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Composting of incense industrial bamboo waste with and without added organic, inorganic and effective microorganism as a renewable alternative

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Abstract
The present investigation is related to "Influence of organic and inorganic additives on composting of incense bamboo waste". The incense bamboo waste was decomposed by using small quantity of decomposing starter like organic (cow dung and poultry soil), inorganic (nitrogen) and biological additives (*Phanerochaete chrysosporium*). The decomposition rate of incense bamboo waste was more with combination of all additives and it was measured maximum in treatment BW+ 5 kg CD + 2.5 kg PM + 0.2 kg LF (T_{14}).The significantly lowest total organic carbon (27.33%), C:N ratio (17.34) and highest total nitrogen (1.58%), total Phosphorus (0.52%), total potassium (1.16%), total sulphur (0.32%), percent reduction in weight loss (53.72%) was recorded in treatment BW+ 5 kg CD + 2.5 kg PM + 0.2 kg LF (T_{14}). The desirable physico-chemical properties i.e. pH, EC, ash content, bulk density and colour was observed in matured compost of treatments BW+ 5 kg CD + 2.5 kg PM + 0.2 kg LF (T_{14}), BW + 5 kg PM+ 0.2 kg LF (T_9) and BW + 2.5 kg PM + 0.06 kg N + 0.2 kg LF (T_{13}). Whereas limited decomposition was observed in treatment BW (control) (T_1) without any additives. The result suggests that for composting of incense bamboo waste with organic (cow dung and poultry soil) and biological (lignolytic fungi) additives can be a suitable source for recycling incense industrial bamboo waste.

Keywords: Bamboo waste, composting, decomposition, additives

Introduction
Bamboo is an important raw material in the agarbatti industry. It is a fast-growing, widely present, renewable, versatile and a low-cost natural resource, due to which it is aptly known as 'green gold' and 'poor man's timber'. The durability and strength of bamboo are due to the physico-chemical characteristics of bamboo culms, which determine its end uses. Bamboo constitutes around 50% parenchyma, 40% fibers, and 10% vessels and sieve tubes with microscopic structures of the bamboo fibers consisting of cellulose, hemicellulose, lignin and pectin.

Bamboo incense stick production plays a vital role in the rural subsistence economy of the household income basket by providing livelihood and enhancing income levels of women. Indian agarbatti has a high demand both in the local and international markets. India is presently one of the largest producers and exporters of incense sticks with global domination by countries such as the U.S.A., Brazil and China. India's incense stick market is likely to reach ₹ 7500–8000 crore with its exports to more than 150 countries (Varuvel *et. al*., 2021) [51]. In India, bamboo is mostly used in manufacturing of agarbatti wherein, a maximum of 16% i.e. the upper layers of the bamboo, is used for manufacturing of bamboo sticks while the remaining 84% of bamboo is a complete waste. The bamboo waste generated in agarbatti and bamboo craft industries is not being utilized commercially, as a result, the bamboo input cost for round bamboo sticks is in the range of Rs 25,000 to Rs 40,000 per MT as against the average bamboo cost of Rs 4,000 to Rs 5,000 per MT. Compared to this, the bamboo price in China is Rs 8,000 to Rs 10,000 per MT but their input cost is Rs 12,000 to Rs 15,000 per MT owing to 100% waste utilization. Considering all the above points in view, it is necessary to undertake the research to study the effect of organic and inorganic additives on composting of incense bamboo waste for value addition and utilization of bamboo waste https://pib.gov.in/PressReleasePage.aspx KVIC, (2022) [17].

Composting is the microbial degradation of different organic materials under moist, self-heating and aerobic conditions and is a process characterized by a succession of various microbial populations. Large numbers of different mesophilic, thermotolerant and thermophilic aerobic microorganisms play key roles in the composting process. In this process, microorganisms break down organic matter and produce carbon dioxide, water, heat and relatively stable organic products. Microorganisms promote the degradation of organic materials through the activity of different hydrolytic enzymes (Raut *et al.*, 2008) [40]. Important enzymes involved in the composting process included cellulase, β-glucosidase, protease and xylanase, which depolymerize cellulose, hydrolyze glucosides, promote N-mineralization and hydrolyzexylan, respectively (Mondini *et al.*, 2004) [28]. Characterizing and quantifying enzymatic activities during composting can reflect the dynamics of the composting process in terms of the decomposition of organic matter and nitrogen transformations and may provide information about the maturity of composted products (Tiquia, 2002) [47].

Composting proceeds through three phases: the mesophilic phase, which lasts for a few days, is characterized by the activity and growth of mesophilic organisms, leading to a rapid increase in temperature. The thermophilic, or high-temperature, phase can last from a few days to several months. In this phase, thermophilic organisms dominate the degradation process and the growth and activity of non-thermotolerant organisms are inhibited. Finally, a several-month cooling and maturation phase occurs, characterized by the development of new mesophilic communities (Amir *et al.*, 2008) [1]. Therefore, the aim of this study to asses the effect of additives (organic, inorganic and biological) on decomposition incense bamboo waste and to evaluate physico-chemical properties of compost prepared from incense bamboo waste.

Materials and Methods

The present investigation was carried out to explore the suitability and potential use of incense industrial bamboo waste as substrate used for compost preparation, during 2022-23 for 120 days at Agroforestry farm (Futala farm), College of Agriculture, Nagpur. Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Dist. Akola, Maharashtra.

Composting process and sampling

Incense industrial bamboo waste was collected from agarbatti industry, MIDC, Butibori, Nagpur, were used as the main component for composting. Due to high initial C:N ratio of the bamboo waste (115.79, Table 3), organic, inorganic and biological additives were used to adjust the C:N ratio and to initiate microbial activities. The incense bamboo waste was weighed 20 kg per treatment and then treated with additives such as cow dung, poultry soil, urea, lignolytic fungi as per the respective treatments (Table 1). The additives were mixed with the required amount of water (moisture more than 50%) and then added to the bamboo waste and mixed with hands properly and filled in the polythene bags and again weighed and then put it in grow bags treatment wise. Turning up of the bamboo waste was done at frequent intervals and proper moisture were maintained. Temperature was measured regularly after every two days interval. The experiment was designed following the principles of Completely Randomized Design (CRD), with fourteen treatments each replicated three times. The observations recorded during composting of incense bamboo waste and after 120 days were tabulated and subjected to statistical analysis.

The initial characteristics of incense industrial bamboo waste such as moisture content, total organic carbon, ash content, C:N ratio and Total Nitrogen were analysed (Table 3). The characteristics of additives used for composting such as Total N, P, K, S were also estimated (Table 4). The treatment wise weight of composting mixtures was measured at the beginning of composting process and periodically during composting upto 120 days by weighing balance. The physico-chemical properties of different composting mixtures were estimated including bulk density (BD) determined with Core method by Blake and Hartge, (1986) [7]; ash percent determined by ignition method, pH was measured on digital pH meter using 1: 2.5 (soil: water) suspension and EC measured using digital conductivity meter according to Jackson, (1973) [20]; moisture percent was determined using gravimetric method Khanna and Yadav, (1973) [24]; colour was determined with the help of Munsell colour chart by Munsell (1994) [32]; total organic carbon was estimated by procedure given by Jackson, (1973) [20]; total nitrogen was estimated by Micro-Kjeldahl method Piper, (1966) [38] and C:N ratio was calculated by dividing percent of organic carbon by percent total nitrogen. The data of various observations was analysed by the standard statistical method. The null hypothesis was tested by F-test of significance to know whether treatments effect was real or not. The standard error (S. E.) and critical difference (C. D.) at 5% level was computed wherever 'F' test was significant (Panse and Sukhatme, 1985) [37].

Results and Discussion

Initial characteristics of incense bamboo waste on dry basis and additives used for composting

Initially percent ash, moisture, organic carbon, C:N ratio and total nitrogen content in incense bamboo waste on dry basis were estimated and presented in Table 3 and also macronutrient content of additives used for decomposition were estimated and presented in Table 4. The elevated C:N ratio of incense bamboo waste, standing at 115.79, prompted measures to expedite its decomposition rate. To achieve this, the C:N ratio was reduced by incorporating organic elements such as cow dung and poultry soil, inorganic nitrogen, and biological additives like lignolytic fungi.

Temperature changes and compost characteristics:

Temperature is one of the most important indicators for composting process and can directly reflect composting status and difference between or among composting treatments (Golueke and Diaz, 1996; Nakasaki *et al.*, 2013) [14, 33]. The temperature development of the composting media depends both on the compost composition and aeration (Aydn and Kocasoy, 2003) [3]. Temperature variation during composting of all compost followed in typical pattern and it started increasing between 3 to 6 days, but reach a maximum above 50ºC within 7 to 15 days of composting in composting mixture prepared from organic (cow dung and poultry soil) and biological (*Phanerochaete chrysosporium*) additives (Fig 1). It was also observed that after 15 to 30 days, it decreases gradually but remain in thermophilic stage more than 40ºC up to 70 days in treatment BW+ 5 kg CD + 2.5 kg PM + 0.2 kg LF (T_{14}), BW + 5 kg PM+ 0.2 kg LF (T_9) and BW + 2.5 kg PM + 0.06 kg N + 0.2 kg LF (T_{13}). It further decreases and reach ambient level after 120 days of composting.

The maximum temperature 58ºC was recorded in treatment BW+ 5 kg CD + 2.5 kg PM + 0.2 kg LF (T_{14}) followed by BW + 5 kg PM+ 0.2 kg LF (T_9) and BW + 2.5 kg PM + 0.06 kg N (T_{13}). Whereas, minimum temperature variations were recorded in treatment BW (control) (T_1), BW + 0.125 kg N + 0.2 kg LF (T_{10}) and BW + 0.250 kg N + 0.2 kg LF (T_{11}) without organic additives. Chefetz *et al.* (1998) [8] also reported that the thermophilic phase is a very important period in the composting process, because a large number of polymers (i.e., starch, cellulose, lignin, hemicellulose) and phytotoxic compounds produce in the earlier phases of composting are decomposed by thermophilic bacteria. Moreover, temperature must remain above 55ºC for three consecutive days in order to kill pathogens (Moral *et al.*, 2009; Zhou *et al.*, 2015) [29, 55], which was accomplished in composting treatment BW+ 5 kg CD + 2.5 kg PM + 0.2 kg LF (T_{14}), BW + 5 kg PM+ 0.2 kg LF (T_9) and BW + 2.5 kg PM + 0.06 kg N (T_{13}). After 120 days of composting the compost prepared from addition of all additives i.e. organic, inorganic and biological reached a constant temperature with no measurable changes. Bernal *et al.* (2009) [5] narrated that 40-65°C was the optimum temperature for composting and greater than 55°C was necessary to eliminate pathogenic microorganisms. Similar findings were also recorded by Rashad *et al.* (2010) [39], Latifah *et al.* (2015) [27], Mulec *et al.* (2016) [31] and Zhong *et al.* (2018) [54].

The initial organic carbon content of incense bamboo waste, presented in Table 3, was recorded at 48.63%.The peak rate of mineralization and organic carbon loss was observed within the initial 90 days, followed by a gradual deceleration in the later stages of composting. The incorporation of organic, inorganic, and biological additives facilitated a higher decomposition rate in the compost mixtures BW + 5 kg CD + 2.5 kg PM + 0.2 kg LF (T_{14}) and BW + 5 kg PM + 0.2 kg LF (T_9), resulting in the most substantial reduction in total organic carbon at 27.33% in both treatments after 120 days of composting (Table 5). The individual addition of organic and inorganic additives failed to supply sufficient nitrogen for the decomposing microflora, resulting in minimal decomposition of organic matter. Consequently, the total organic carbon reduction was notably limited in the compost treatments BW (control) (T_1), BW + 0.125 kg N + 0.2 kg LF (T_{10}), and BW + 0.250 kg N + 0.2 kg LF (T_{11}). The most significant decline in total organic carbon content was registered in treatment BW + 5 kg CD + 2.5 kg PM + 0.2 kg LF (T_{14} - 27.33%), which equalled the reduction in treatment BW + 5 kg PM + 0.2 kg LF (T_9 - 27.33%) and BW + 2.5 kg PM + 0.06 kg N + 0.2 kg LF (T_{13} - 27.51%). This concurrence indicates the maturity of these compost treatments. Conversely, the smallest reduction in total organic carbon content was noted in treatment BW (control) (T_1 - 38.50%), followed by BW + 0.125 kg N + 0.2 kg LF (T_{10} - 36.93%) and BW + 0.250 kg N + 0.2 kg LF (T_{11} - 36.17%), signifying the relative immaturity of the compost.

The initial nitrogen content in incense bamboo waste was 0.42% (Table 3), exhibiting a significant increase over time with the incorporation of organic additives (cow dung and poultry soil), inorganic nitrogen, and biological additives (*Phanerochaete chrysosporium*) in all treatments. At the 120-day mark of composting, the most substantial increase in total nitrogen content was recorded in treatments BW + 5 kg CD + 2.5 kg PM + 0.2 kg LF (T_{14} - 1.58%), matching the increase in treatment BW + 5 kg PM + 0.2 kg LF (T_9 - 1.55%). Among the diverse treatments, those without additive additions, such as BW (control) (T_1 - 0.89%), exhibited poor nitrogen content due to inhibitory effects on microbial populations, resulting in a sluggish rate of organic matter decomposition (Table 5).Remarkably, composting mixtures that received either organic/inorganic additives, with or without biological additives, demonstrated an increasing trend in total nitrogen content, ranking as follows: BW + 0.125 kg N + 0.2 kg LF (T_{10}) < BW + 0.250 kg N + 0.2 kg LF (T_{11}) < BW + 5 kg CD (T_2) < BW + 2.5 kg PM (T_4) < BW + 10 kg CD (T_3) < BW+ 5 kg CD + 0.2 kg LF (T_6) < BW + 5 kg PM (T_5) < BW + 2.5 kg PM + 0.2 kg LF (T_8) < BW + 5 kg CD + 0.06 kg N + 0.2 kg LF (T_{12}) < BW + 10 kg CD + 0.2 kg LF (T_7), compared to the control BW (control) (T_1).

The initial C:N ratio of incense bamboo waste was 115.79 (Table 3), gradually decreasing over the course of composting. The lowest C:N ratio was recorded in treatment BW + 5 kg CD + 2.5 kg PM + 0.2 kg LF (T_{14} - 17.34) (Table 5). However, it was comparable to treatment BW + 5 kg PM + 0.2 kg LF (T_9 - 17.63) and BW + 2.5 kg PM + 0.06 kg N + 0.2 kg LF (T_{13} - 18.43) at 120 days of composting, signifying compost maturity. The highest C:N ratio was observed in treatment BW (control) (T_1 - 43.19) at 120 days after composting incense bamboo waste without additives. The highest percentage decrease in the C:N ratio was recorded in treatment BW + 5 kg CD + 2.5 kg PM + 0.2 kg LF (T_{14} - 68.75%) at 120 days compared to the initiation of composting (15 days).

Conversely, the lowest percentage decrease in the C:N ratio was reported in treatment BW (control) (T_1 - 57.20%) at 120 days compared to the initiation of composting (15 days). The observed C:N ratio range of 17.34-19.64 in matured compost, such as BW + 5 kg CD + 2.5 kg PM + 0.2 kg LF (T_{14} - 17.34), BW + 5 kg PM + 0.2 kg LF (T_9 - 17.63), BW + 2.5 kg PM + 0.06 kg N + 0.2 kg LF (T_{13} - 18.43), BW + 10 kg CD+ 0.2 kg LF (T_7 - 19.33), and BW + 5 kg CD + 0.06 kg N + 0.2 kg LF (T_{12} - 19.64), fell within the standard compost range of 20:1 as per the Fertilizer Control Order (Table 3) prescribed by the Ministry of Agriculture and Rural Development, Government of India. Researchers have proposed various ideal C:N ratios ranging from 12 to 25 for matured compost (Tiquia *et al.*, 2010) [49]. Hansen *et al.* (1990) [16] also recommended a C:N ratio of 30:1 as the ideal value to expedite the microbial decomposition of organic matter. Sullivan and Miller (2001) [44] suggested that ideal compost feedstock mixtures should have an initial C:N ratio of about 30:1, decreasing to less than 20:1 as the composting process progresses. A similar range of C:N ratios in matured compost has been reported by Thambirajah *et al.* (1995) [46], Verma *et al.* (1999) [52], and Iqbal *et al.* (2012) [18].

The initial total P content of incense bamboo waste was 0.07% (Table 3). There was a gradual increase in total P content of composting material with composting time. The highest phosphorous content was recorded in treatment BW+ 5 kg CD + 2.5 kg PM + 0.2 kg LF (T_{14}- 0.52%) however, it was at par with treatment BW + 5 kg PM+ 0.2 kg LF (T_9- 0.49%) at 120 days of composting (Table 6).The lowest phosphorous content was recorded in treatment BW (control) (T_1- 0.09%) at 120 days after composting when incense bamboo waste is composted without any additives. Phosphorus is not loss by volatilization during the composting process, but phosphorus content might increase as composting proceeds (Warman and Termeer, 1996) [53]. Kadalli *et al.* (2002) [22] recorded considerable increase in N, P and K content in coir dust based compost. Bharne *et al.* (2003) [6] also recorded significant increase in N, P and K content in the compost prepared by the cotton stalk with *Trichoderma* after its decomposition. The results was also in agreement with the findings of Sannigrahi (2003) [41], Tiquia (2003) [48], Bera *et al.* (2013) [4] and Kakde (2017) [23].

There was a gradual increase in total potassium content of composting material with composting time. The initial total potassium content of incense bamboo waste was 0.36% (Table 3). The significantly highest potassium content (Table 12 and Fig 8) was recorded in treatmentsBW+ 5 kg CD + 2.5 kg PM + 0.2 kg LF (T_{14}- 1.16%) followed by BW + 5 kg PM+ 0.2 kg LF (T_9- 1.07%) and BW + 2.5 kg PM + 0.06 kg N + 0.2 kg LF (T_{13}- 0.96%) at 120 days of composting (Table 6). The lowest potassium content was recorded in treatment BW (control) (T_1- 0.40%) at 120 days after composting when incense bamboo waste is composted without any additives. Similar results were also observed by Sannigrahi (2003) [41], Tiquia (2003) [48], Bera *et al.* (2013) [4] and Kakde (2017) [23].

The highest sulphur content was recorded in treatment BW+ 5 kg CD + 2.5 kg PM + 0.2 kg LF (T_{14}- 0.32%) however, it was at par with treatment BW + 5 kg PM+ 0.2 kg LF (T_9- 0.29%) at 120 days of composting (Table 6). The lowest S content was recorded in treatment BW (control) (T_1- 0.10%) at 120 days after composting when incense bamboo waste is composted without any additives. Debra and Trainer (1995) [11] also reported that composting of organic wastes, increase the sulphur content.

The initial weight of all treatments at 0 days ranged from 48.88-58.74 kg. The weight of the composting mixture in all treatments decrease gradually but the decrease in weight of composting mixture was more in treatments with organic (cow dung and poultry soil), inorganic (nitrogen) and biological (*Phanerochaete chrysosporium*) additives than the treatment without additives at 120 days of composting. The final weight of all treatments at 120 days ranged from 27.19-34.51 kg. The highest percent reduction at 120 days in weight loss was recorded in treatment BW+ 5 kg CD + 2.5 kg PM + 0.2 kg LF (T_{14}-53.72%) followed by BW + 5 kg PM+ 0.2 kg LF (T_9-50.10%) and BW + 2.5 kg PM + 0.06 kg N + 0.2 kg LF (T_{13}- 48.53%) as compared to initiation of composting i.e. 0 days indicating maximum decomposition (Fig 2).It was observed that the composting mixture received either organic/inorganic with or without biological additives showed increasing trend in percent reduction of weight as BW + 0.125 kg N + 0.2 kg LF (T_{10})<BW + 0.250 kg N + 0.2 kg LF (T_{11}) <BW + 5 kg CD (T_2) <BW + 2.5 kg PM (T_4)<BW + 10 kg CD (T_3)<BW+ 5 kg CD + 0.2 kg LF (T_6)<BW + 5 kg PM (T_5)<BW + 2.5 kg PM+ 0.2 kg LF(T_8) <BW+ 5 kg CD + 0.06 kg N + 0.2 kg LF (T_{12})<BW+ 10 kg CD+ 0.2 kg LF (T_7) as compared to control BW (control) (T_1). Nandi *et al.* (1996) [34] also recorded 24 to 50% loss in weight in two steps composting of rice straw. Iyengar *et al.* (2006) [19] also noted more than 90% reduction of volume in aerobic reactor as compared to 12.58% in anaerobic reactor. The findings with regards to weight loss are in conformity with the findings of Verma *et al.* (1999) [52], Iqbal *et al.* (2012) [18] and Kakde (2017) [23].

Physical and chemical characteristics of incense bamboo waste compost:

pH is a measure of acidic or alkaline nature of the compost as composting progress. The pH value for all composting mixture was in decreasing trend and ranged from 7.15 - 8.15. The neutral pH (7 - 7.5) was recorded in treatments BW+ 5 kg CD + 2.5 kg PM + 0.2 kg LF (T_{14}- 7.15) followed by BW + 5 kg PM+ 0.2 kg LF (T_9- 7.16), BW + 2.5 kg PM + 0.06 kg N + 0.2 kg LF (T_{13}- 7.27),BW+ 10 kg CD+ 0.2 kg LF (T_7- 7.33), BW+ 5 kg CD + 0.06 kg N + 0.2 kg LF (T_{12}- 7.36),BW + 2.5 kg PM+ 0.2 kg LF (T_8- 7.37), BW + 5 kg PM (T_5- 7.47) and BW+ 5 kg CD + 0.2 kg LF (T_6- 7.47) whereas, highest pH was recorded in treatment BW (control) (T_1- 8.15) after 120 days of composting (Table 6).The pH of the composting mixture containing organic (cow dung and poultry soil), inorganic (nitrogen) and biological (*Phanerochaete chrysosporium*) additives decrease gradually up to 120 days which is likely to be a consequence of new synthesis of organic acid production of phenolic compounds (Chen and Inbar, 1993; Tiquia *et al.*, 1996 and Satisha and Devarajan, 2007) [9, 50, 42]. It was also observed that the pH of well decomposed composting material at final stage tends to neutral in range. The pH of well decomposed bamboo waste compost ranged from 7.15 - 7.33 which was within the range of recommended value of 6.5-7.5 as prescribed by Fertilizer Control Order (Table 2). Similar trend of decreasing in pH with composting were also recorded by Ko *et al.* (2008) [26], Anqi *et al.* (2014) [2] and Kakde (2017) [23].

Electrical conductivity increases with composting time which was probably due to the release of soluble salt through organic decomposition.It was revealed that at the end of composting EC values where in the ranged from 0.35 - 1.18 dSm^{-1}, with higher value being exhibited by treatments BW+ 5 kg CD + 2.5 kg PM + 0.2 kg LF (T_{14}- 1.18 dSm^{-1}) followed by BW + 5 kg PM+ 0.2 kg LF (T_9- 1.10 dSm^{-1}) and BW + 2.5 kg PM + 0.06 kg N + 0.2 kg LF (T_{13}- 1.03 dSm^{-1}) after 120 days of composting(Table 6). The measured EC values were within the range of recommendation and not more than 4.0 dSm^{-1}as per by Fertilizer Control Order (Table 2) standard prescribed by Ministry of Agriculture and Rural Development, Government of India. Jeevan Rao *et al.* (2007) [21] also recorded EC ranged from 0.32 - 0.45 dSm^{-1} in decomposed urban solid waste in combination with agricultural waste. Rashad *et al.* (2010) [39] recorded final EC values of different composts ranged between 0.79 to 1.04 dSm^{-1}.

The ash content is considered as the quality parameter of compost. The increased ash content with incubation period indicates the decomposition rate of composting. In compost, the ash percentage in all treatments were progressively increased with time. But maximum ash content was recorded under treatments with organic (cow dung and poultry soil), inorganic (nitrogen) and biological (*Phanerochaete chrysosporium*) additives as compared to the treatment without additives at 120 days of composting. The initial ash content in incense bamboo waste was 2% (Table 3). The results revealed that, the highest ash percent (9.76%) was recorded in treatment BW+ 5 kg CD + 2.5 kg PM + 0.2 kg LF (T_{14}) and it was at par with treatment BW + 5 kg PM+ 0.2 kg LF (T_9- 9.10%) and BW + 2.5 kg PM +

0.06 kg N + 0.2 kg LF (T_{13}- 8.76%) at 120 days of composting (Table 6). The lowest ash percent was recorded in treatment BW (control) (T_1- 3.12%) at 120 days after composting when incense bamboo waste is composted without any additives. Muhammad *et al.* (1991) [30] reported 36.38% ash content at the maturity of jute mill waste composting. Garcia *et al.* (1992) [13] also reported 31.3 to 66.9% increase in ash content during composting of different type of waste. Similar trend was observed by Thakur and Sharma, (1998) [45]; Habib *et al.*, (2001) [15].

The density of compost also influences the mechanical properties such as strength, porosity and ease of compaction. On the contrary, very low wet bulk density can indicate excessive substrate aeration and, indirectly, a drop in the available water fraction (Nappi and Barberis, 1993) [35]. Since both the measured bulk density and the percentage air voids are linked to air porosity hence, they are important parameters used by composting facility operators in the blending of feedstocks to achieve optimum efficiency of the biological process (Day *et al.*, 1998) [10]. The bulk density of all the treatments ranged from (0.13-0.36 Mg m^{-3}) at 120 days of composting. The significantly maximum bulk density was recorded in treatment BW+ 5 kg CD + 2.5 kg PM + 0.2 kg LF (T_{14}- 0.36 Mg m^{-3}) followed by BW + 5 kg PM+ 0.2 kg LF (T_9- 0.32 Mg m^{-3}) and BW + 2.5 kg PM + 0.06 kg N + 0.2 kg LF (T_{13}- 0.31 Mg m^{-3}) at 120 days of composting(Table 6). The lowest bulk density was recorded in treatment BW (control) (T_1 - 0.13 Mg m^{-3}) when bamboo waste composted without any additives at 120 days of composting. The recorded bulk density of all treatments are well within the recommended range of < 1.0 g cm^{-3} as prescribed by Fertilizer Control Order (Table 2). Noguera *et al.* (2003) [36] stated that acceptable range in compost of bulk density was less than 0.4 g cm^{-3}. Khater (2015) [25] observed negative correlation between the bulk density of compost and the compost total organic matter (R^2 = -0.89).

The incense bamboo waste compost mixture prepared from organic (cow dung and poultry soil) and biological (*Phanerochaete chrysosporium*) additives appear to be very dark brown (10 YR 2/2) to black (10 YR 2/1) in colour at 120 days except the compost where these additives not used. The black colour of compost was observed in treatment BW+ 5 kg CD + 2.5 kg PM + 0.2 kg LF (T_{14}), BW + 5 kg PM+ 0.2 kg LF (T_9), BW + 2.5 kg PM + 0.06 kg N + 0.2 kg LF (T_{13}) and BW+ 10 kg CD+ 0.2 kg LF (T_7) indicating higher decomposition(Table 6). Whereas, very dark brown compost colour was observed in treatments BW+ 5 kg CD + 0.06 kg N + 0.2 kg LF (T_{12}), BW + 2.5 kg PM+ 0.2 kg LF (T_8), BW + 5 kg PM (T_5) and BW+ 5 kg CD + 0.2 kg LF (T_6). There was no foul odour found in any of the compost at the end of composting. Colour and odour are considered as a simplest criterion to evaluate the maturity and stability of the compost, but other physical, chemical and biological parameter were studied for confirmation. Epstein (1997) [12] reported that all the compost samples which appeared dark brown in colour with an earthy smell, deemed necessary for mature compost. Sullivan and Miller (2001) [44] stated that colour of the compost is one of the indicators that havebeen considered as maturity indices for compost. Black to very dark brown colour of matured compost were reported by Iqbal *et al.* (2012) [18] and Latifah *et al.* (2015) [27].

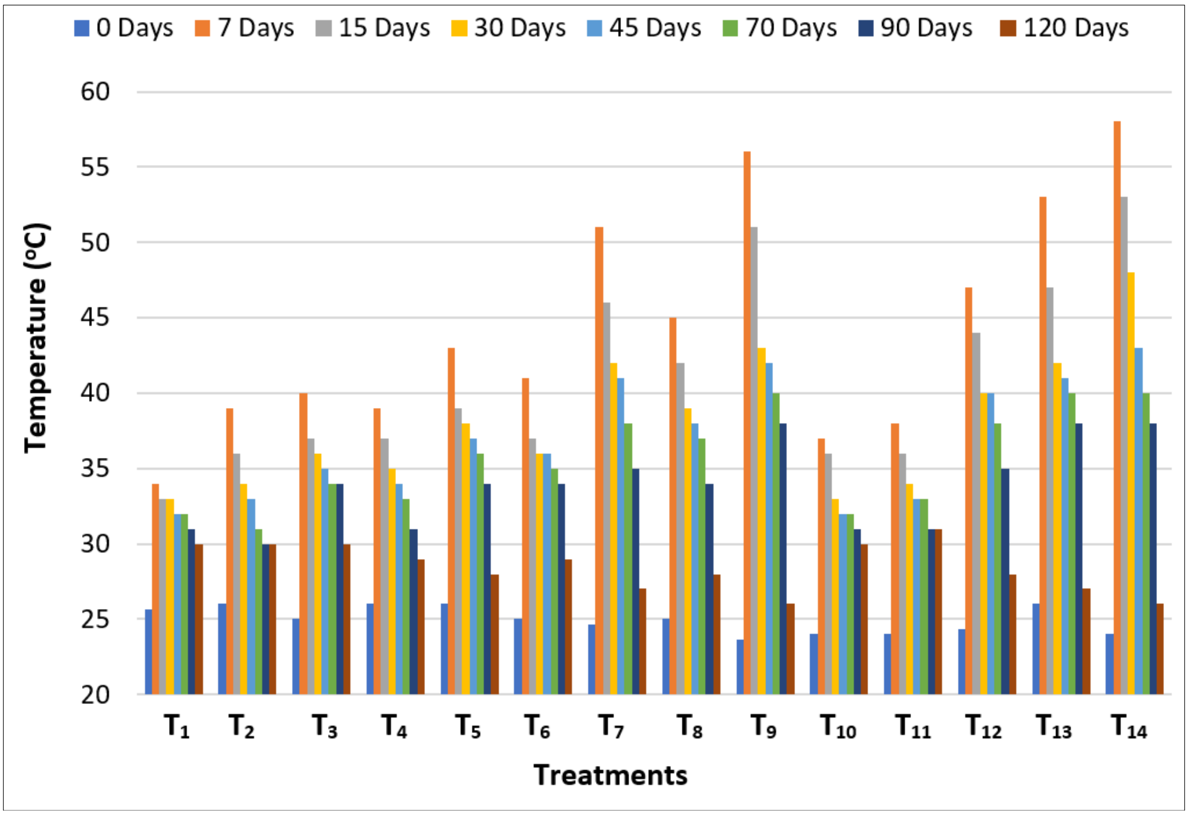

Fig 1: Temperature variation during composting of incense bamboo waste

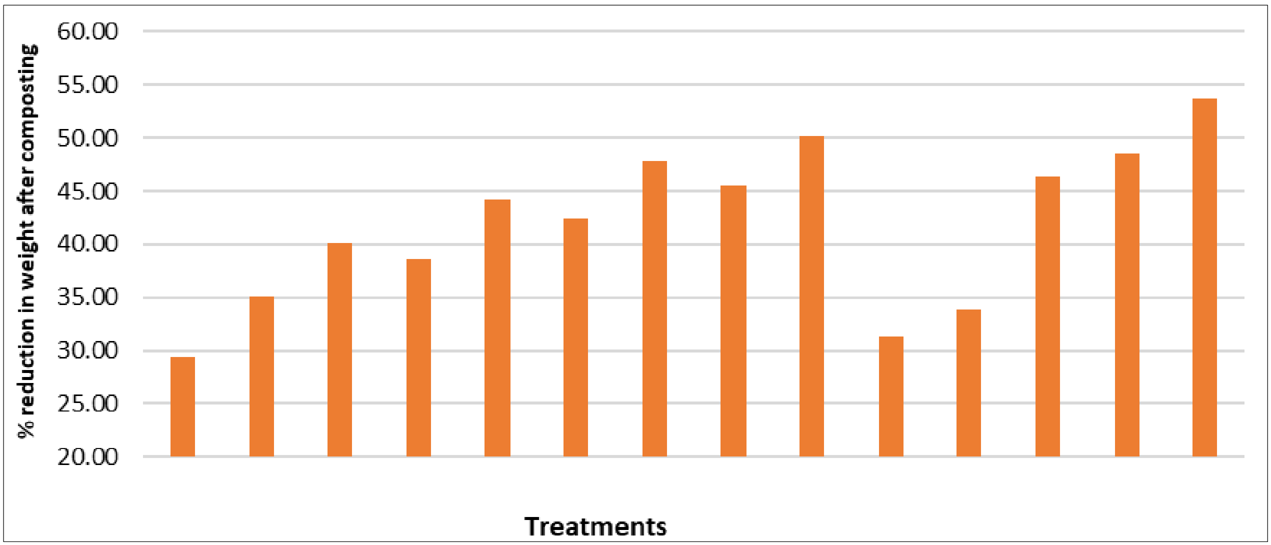

Fig 2: Percent reduction in weight after composting (120 days) as influenced by various treatments

Table 1: Treatment Details

Treatments	Sources	Treatment Details
T_1		Bamboo waste (control)
T_2	Organic additives	Bamboo waste + 5 kg Cow dung
T_3		Bamboo waste + 10 kg Cow dung
T_4		Bamboo waste + 2.5 kg Poultry manure
T_5		Bamboo waste + 5 kg Poultry manure
T_6	Organic and biological additives	Bamboo waste + 5 kg Cow dung + 0.2 kg lignolytic fungi (1% of biomass)
T_7		Bamboo waste + 10 kg Cow dung + 0.2 kg lignolytic fungi
T_8		Bamboo waste + 2.5 kg Poultry manure + 0.2 kg lignolytic fungi
T_9		Bamboo waste + 5 kg Poultry manure + 0.2 kg lignolytic fungi
T_{10}	Mineral and biological additives	Bamboo waste + 0.125 kg N + 0.2 kg lignolytic fungi (1% of biomass)
T_{11}		Bamboo waste + 0.250 kg N + 0.2 kg lignolytic fungi (1% of biomass)
T_{12}	Organic, Mineral and biological additives	Bamboo waste + 5 kg Cow dung + 0.06 kg N + 0.2 kg lignolytic fungi
T_{13}		Bamboo waste + 2.5 kg Poultry manure + 0.06 kg N + 0.2 kg lignolytic fungi
T_{14}		Bamboo waste + 5 kg Cow dung + 2.5 kg Poultry manure + 0.2 kg lignolytic fungi
Note: 1. Bamboo waste required per treatment is 20 kg. 2. Poultry manure or Poultry soil can be used.		

Table 2: Standards of compost (Fertilizer control order, 1985)

Parameter	Compost
Moisture percent by weight	15.0-25.0
Colour	Dark brown to black
Odour	Absence of foul odour
Particle size	Minimum 90% material should pass through 4.0 mm IS sieve
Bulk density (g cm^{-3})	<1.0
Total organic carbon, percent by weight, minimum	12.0
Total nitrogen percent by weight, minimum	0.8
Total phosphates percent by weight, minimum	0.4
Total potash percent by weight, minimum	0.4
C:N ratio	20:1 or less
pH	6.5-7.5
Electrical Conductivity (as dS m^{-1}), not more than	4.0
Pathogens	Nil
Heavy metal content, (as mg kg^{-1}), per cent by weight, maximum	
Arsenic (as As_2O_3)	10.0
Cadmium (as Cd)	5.0
Chromium (as Cr)	50.0
Copper (as Cu)	300.0
Mercury (as Hg)	0.15
Nickel (as Ni)	50.0

Singh *et al.* (1980) [43]

Table 3: Initial characteristics of incense bamboo waste on dry basis used for composting

Characteristics	Bamboo Waste (dry basis)
Moisture content (%)	5.00
Organic carbon (%)	48.63
Ash content (%)	2.00
C:N ratio	115.79
Total Nitrogen (%)	0.42

Table 4: Initial characteristics of additives used for composting

Additive Material	Macronutrients (%)			
	N	P	K	S
Cow dung	1.2	0.4	0.82	0.22
Poultry Soil	3.08	2.65	1.47	0.38

Table 5: Change in total organic carbon, total Nitrogen and C: N ratio at an interval of 20-30 days during composting as influenced by various treatments

TREATMENTS	Organic carbon (%)					Nitrogen (%)					C:N ratio				
	15 days	45 days	70 days	90 days	120 days	15 days	45 days	70 days	90 days	120 days	15 days	45 days	70 days	90 days	120 days
T_1- BW (control)	45.57	43.56	40.69	40.23	38.50	0.45	0.50	0.66	0.74	0.89	100.93	88.35	62.15	54.84	43.19
T_2- BW + 5 kg CD	41.25	38.55	35.64	34.94	34.36	0.52	0.61	0.84	1.11	1.25	79.57	62.98	42.65	31.53	27.50
T_3- BW + 10 kg CD	38.43	37.18	35.24	33.43	31.99	0.55	0.65	0.87	1.19	1.33	70.18	57.30	40.70	28.20	24.12
T_4- BW + 2.5 kg PM	40.67	37.41	35.24	34.71	32.62	0.54	0.64	0.86	1.15	1.30	76.02	58.51	41.02	30.30	25.17
T_5- BW + 5 kg PM	37.52	36.36	34.31	32.16	30.84	0.58	0.68	0.89	1.22	1.40	65.40	53.56	38.60	26.45	22.04
T_6- BW+ 5 kg CD + 0.2 kg LF	37.69	37.04	35.00	32.81	30.94	0.58	0.68	0.90	1.21	1.36	64.91	54.53	39.13	27.13	22.75
T_7- BW+ 10 kg CD+ 0.2 kg LF	36.73	35.33	32.52	28.52	28.14	0.62	0.72	0.94	1.25	1.46	59.40	49.48	34.51	22.78	19.33
T_8- BW + 2.5 kg PM+ 0.2 kg LF	37.43	35.55	33.60	31.55	29.71	0.59	0.69	0.91	1.23	1.41	63.54	51.56	36.99	25.73	21.13
T_9- BW + 5 kg PM+ 0.2 kg LF	35.90	34.85	31.39	28.00	27.33	0.65	0.76	1.07	1.40	1.55	55.30	46.12	29.39	20.01	17.63
T_{10}- BW + 0.125 kg N + 0.2 kg LF	45.30	42.54	40.27	39.87	36.93	0.49	0.59	0.81	1.08	1.19	92.23	71.87	50.01	37.06	31.05
T_{11}- BW + 0.250 kg N + 0.2 kg LF	41.86	40.54	36.34	36.29	36.17	0.51	0.61	0.83	1.10	1.22	82.27	66.15	43.69	33.02	29.58
T_{12}- BW+ 5 kg CD + 0.06 kg N + 0.2 kg LF	37.30	35.43	32.58	28.60	28.20	0.61	0.71	0.93	1.24	1.44	61.26	50.28	35.22	23.02	19.64
T_{13}- BW + 2.5 kg PM + 0.06 kg N + 0.2 kg LF	36.25	34.99	31.52	28.05	27.51	0.63	0.73	0.95	1.27	1.49	58.05	48.05	33.32	22.15	18.43
T_{14}- BW+ 5 kg CD + 2.5 kg PM + 0.2 kg LF	35.85	33.89	29.26	27.95	27.33	0.65	0.78	1.10	1.42	1.58	55.49	43.53	26.63	19.73	17.34
F Test	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.
SE (m) ±	0.12	0.16	0.14	0.12	0.11	0.022	0.022	0.024	0.025	0.021	2.95	2.19	1.20	1.06	0.50
CD at 5 %	0.35	0.46	0.40	0.35	0.31	0.062	0.062	0.070	0.071	0.059	8.42	6.26	3.42	3.04	1.42

Table 6: Total macronutrient content and physico-chemical properties of compost in incense bamboo waste compost as influenced by various treatments.

Treatments	Total macronutrients (%)				Chemical and Physical properties				
	N	P	K	S	pH	EC (dS m^{-1})	Ash (%)	Bulk density (Mg m^{-3})	Colour
T_1- BW (control)	0.89	0.09	0.40	0.10	8.15	0.35	3.12	0.13	Light Brown
T_2- BW + 5 kg CD	1.25	0.16	0.56	0.15	7.83	0.61	5.00	0.17	Brown
T_3- BW + 10 kg CD	1.33	0.20	0.65	0.19	7.75	0.67	6.39	0.21	Brown
T_4- BW + 2.5 kg PM	1.30	0.18	0.60	0.16	7.81	0.64	5.95	0.20	Brown
T_5- BW + 5 kg PM	1.40	0.29	0.78	0.18	7.47	0.78	7.54	0.25	Very Dark Brown
T_6- BW+ 5 kg CD + 0.2 kg LF	1.36	0.23	0.72	0.20	7.47	0.70	6.73	0.22	Very Dark Brown
T_7- BW+ 10 kg CD+ 0.2 kg LF	1.46	0.43	0.90	0.25	7.33	0.98	8.25	0.30	Black
T_8- BW + 2.5 kg PM+ 0.2 kg LF	1.41	0.36	0.83	0.23	7.37	0.85	7.87	0.26	Very Dark Brown
T_9- BW + 5 kg PM+ 0.2 kg LF	1.55	0.49	1.07	0.29	7.16	1.10	9.10	0.32	Black
T_{10}- BW + 0.125 kg N + 0.2 kg LF	1.19	0.11	0.42	0.18	8.06	0.47	4.02	0.15	Light Brown
T_{11}- BW + 0.250 kg N + 0.2 kg LF	1.22	0.13	0.45	0.19	7.90	0.56	4.54	0.16	Light Brown
T_{12}- BW+ 5 kg CD + 0.06 kg N + 0.2 kg LF	1.44	0.39	0.88	0.24	7.36	0.94	8.01	0.27	Very Dark Brown
T_{13}- BW + 2.5 kg PM + 0.06 kg N + 0.2 kg LF	1.49	0.45	0.96	0.27	7.27	1.03	8.76	0.31	Black
T_{14}- BW+ 5 kg CD + 2.5 kg PM + 0.2 kg LF	1.58	0.52	1.16	0.32	7.15	1.18	9.76	0.36	Black
F Test	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	-
SE (m) ±	0.021	0.017	0.020	0.015	0.03	0.01	0.39	0.01	-
CD at 5 %	0.059	0.049	0.057	0.043	0.08	0.04	1.11	0.03	-

Conclusion

From the obtained data, Itcan be concluded that, the incense bamboo waste residues can be successfully composted with the use organic, inorganic and biological additives. The addition of organic, inorganic and biological additivesin incense bamboo waste residues markedly changed the temperature profile during composting, producing compost with different physical and chemical properties. Hence, it is concluded that, for composting of incense bamboo waste with organic (cow dung and poultry soil) and biological (lignolytic fungi) additives can be a suitable source for recycling bamboo waste.

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