn inoculation was achieved rapidly within 14-16 days naturally. This was possibly due to sufficient amount of aeration provided through perforated HDPE pipes to accelerate the compost decomposition process caused by thermophilic fungi. Variation in physico-chemical characteristics of compost was noted in previous reports also (Sharma *et al.*, 2009 and Parati *et al.,* 2011).

Comparison with other composting methods

The quality of matured compost in terms of bioengineering characteristics prepared using standardized zero energy polytunnel composting technique was compared with the same of long and short methods. The standard values of moisture content (55-68% wb), pH (7.2-7.7), EC (3-5 dS m^{-1}), bulk density (350-500 kg.m^{-3}), C: N ratio (16:1) and thermophilic microbes population of matured compost obtained from 14-16 days zero energy polytunnel were almost similar with short (18-20 days) and long (28-30 days) compost methods. The temperature profile depicted in Fig. 2 showed wide variation in average pile temperatures patterns during composting with respect to compost period for all three composting methods. In zero energy polytunnel method, the average substrate temperatures increased rapidly 65–70 °C within initial two-three days, remained

Table 4. Bioengineering characteristics of composted substrate prepared using zero energy polytunnel method.

Compost period	Moisture content (w.b.)%	Bulk density (kg/m^3)	pH	EC	O_2 gas	CO_2 gas	C:N ratio	Microbial load (x 10^{-4} CFU/g)
0 day	73.00 *a*	445.88 *a*	9.60 *a*	2.40 *d*	10.80 *b*	16.30 *a*	33.07 *a*	14.00 *a*
6 days (1st turning)	69.00 *b*	431.23 *ab*	8.90 *b*	2.86 *c*	16.20 *a*	6.10 *b*	26.57 *b*	23.00 *a*
11 days (2nd turning)	68.00 *b*	425.30 *bc*	8.10 *c*	3.40 *b*	16.50 *a*	5.40 *bc*	23.13 *c*	20.00 *a*
14 days (matured compost)	66.00 *b*	410.23 *c*	7.30 *d*	4.97 *a*	17.40 *a*	4.70 *c*	16.15 *d*	14.00 *a*
SEm±	1.19	4.96	0.15	0.12	0.69	0.30	0.77	12.25
CD (*pd"*0.05)	3.88	16.18	0.48	0.39	2.27	0.96	2.52	39.96
CV	3.00	2.00	3.00	6.10	7.90	6.30	5.40	119.60

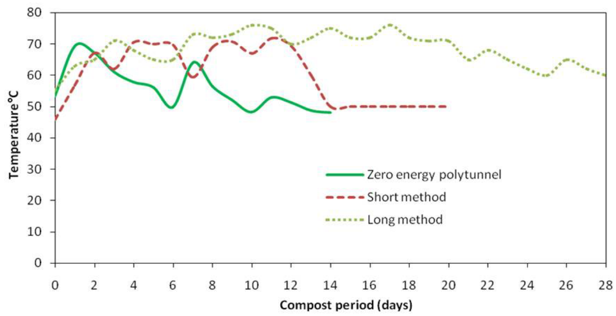

Fig. 2. Comparison of temperature patterns, zero energy polytunnel, short and long methods

stabilized 50–55 °C for next four-days. The pile was turned when temperature gone below 50° C on sixth day. The temperature again started to increase rapidly upto 64°C and same patteren was observed after second turning till get 45–48°C conditioning temperature. Whereas, in a long method, substrate temperature increased slowly and touched its highest level of 76°C in 9–11th days, stabilized at 70–75°C for 10–19 days and subsequently decreased up to 60°C during composting. Almost similar temperature profile was obtained for short method of composting for 12 days (phase-I) and thereafter composted substrate was shifted for pasteurization (58°C for 6–8 h) and conditioning (45-47°C for 7–8 days) in a phase II tunnel. The desirable temperature range of 47–62°C, as indicator of completion of composting process was achieved after 14, 18 and 28 days in zero energy polytunnel, short and long methods, respectively. Thus the perforated HDPE pipes in zero energy polytunnel mainly altered the temperature pattern of substrate in comparison to other methods. This variation in temperature pattern was mainly due to numbers of perforations on HDPE pipes, which facilitated better aeration needed to enhance the colonization of thermophilic microbes.

Fig. 3 showed that total compost produced was about 3.3–3.5 times of basic ingredients in zero energy polytunnel method. The total compost volume reduction was about 24% with maximum reduction during first turning as against 30–40% volume reduction reported in short and long methods (Vijay, 2011). In the form of numbers of manual turning, compost was matured within two-three turning as compared to the long method (six-eight turning) and short method (three turning). Thus passive aeration zero energy composting method helped to reduce 50–60% laborious turning and almost 50% time as compared to long method of compost. Similarly, as compared to short method, it helped to reduce around 40% time and additional tunnel cost. Overall, zero energy low cost tunnels with 10% pipe perforations was found better in term of early maturity of compost. The cost of compost production with use of zero energy tunnels was only Rs. 1.75/ kg as against the Rs. 3.30/ kg for short and Rs. 2.69/kg for long methods. The main benefit of zero energy polytunnel method/technique was that it reduces 50% and 37% compost production cost as compared to short and long methods.

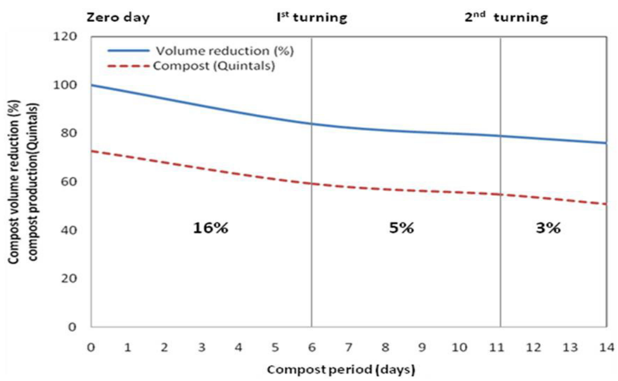

Fig. 3. Compost production and percentage compost volume reduction for zero energy polytunnel

For the both button mushroom strains i.e. S–11 and U–3, highest average yield i.e. 27% and 22% respectively, were recorded for the compost prepared from zero energy polytunnel, which was much higher than that of short method (18-20%) and long method (12–14%). Statistical analysis showed the significant differences in yield for both strains of mushrooms for compost prepared from zero energy polytunnel (Table 5). The highest yield reported in passively aerated zero energy polytunnel may due to uniform and sufficient

Table 5. Comparison of *Agaricus bisporus* yields

Mushroom strains	Zero energy polytunnel method	Short method	Long method
U-3	22.33 b	18.82 a	12.57 a
S-11	27.55 a	19.98 a	14.07 a
SEm±	0.882713	1.43339	0.68592
CD (*pd*"0.05)	3.47	5.63	2.69
CV	6.10	12.80	8.90

amount of passive aeration provided for achieving all bioengineering properties of matured compost including ammonia released during composting. Lower yield of U-3 strains may be due to its typical non-uniform fruiting characteristics.

CONCLUSIONS

The design of zero energy polytunnel and quality of matured compost depend on bioengineering properties of the compost ingredients. The heat generated during the composting was used for pasteurization and conditioning. Hence it is energy free process and techniques was named as zero energy polytunnel. The method increases compost production significantly and improves quality and yield of button mushroom. Also the natural and environment friendly zero energy polytunnel composting process reduces cost, time and energy significantly as compared to existing long and short composting methods.

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