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An improved rapid composting procedure enhance the substrate quality and yield of *Agaricus bisporus*

G. C. Wakchaure[1]*, Kamlesh K. Meena[1], R. L. Choudhary[1], Manjit Singh[2] and Mahesh S. Yandigeri[3]

[1]National Institute of Abiotic Stress Management, Indian Council of Agricultural Research, Baramati, Pune, Maharashtra 413115, India.
[2]Directorate of Mushroom Research, Indian Council of Agricultural Research, Solan, Himachal Pradesh 173213, India.
[3]National Bureau of Agriculturally Important Insects, Indian Council of Agricultural Research, Hebbal, Bangalore, Karnataka 560024, India.

The effect of passive aeration on substrate quality, composting period and yield was studied using different perforated high-density polyethylene (HDPE) pipes arrangements, as a composting method for substrate preparation to *Agaricus bisporus* cultivation. The ingredients are, mixture of wheat straw (60%), wheat bran (5.5%), chicken manure (31%), urea (0.5%) and gypsum (3%) with initial moisture (75%) used for composting. It was demonstrated that passive aeration is the key parameter controlling composting process, shortened the compost period, enhance the substrate quality and *Agaricus* yield as of pile composting. The substrate physico-chemical characteristics that is, moisture content, temperature pattern, bulk density, pH, electric conductivity, C: N ratio and thermophilic fungi activity varied significantly with composting period. The parallel arrangement (10% perforations) was found best among all the passive aeration treatments for achieving the quality substrate in shortest composting period of 16 day and enhance the *A. bisporus* yield up to 27.6%. This study also opens possibility to cultivate *A. bisporus* on a lingo-cellulosic, non-pasteurized, non-conditioned, aerated substrate and that composting for 16 days improve the mushroom yield with minimum energy, labor and infrastructure.

Key words: *Agaricus bisporus*, physico-chemical characteristics, composting, high-density polyethylene (HDPE) pipe, passive aeration, thermophilic fungi.

INTRODUCTION

Commercial cultivation of *Agaricus bisporus* is highly scientific and engineering activities necessitates well composted substrate for its growth (Harper et al., 1992; Sanchez et al., 2008). The solid state fermentation and microbial decomposition of organic/inorganic wastes are the key processes involved in preparation of the composted substrate (Pandey et al., 2004; Van Lier et al., 1994). At present, long (pile) and short (phase I and II

bunker) methods of composting remained vague in India for *A. bisporus* cultivation. The pile composting (Sinden and Hauser, 1953), first known method requires 4 to 6 weeks to complete the process in 7 to 8 turnings irrespective to the different proportion of ingredients used (Suman and Sharma, 2007). But it has disadvantages of not maintaining efficient temperature or moisture control and of requiring manpower to oxygenate the pile

*Corresponding author. E-mail: goraksha.wakchaure@gmail.com. Tel: + 91-2112-254057. Fax: +91-2112-254056.

(Hernandez et al., 2003). The short method involved 10 to 15 days outdoor aerobic composting (phase I) followed by indoor pasteurization (57°C for 6 to 8 h) and conditioning (45°C for 7 to 8 days) inside an insulated bunker (phase II) (Beyer, 2005; Sinden and Hauser, 1950, 1953). In phase II, ammonia is reduced to levels that are non-toxic to *A. bisporus*. The boiler for pasteurization and blower for conditioning of compost in two-phase short method are the energy consuming operations with the additional bunker cost. Thus, both 28 to 30 days pile and 18 to 20 days two-phase short methods are highly laborious, energy and time intensive activities. As per growers demand, other alternative non-composted methods (Garcia et al., 2005; Sanchez et al., 2002), and complete composted indoor methods (Gerrits et al., 1993; Laborde, 1991) have been developed based on forced ventilation for rapid substrate preparation without offensive odor generation during composting. These methods studied successfully and employed in profitable *A. bisporus* farming in developed countries (Sanchez et al., 2008). However, the major disadvantages of these methods are the use of costly ingredients, infrastructure for example tunnel, and high energy requirement for maintaining higher temperatures to pasteurize the substrate. As a result, these methods were not found commercially economical for small scale growers across the world including 80 to 90% of Indian seasonal mushroom growers which uses pile method for composting. It is possible to produce *A. bisporus* on non composted substrate using passive aeration during composting. Also, aeration helps to maintain the appropriate conditions of compost viz., CO_2/O_2 levels, temperature, pH, moisture content required for ideal thermophilic microorganisms growth.

Previous studies reveal that the temperature was a good indicator for microbial activities, influenced by moisture content and oxygen availability in the compost pile (Chang and Hudson, 1967; Collins, 2009; Parati et al., 2011). The compost ingredients vary widely in their characteristics, which causes variation in composted substrate physico-chemical characteristics. Hence, various studies have been conducted to access the impact of composted substrate characteristics on quality and yield of *A. bisporus*. For instance, a significant relationship between the moisture content, organic matters and mushroom yield was reported (Sanchez et al., 2008). Compost as compressible material exhibits both elastic and plastic behavior causes variation in bulk densities and porosity due to occurrence of subsidence during composting with respect to height and time (Randle and Flegg, 1985). The C: N ratio of 33:1 during fermentation, 18:1 during mycelial growth and 14:1 during fruitification has standardized to produce quality mushroom with desired yield (Zheng et al., 1995). The pH of compost has found to be 9 during phase I of composting due to rise in ammonia level and reduced to 7.2 at the end of phase II due to fall in ammonia

concentration (Savoie et al., 1995). In research for improvement of substrate preparation methods for *A. bisporus* including pile composting, several researchers have studied the influence of passive/forced ventilation on composted substrate quality mainly for shortening the composting cycle, control the compost process and achieve a further homogenous substrate (Schaub and Leonard, 1996; Yue et al., 2008). Most of these studies have reported positive impact of ventilation on quality of compost and mushroom yield. But the exact effects of passive aeration in pile composting on compost physico-chemical characteristics, composting period and mushroom yield is still unclear.

In this study influence of passive aeration on composted substrate quality in terms of physico-chemical characteristics and composting period was investigated to enhance the *A. bisporus* yield using perforated HDPE pipes. This work also steps towards the development of a reliable environment friendly low cost, short duration, natural pasteurization, and outdoor composting technique based on self-heating of thermophilic fungi to improve the profitability of mushroom farming.

MATERIALS AND METHODS

### Ingredients collection and characterization

Wheat straw (60%), chicken manure (31%), wheat bran (5.5%), urea (0.5%) and gypsum (3%) used for composting were collected from the local market, agricultural and poultry farms, Solan, India. The characteristics of these ingredients like average particle size, moisture content, bulk density and porosity, EC and pH were measured using standard methods that is, screen analysis, air oven at 60°C for 6 to 8 h, mass volume cylinder method, glass electrode pH meter and conductivity bridge, respectively. The values of basic compost ingredients characteristics are presented in the Table 1.

Perforated pipe material, treatments and compost processing

The high heat resistance HDPE pipe material (0.15 m diameter, 0.01 m thickness) was selected which could withstand during composting at 70 to 80°C. Sixty eight holes of 0.03 m diameter per meter length were drilled in staggered manner on pipe peripheral surface at uniform spacing of 0.08 m. This has maintained the 10% perforations of the total pipe peripheral surface area to provide aeration by natural convection. The total four treatments were designed as follows: In triangular arrangement, three perforated HDPE pipes each of 6.1 m length were adjusted in equilateral triangle of 1 m sides in such a way that base of triangle was parallel to the compost yard platform at 0.3 m distance shown in Figure 1A. This was designated T1. For pile composting method, a separate pile was made as a control (T2). In design of parallel arrangement, three perforated HDPE pipes each of length 6.1 m were adjusted longitudinally parallel one above the other at 0.45 m equidistance and maintained 0.3 m distance between bottom pipe and compost yard platform (Figure 1B). This was designated T3. The design of perpendicular arrangement consist of four perforated vertical HDPE pipes of 1.5 m height connected at bottom by five 1.5 m length horizontal perforated HDPE pipes at 0.3 m distance above the compost yard platform (Figure 1C). This was designated T4. Total

Table 1. Characteristics of basic ingredients used for composting.

Ingredients	M.C.% (wb)	Bulk density (kg.m^{-3})	Porosity (%)	pH	E.C. (dS m^{-1})	Particle size (mm)
Wheat straw	13.5	100.5	75.5	6.40	3.9	0.5-30.0
Wheat bran	9.9	344.5	71.5	6.14	2.0	0.5
Urea	-	714.3	46.6	8.32	0.6	0.75
Gypsum	3.4	782.7	66.1	8.01	5.5	0.02
Chicken manure	26.7	513.9	60.3	8.28	9.8	0.67
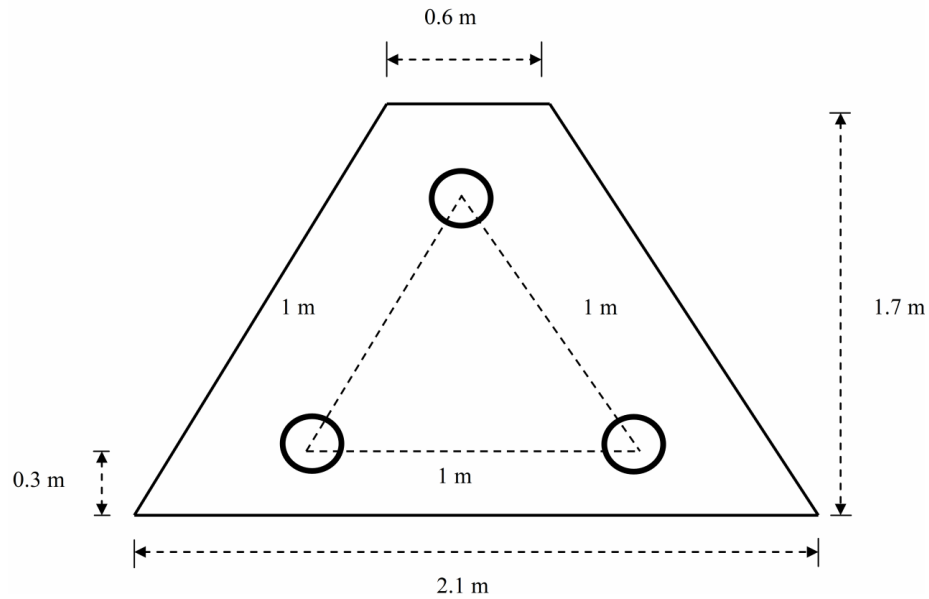
Figure 1A. Triangular arrangement of perforated HDPE pipe in the compost pile.
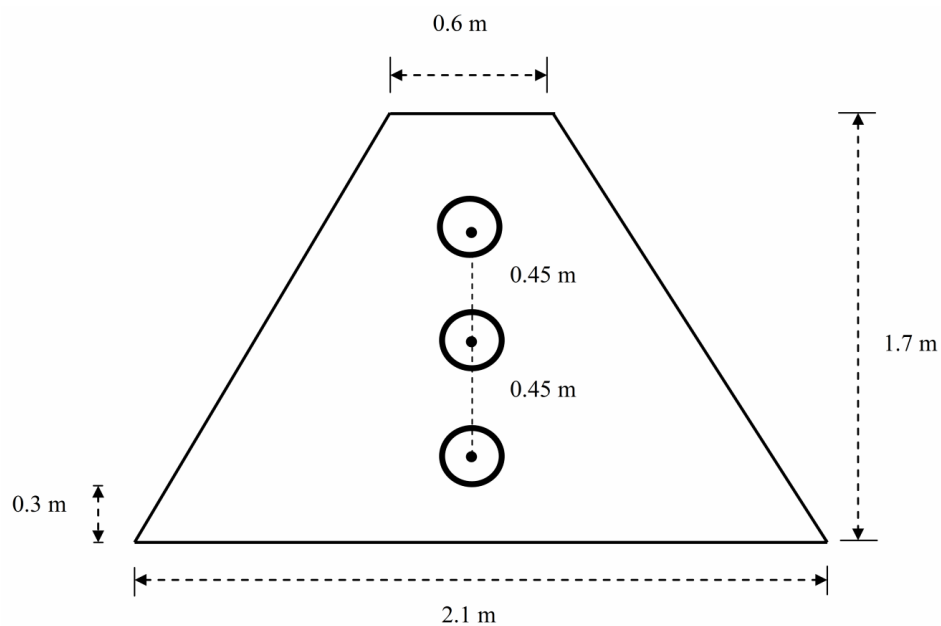
Figure 1B. Parallel arrangement of perforated HDPE pipe in the compost pile.
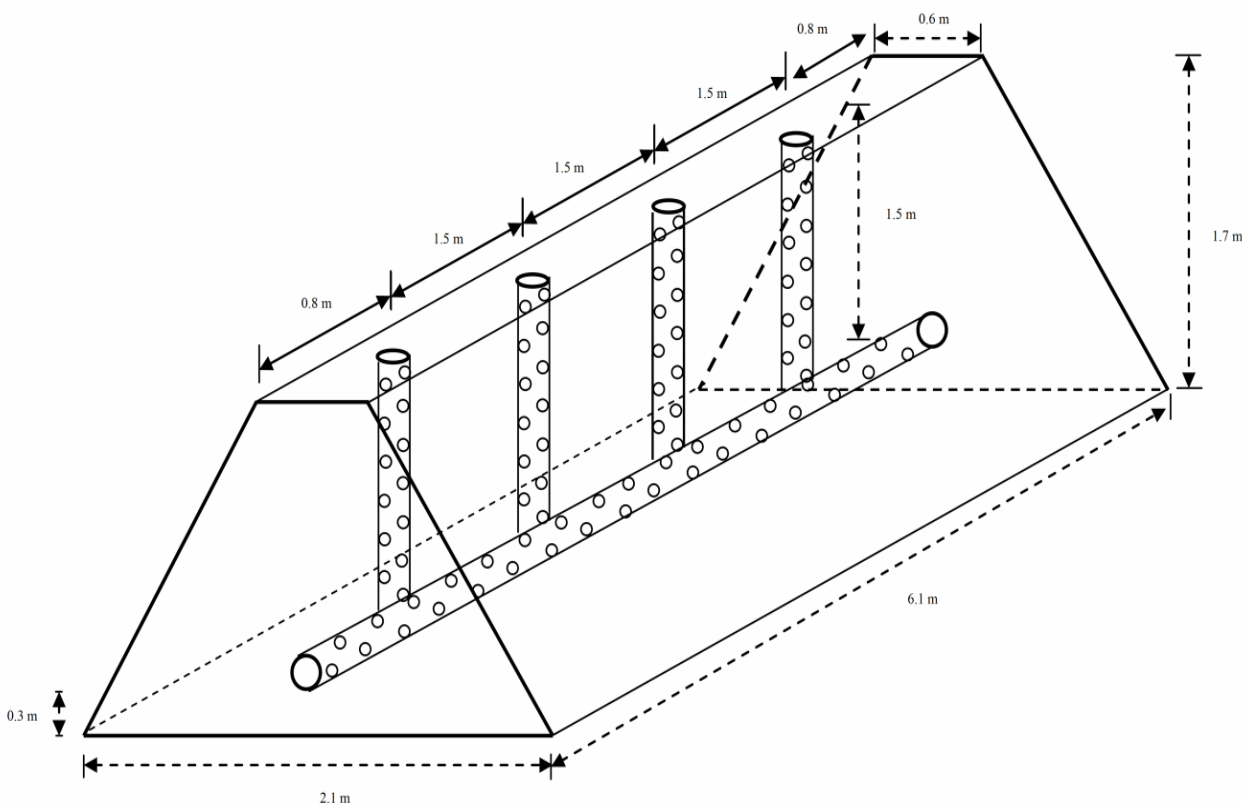
Figure 1C. Perpendicular arrangement of perforated HDPE pipe in the compost pile.

2000 kg of ingredients per pile in each treatment were used, based on designed dimension of HDPE pipe arrangements. The thoroughly mixed compost ingredients naturally exhibit the trapezoidal shape. Thus, four trapezoidal shape compost piles of size 6.10 m length as its of pipe length, 1.7 m height, 2.1 m bottom width and 0.6 m top width were made simultaneously separately. For making each compost pile, 1200 kg (60% of ingredients) of wheat straw, pre-wetted with water properly for 1 to 2 days was used to adjust 75 to 80% moisture content. Thereafter various ingredients like wheat bran (5.5%), chicken manure (31%) and urea (0.5%) were mixed thoroughly. The three designed HDPE pipe arrangements T1, T3 and T4 were inserted simultaneously inside the three separate compost piles. For pile method, separate pile without pipes was kept as control (T2) for comparison. Thereafter, every fourth day all treatments piles turned manually and turning was repeated till matured compost was gotten for *A. bisporus* spawn colonization. The pH of substrate was controlled by adding 3% gypsum during second turning for all treatments piles. At the time of composting, the environmental conditions were 28 ± 2°C and 65 to 85% relative humidity. Effect of the composting period with four days turning intervals on substrate physico-chemical characteristics also studied.

Sampling and physico-chemical characteristics of substrate

During every turning, three different samples of 250 g substrate were randomly taken from the center of each pile of all treatments. The substrate physico-chemical characteristics like moisture content, bulk density, pH, EC, C: N ratio and thermophilic fungi were measured.

Temperature, moisture content, bulk density, pH and EC

The temperature at three different sites (bottom, center and top) of the each compost pile were measured using probe thermometer (Model: International 5010122 K6) once a day during the composting process to calculate the average temperature. A 25 g substrate samples were used to measure moisture content (wb) using standard protocol given by Horotwitz (2000). The box method (0.25 × 0.25 × 0.25 m) was used for composted substrate bulk density analysis by dividing substrate mass to its volume. The pH and EC were measured in 1:10 compost water suspension using glass electrode pH meter and Conductivity Bridge (Williams, 1984).

C: N ratio

For C : N ratio analysis, substrate dried in hot air oven at 60°C for 6 to 8 h and ground in a willy mill using stainless steel grinder and stored in labeled containers. The amount of carbon and nitrogen available in composted substrate were determined using muffle furnace method of Horotwitz (1980) and rapid titration methods given by Humphrises (1956), respectively. The percentage ratio of carbon and nitrogen was used to calculate C : N ratio of composted substrate.

Thermophilic fungi population count

The population of thermophilic fungi was counted at every four days interval (piles turning) during the composting process. Serial dilution method of Cooney and Emerson (1964) was used for the isolation
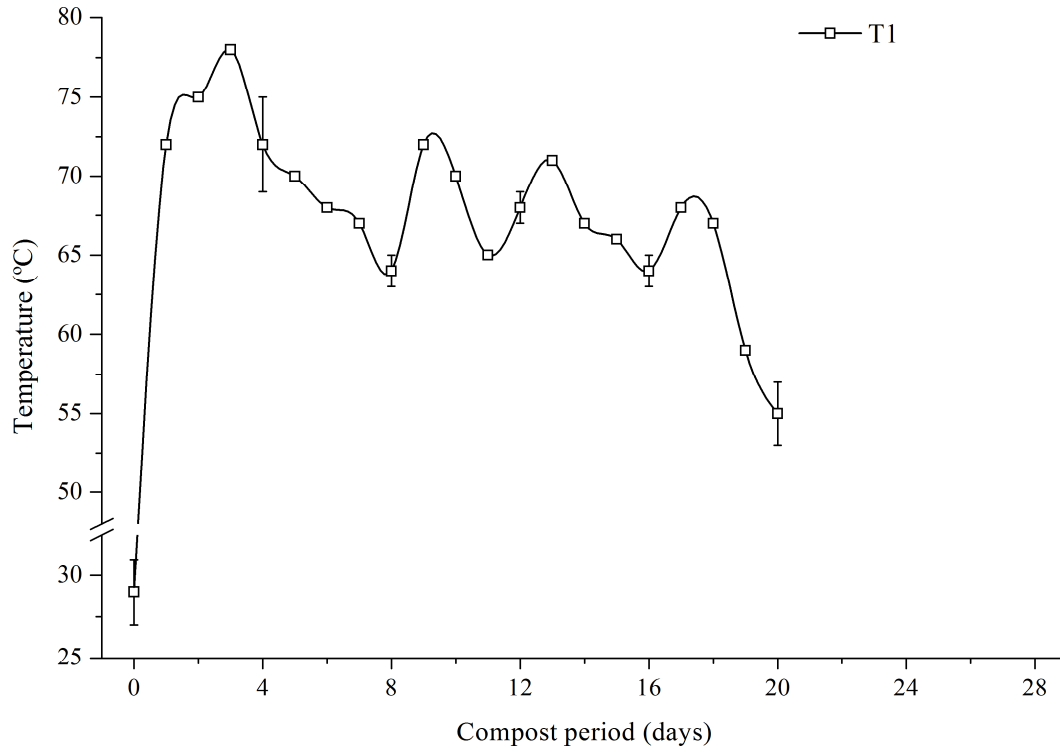
Figure 2A. Temperature pattern during composting process for T1.

of thermophilic fungi on yeast starch agar (YSA) medium. Rose Bengal and streptomycin each at the rate of 50 mg ml^{-1} were added as antibacterial agent. The inoculated plates were incubated at 47°C for a week. The total and mean fungal population was calculated as colony forming units (CFU) per gram of composted substrate. The fungal isolates were identified by ITS amplification using universal primers.

Measurement of gases

As a maturity indicator and completion of composting process the quantity (ppm) of gases *viz.,* ammonia, oxygen and carbon-dioxide present in the composted substrate were measured. Ammonia detection tube (Model: Gastec, Japan) was used to quantify the ammonia whereas the oxygen and carbon dioxide were measured using the portable O_2/CO_2 meter (Model: PBI Dan sensor, Checkpoint II).

Cultivation and yield

Two *A. bisporus* mushroom strains S-11 and U-3 obtained from Directorate of Mushroom Research, Solan, were cultivated in seasonal bamboo hut covered with paddy straw in three bed replications. The 500 kg substrate samples were cooled to ambient temperature, inoculated with 1% wheat grain spawn and spread uniformly in bamboo beds each of size 15 × 1.2 × 0.075 m. The polyethylene sheet was used to maintain the incubation temperature 22 ± 3°C required for better colonization for the period of 8 to 12 days. After incubation, the uncovered beds were roofed with 0.025 m casing material (1:0.6:0.4, spent mushroom substrate: cow dung: rice husk fly ash). The favorable conditions required for

A. bisporus fruiting like temperature (18 ± 2°C) and relative humidity (85 to 90%) were maintained. The yield (biological efficiency) was recorded as percentage of the fresh weight obtained during first three harvests over wet weight of the composted substrate used.

Statistical analysis

The study was replicated thrice with four main treatments (composting arrangements) and average value for each compost parameter measured during composting used for 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 ≤ 0.05) and standard error of means (SEM) were tabulated. Mean separations were calculated based on the mean rankings at P ≤ 0.05 using Duncan`s Multiple Range Test.

RESULTS AND DISCUSSION

Compost temperature profile

The variation in temperature profile obtained during composting started at ambient temperature (28 ± 2°C) in each treatment is shown in Figure 2A to D. In general, highest average temperature 65 to 72°C obtained during initial stage were decreased upto 52 to 60°C at the end of composting in all four treatments. Statistical analysis showed the significant differences between the treatments
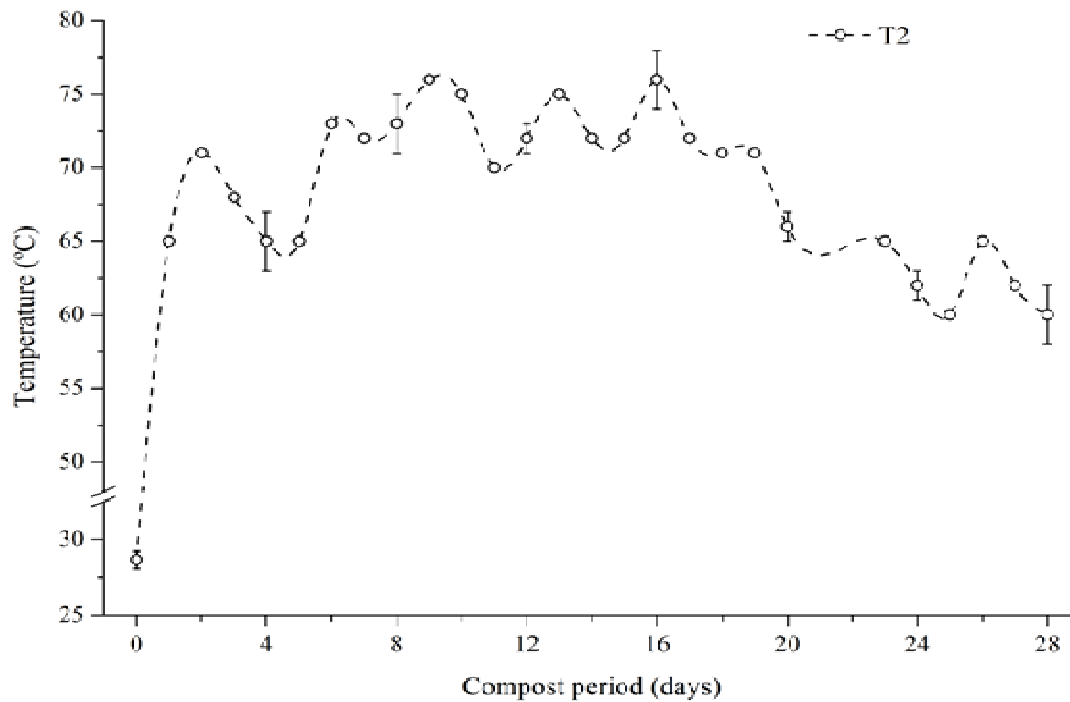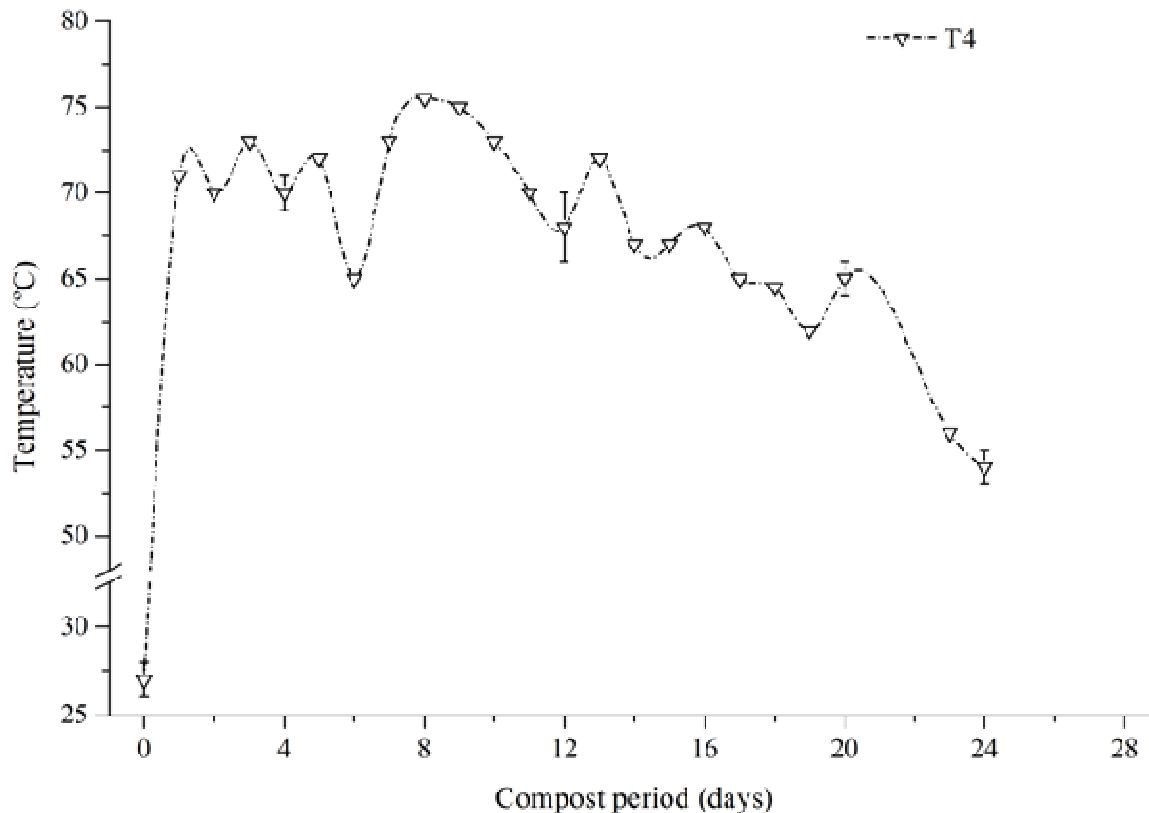
Figure 2B. Temperature pattern during composting process for T2.
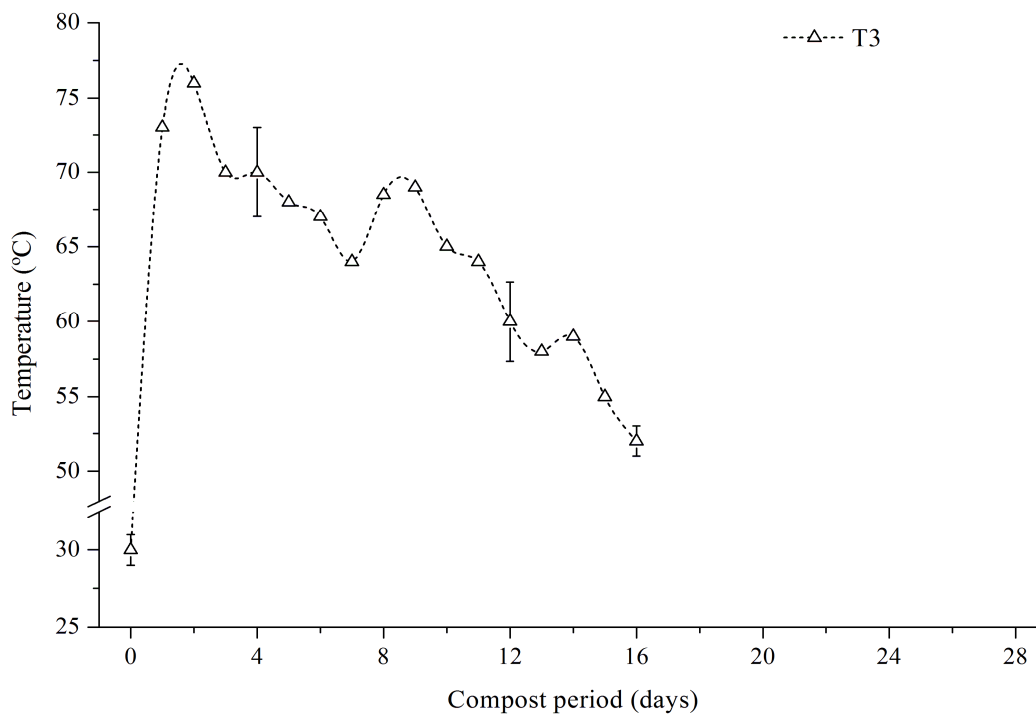
Figure 2C. Temperature pattern during composting process for T3.

and compost period (P ≤ 0.05). In treatments T1, T3 and T4 the highest substrate temperature 71 to 78°C

increased rapidly within initial two-three days, stabilized 64 to 75°C for four days and then decreased rapidly upto

**Figure 2D.** Temperature pattern during composting process for T4.

52°C at end of composting rather depending on the passive aeration. Whereas in T2, temperature increased slowly of its highest level 76°C in nine days. Thereafter, temperature stabilized at 70 to 75°C for 10 to 19 days and decreased gradually up to 60°C at end of composting. Also noteworthy is that in all treatments, temperature increased slightly (2 to 5°C) for two days immediately after each turning despite of normal declining temperature gradient. The desirable temperature range of 47 to 62°C, as indicator for completion of composting process was achieved after 20, 28, 16 and 24 days in T1, T2, T3 and T4, respectively. The highest temperature reduction (25.7%) achieved for T3 in shortest period (16 days) and found better to accomplish the early maturity of compost due to its optimum design specifications (0.45 m pipe spacing and 10% perforated area).

The composting using perforated HDPE pipe arrangements mainly altered the temperature pattern in comparison to the pile method. This variation in temperature pattern was mainly due to perforated HDPE pipes (10% peripheral perforations) facilitated better aeration needed to enhance the colonization of thermophilic microbes during composting. Also the highest temperature in aerated composting at initial stage have a physical effect on straw tending to soften straw

structure, reduces the surface tension and makes straw easier to wet. Besides, the higher temperature favoring the efficient thermophilic microbial metabolism as result of it more nutrients released by accelerating the various enzymatic and non-enzymatic reactions (Saini, 2008). Similarly, mixing of substrate during the each turning was determining factor to raise temperature of substrates exposed to the additional atmospheric ventilation. These results are in agreement with the previous studies denoting the impact of aeration for changing temperature profile during composting (Hernandez et al., 2003).

Moisture content

The change in substrate moisture content for each treatment during composting is shown in Figure 3. In treatments T1, T2, T3 and T4 the initial moisture of 75 ± 1% (wb) decreased to desired level of 64 to 67% (wb) for spawn colonization after 20, 28, 16 and 24 days, respectively. The faster desired moisture level achieved in passive aeration treatments might be due to higher evaporation rate maintained in aerated composting process. Statistical analysis revealed significant differences in moisture contents between the treatments and compost period (P ≤ 0.05). The highest linear
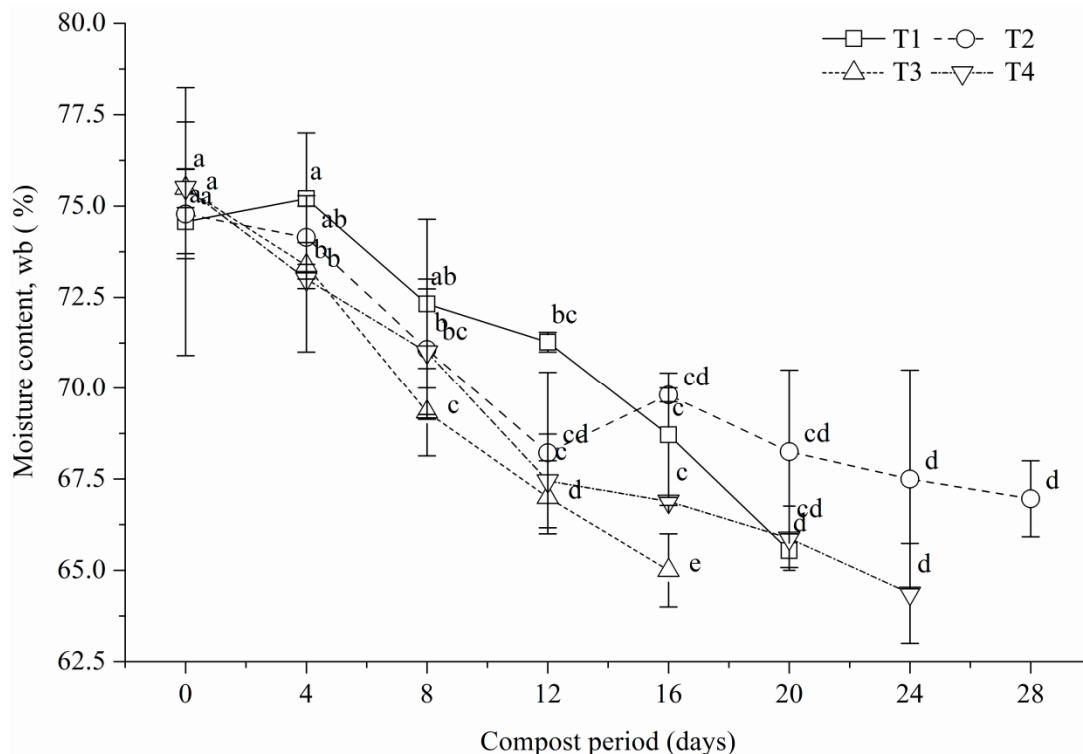
Figure 3. Variations in moisture contents during composting.

decreased in moisture content of 0.8% daily was reported for T3 (Y = − 2.566x + 77.57; r² = 0.978). The uniform spacing 0.45 m between the perforated HDPE pipes (10% perforations) for T3 accelerates upward convectional air movement through substrate resulted the rapid evaporation of moisture content. Indeed, passive aeration benefits to reduce substrates anaerobic condition for early maturity by maintaining appropriate moisture/air composition in a composting process. These results correlated with previous reports, the optimum moisture content of compost at time of spawning prepared from various substrates viz., wheat straw, paddy straw or in combination of different ingredients was found to 59 to 68% for enhancing the mushroom yield (Kaur and Khanna, 2001). Moreover, it is reported that high moisture content (> 70%) in the decomposed compost tends to reduce the mushroom yield (Cormican and Staunton, 1991).

Bulk density

In general, for all treatments the initial average substrate bulk density 416 kg m^{-3} decreased up to 4 days, increased slightly after second turning (on 8 days) and again decreased to optimal maturity level 342-362 kg m^{-3} at the end of composting process (Figure 4). Statistical analysis revealed significant differences between substrate bulk density (P ≤ 0.05) and compost period (P ≤ 0.05), and in their interaction (P ≤ 0.05). The total 15 to 16% reduction in substrate bulk density recorded after second turning for treatment T1, T3 and T2 (control). However, slightly higher reduction of 18% in substrate bulk density was noted for T3. It means no additional losses in mass of composted substrate prepared using passive aeration in pile composting. But an optimized amount of air supplied through perforated HDPE pipes was essential to accelerate the composting process and shortened the compost period. The highest bulk densities values 419.0 to 427.3 kg m^{-3} were reported between second-third turning (8 to 12 days) for all treatments. It was probably addition of high-density (788.7 kg m^{-3}) gypsum powder during second turning for lowering the compost pH to neutral. An overall use of perforated HDPE pipes for passive aeration possibly altered the substrate bulk density patterns. The loss of moisture content caused by evaporation and release of ammonia due to decomposition of substrate during composting leads to decrease in bulk densities values with respect to compost period (Hernandez et al., 2003).
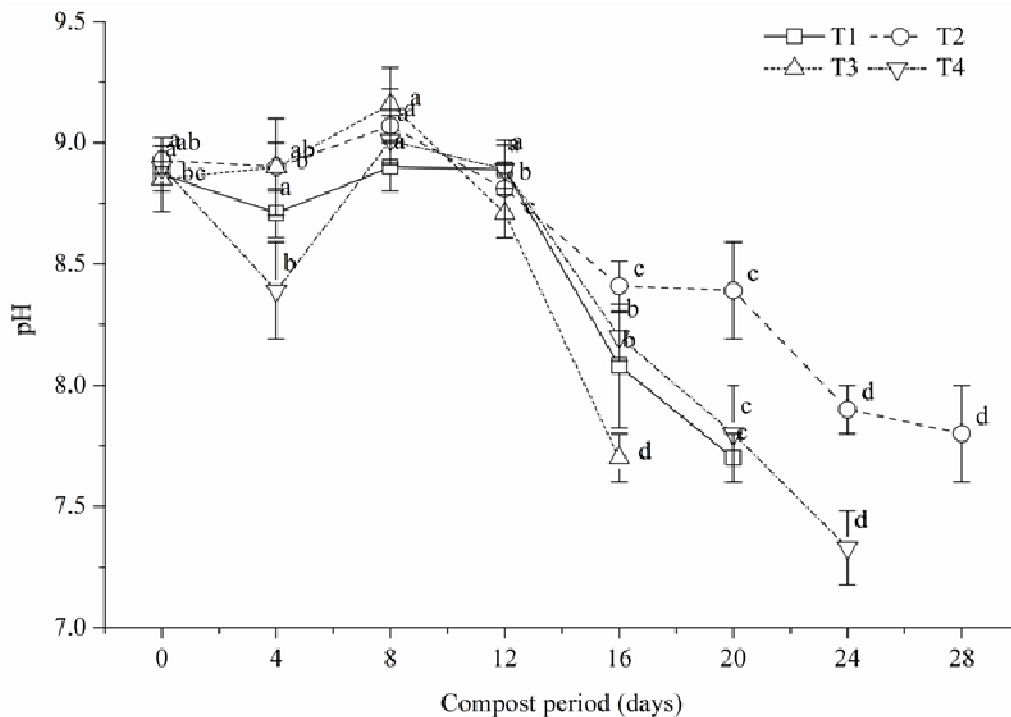
pH and electric conductivity (EC)

The pH and EC are the temperature sensitive properties varied with temperature during the composting. In
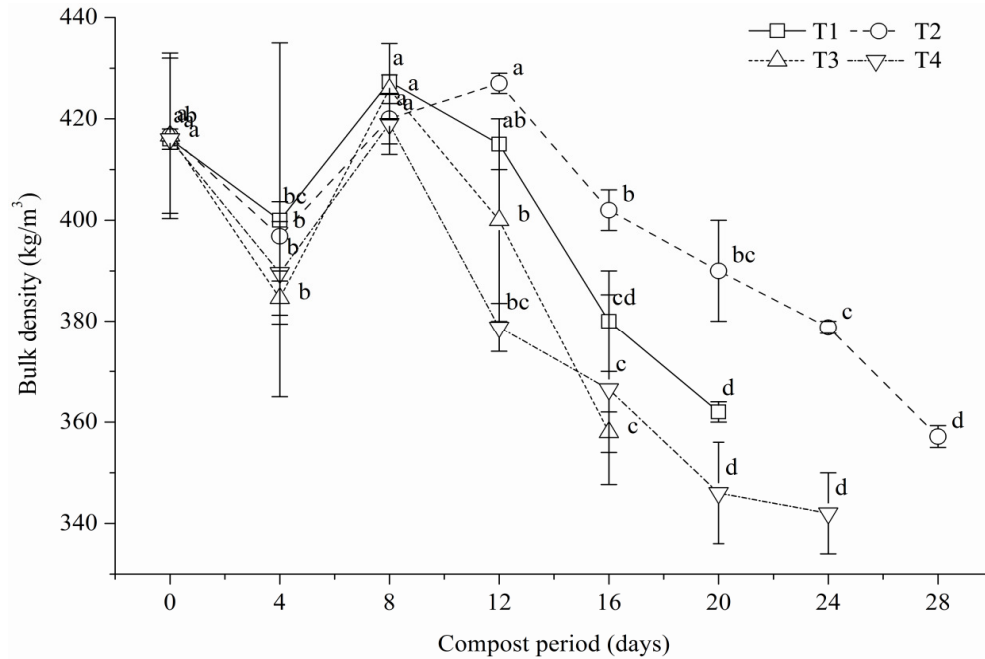
Figure 4. Variations in bulk density pattern during composting.

Figure 5A. Profiling of pH during composting process.

general, for all the treatments the substrate pH increased with temperatures and reverse trend was obtained for EC of the substrate (Figure 5A and B). The initial substrate pH 8.9 ± 0.1 at zero days decreased slightly up to 4th day; rise slowly to 8.9 to 9.2 on 8th day (second turning) and decreased suddenly towards neutral level 7.3 to 7.8 for all treatment piles at the end of composting period. The decreasing trend in pH was almost similar to
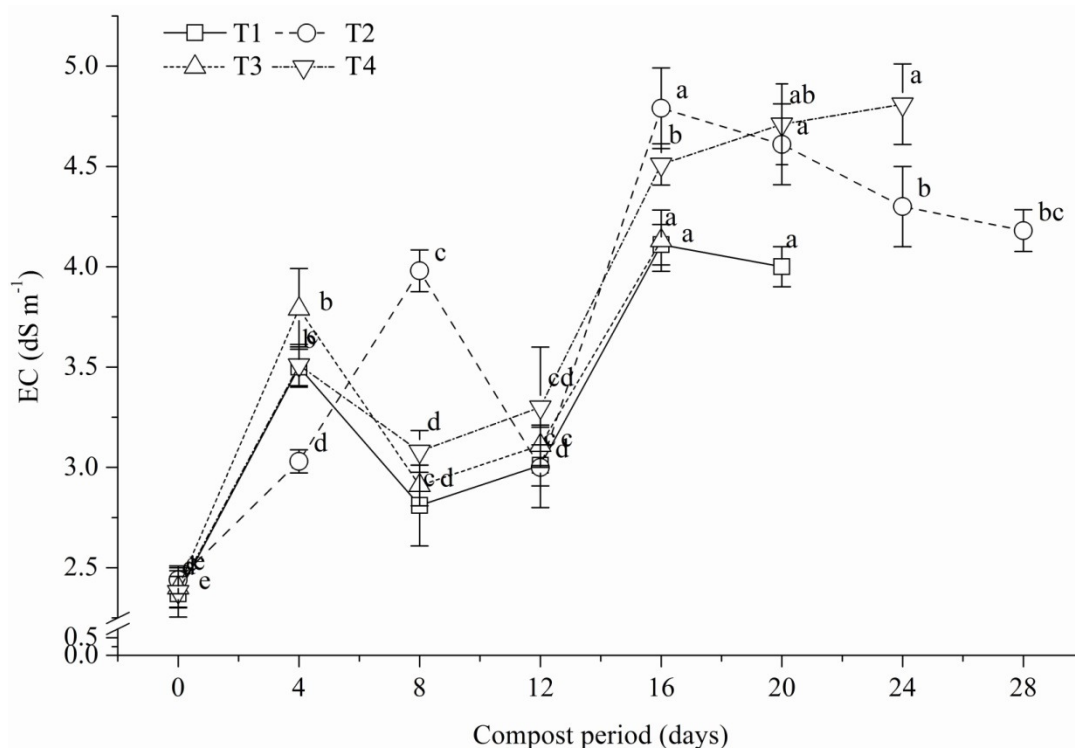
Figure 5B. Change in EC values during composting process.

temperature profile for all treatment piles. However, for all the treatments initial substrate EC values 2.4 dS m^{-1} were increased up to 4.1 to 4.8 dS m^{-1} at the end of composting process. The desirable values of composted substrate pH 7.7 and EC 4.1 dS m^{-1} for mushroom mycelium growth were achieved in shortest period of 16 days in T3 and found better over the other passive aeration treatments (T1, T4) and control (T2). Significant differences were observed between the various treatments (P ≤ 0.05), with compost period. The rise in pH values at the initial stage is due to ammonia released and increased the substrate temperature by efficient thermophilic microbial metabolism (Labance et al., 2006). Also reduction in pH after eight days in each treatment was reported due to addition of gypsum (2 to 3%) in second turning. However, in aerated treatments the substrate pH declined rapidly as compared to control. Overall, the passive aeration altered the substrate pH patterns during composting process and helped to reduce the composting period. However, substrate EC value unaffected by addition of gypsum rather it was increased continuously in composting period.

C: N ratio versus compost period

The initial substrate C:N ratio 34 ± 0.3:1 decreased to maturity level of 16.15:1 to 18.70:1 during composting for

all the treatments (Figure 6). Significant difference was reported between substrate C: N ratio (P ≤ 0.05) and compost period (P ≤ 0.05), and their interaction (P ≤ 0.05) for all treatments. The decrease C: N ratio during composting was due to loss of organic carbon contents and corresponding relative increase in nitrogen contents. The substrate decomposition as reflected by loss of carbon contents varied from 21 to 48% to get matured compost for all treatments piles. The corresponding increase in nitrogen levels was ranged from 1.3 to 1.5%. The C: N ratio reduced rapidly 2.0 to 3.3% daily for passive treatments during composting in shortest duration (16 to 24 days) over the control, 1.3% (28 days). This was possibly due to sufficient amount of aeration provided in passive aeration treatments (rather depends on perforated HDPE pipe arrangements used) to accelerate the compost decomposition process caused by thermophilic fungi. The decline in C: N ratios correlated with the previous report of Fermor et al. (1985).

Compost thermophilic fungi

The population of thermophilic fungi monitored at the set interval of time during the composting. The thermophiles population increased up to 8 days of composting with highest mean population (23 × 10^4 CFU g^{-1}) in T3 and
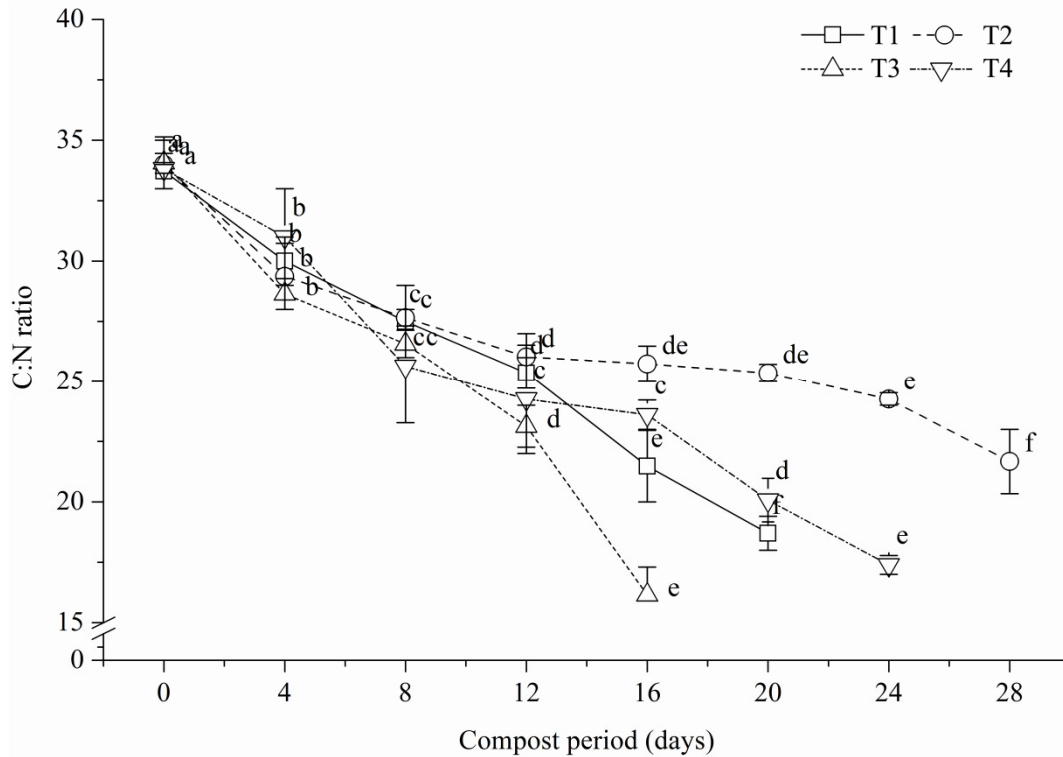
Figure 6. Analysis of C: N ratio during composting process.

thereafter decreased slightly for all the treatments (Table 2). A positive correlation between the thermophiles population and amount of air supplied was recorded in all the passive aeration treatments. Due to better aeration, the thermophiles population showed increasing trends that helped to fasten the degradation and reduced the compost period of 16, 20, 24 days in T3, T1, T4 over the control, T2 (28 days). In conclusion the availability of sufficient air provided in passive aeration treatments creates favorable growth condition to thermophilic fungi. The *Scytalidium thermophilium* and *Thermomyces lanuginosus* identified *as a* dominant groups in all compost piles (Table 2). The similar types of thermophilic fungi responsible for compost faster degradation are also noted in previous reports of Sharma et al. (2009).

Compost gas analysis

The appropriate concentrations of ammonia (NH_3), oxygen (O_2) and carbon dioxide (CO_2) present in the matured compost played vital role for enhancing the *Agaricus* yields. The desired levels of ammonia (NH_3), oxygen (O_2) and carbon dioxide (CO_2) that is, 2 to 7 ppm, 14.4 to 17.9% and 5.3 to 8.6% were reported in 20, 28, 16 and 24 days for treatments T1, T2, T3 and T4, respectively. These gases levels achieved comparatively faster in parallel pipe arrangement (T3) in shortest

compost period of 16 days than other treatments as of sufficient passive aeration. This result has also supported previous studies on composting for *A. bisporus* cultivation (Suman and Sharma, 2007; Vijay, 2010).

Agaricus yield and substrate comparison with pile method

The yield of *A. bisporus strains* S-11 and U-3 obtained in three harvests for substrates matured under different composting periods (16 to 28 days) are presented in Table 3. The yields varied between 8.2 to 27.6% with composting period for different treatments, irrespective to strains evaluated. The highest average yields 27.6% (S-11) and 21.0% (U-3) reported for T3 (with substrate matured in 16 days), found superior than previously reported pile composting (10 to 15%) and two phase tunnel (18 to 22%) methods (Dhar, 1996). This was possibly due to uniform and sufficient amount passive aeration provided during composting, which could be helped for achieving desired quality of matured substrate in terms of physicochemical characteristics. The lowest average *Agaricus* yields 16.4% (S-11) and 13.8% (U-3) were recorded for matured substrate prepared from T4 due to inadequate substrate mixing during composting. Related results were noted in previous reports; as a lack of ventilation during composting causes an inadequate

Table 2. Colonization of the thermophilic fungus under different treatment during composting.

Compost period (days)	Treatments	Total (CFU.g^{-1} × 10^4)^a	Mean (CFU. g^{-1}x 10^4) ± SD^b	Representation of different Thermophilc species
0	T1	32	10.6 ± 2.3	*S. thermophilum* (32)
	T2	10	3.3 ±1.5	*S. thermophilum* (10)
	T3	42	14.0 ± 1.7	*S. thermophilum* (42)
	T4	20	6.6 ±3.5	*S. thermophilum* (20)
4	T1	31	10.3 ±3.5	*S. thermophilum* (31)
	T2	29	9.6 ±2.5	*S. thermophilum* (29)
	T3	45	15.0 ±3.0	*S. thermophilum* (45)
	T4	30	10.0±1.0	*S. thermophilum* (27), *T. lanuginosus*(3)
8	T1	50	16.6 ±3.5	*S. thermophilum* (50)
	T2	35	11.6 ± 1.5	*S. thermophilum* (35)
	T3	69	23.0 ± 1.7	*S. thermophilum* (69)
	T4	37	12.3 ± 2.5	*S. thermophilum* (30), *T. lanuginosus* (7)
12	T1	48	16.0 ± 1.7	*S. thermophilum* (48)
	T2	17	5.6 ± 1.2	*S. thermophilum* (17)
	T3	60	20.0 ± 2.0	*S. thermophilum* (60)
	T4	33	11.0 ± 3.6	*S. thermophilum* (30), *T. lanuginosus* (3)
16	T1	32	10.6 ± 1.2	*S. thermophilum* (32)
	T2	10	3.3 ± 1.5	*S. thermophilum* (10)
	T3	42	14.0 ± 3.6	*S. thermophilum* (42)
	T4	26	8.6 ± 1.5	*S. thermophilum* (24), *T. lanuginosus* (2)
20	T1	29	9.6 ± 2.5	*S. thermophilum* (29)
	T2	12	4.0 ± 1.0	*S. thermophilum* (12)
	T4	27	9.0 ± 2.0	*S. thermophilum* (27)
24	T2	14	4.6 ± 0.6	*S. thermophilum* (14)
	T4	16	5.3 ± 1.5	*S. thermophilum* (16)
28	T2	10	3.3 ± 1.5	*S. thermophilum* (10)

^{a} Mean CFU. g^{-1} = Mean colony forming units per gram; ^{b} SD = Standard deviation.

Table 3. Means of yields (%) and standard deviations of two *Agaricus* strains on compost prepared under different treatments.

Compost period (days)	T1		T2		T3		T4	
	S-11 strain	U-3 strain	S-11 strain	U-3 strain	S-11 strain	U-3 strain	S-11 strain	U-3 strain
16	12.2 ±1.1	11.8 ± 0.7	9.7 ± 1.6	8.7 ± 0.5	27.6 ± 1.0	21.0 ± 1.1	8.5 ± 0.5	8.2 ± 0.5
20	19.8 ± 0.6	17.1 ± 0.1	11.0 ± 1.9	9.5 ± 0.4	-	-	12.5 ± 1.3	11.3 ± 1.5
24	-	-	14.7 ± 0.6	13.2 ± 0.2	-	-	16.4 ± 0.1	13.8 ± 1.3
28	-	-	19.2 ± 1.8	18.7 ± 0.2	-	-	-	

breakdown of the substrate and negatively affects the *Pleurotus ostreatus* yields (Hernandez et al., 2003). Also lower the yield of U–3 strains was due to its typical non-uniform fruiting characteristics. Significant differences

in yields (P ≤ 0.05) for both strains of *A. bisporus* were reported for all passive aeration treatments.

The quality of matured substrate prepared using different passive aerated conditions was almost similar to the pile composting method. However, variations in *Agaricus* yields with substrate prepared under different composting conditions may due to time taken for completing the composting process (16-28 days). As per the data obtained relevant to substrate quality in terms of physico-chemical characteristics, composting period and optimization of passive aeration arrangements, T3 was found best. The shortest maturity period of composted substrate was reported in T3 (16 days) followed by other two passive aerated treatments T1 (20 days) and T4 (24 days). In the form of numbers manual turnings, the substrate was matured within three turnings for pile T3 followed by for pile T1 (4 turnings), T4 (5 turnings) and T2 (6 turnings). An overall, the passive aerated treatment T3 helped to reduce 50% laborious turnings and almost 50% composting period as compared to pile method (T2, control). Similarly, as compared to two phase tunnel method, passive aerated treatment T3 that is,parallel arrangement with 10% perforation helped to reduce around 25% time and additional tunnel cost. However, numbers of turning remained as like in phase-I of two phase tunnel short method of composting.

Conclusions

Use of perforated HDPE pipes (10% perforations) in the compost piles was investigated as an alternative option for pile composting. This procedure of aeration significantly altered the substrate physico-chemical characteristics, shortens the composting period and increases the mushroom yield up to 27.6 % as of pile composting. Overall among the all passive aeration treatments, T3 (parallel arrangement with 10% perforations) was found best for achieving the quality substrate in shortest composting period (16 days) for *A. bisporus* cultivation. The ingredients characteristics including particle size and its distribution; percent ventilated area, HDPE pipe arrangements and environmental conditions during composting also affects the substrate quality. Thus detailed study for optimization of these factors is needed to understand the exact phenomenon for utilization of perforated HDPE pipes for passive aerations.

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