Mageshwaran et al | Article 9515
J Pure Appl Microbiol. 2024;18(4):2619-2635. doi: 10.22207/JPAM.18.4.34
Received: 28 May 2024 | Accepted: 11 October 2024
Published Online: 25 November 2024

JPAM JOURNAL OF PURE AND APPLIED MICROBIOLOGY
P-ISSN: 0973-7510; E-ISSN: 2581-690X

RESEARCH ARTICLE **OPEN ACCESS**

Comparative Efficacy Evaluation of Microbial Consortia for Rapid Composting of Paddy Straw

Vellaichamy Mageshwaran*, Pratyush Tripathi, Ashish K. Vishvakarma and Amit Yadav

Microbial Technology Lab, ICAR-National Bureau of Agriculturally Important Microorganisms, Kushmaur, Mau, Uttar Pradesh, India.

Abstract

The present study was aimed to evaluate five different microbial consortia for rapid composting of paddy straw and analyse the quality of compost produced. The experimental study on rapid composting of paddy straw was taken at ICAR-NBAIM, Kushmaur, Mau, Uttar Pradesh, India, during the period February to April 2022. The paddy straw was collected from the farm of ICAR-IISS, Mau, U.P., India and the collected paddy straw was chopped into 4-5 cm and further used for the study. The composting experiment was performed in bio-conversion bags of size [12 (L) x 4 (B) x 3 (H) feet]. There were six treatments in which five treatments were taken to evaluate five different microbial consortia and one control (no microbial consortium added). The five different microbial consortia tested were BIO-FAST, BIO-COMPOST, NCOF, PUSA and TEJAS. The results showed that Carbon-Nitrogen (C:N) ratio was reached to less than 20 at 60 days in BIO-FAST applied paddy straw followed by NCOF. While, the C:N ratio of control at 60 days was 33.71. Similarly, the primary nutrients (N, P and K) were higher ($p < 0.05$) in BIO-FAST followed by NCOF applied compost. The microbial activity and enzymatic activities were found to be insignificant ($p < 0.05$) in microbial consortia added treatments. The diluted extract of compost (50% and 20%) had higher germination index and no phytotoxicity effect. Thus, the results revealed that the addition of BIO-FAST accelerate the composting process and produce quality compost from paddy straw in 60 days.

Keywords: Paddy Straw, Microbial Consortia, Bioconversion, Degradation, Compost, Maturity, Bioaugmentation, Recycling

***Correspondence:** mageshbioiari@gmail.com

Citation: Mageshwaran V, Tripathi P, Vishvakarma AK, Yadav A. Comparative Efficacy Evaluation of Microbial Consortia for Rapid Composting of Paddy Straw. *J Pure Appl Microbiol.* 2024;18(4):2619-2635. doi: 10.22207/JPAM.18.4.34

INTRODUCTION

Rice is a major staple crop worldwide as well as in India. According to estimates, rice production worldwide increased from 694.47 to 756.74 million tonnes from 2010 to 2020. According to Food and Agriculture Organization of the United Nations, for the year 2020, China, mainland (211.9 MT), India (178.3 MT) and Bangladesh (54.9 MT) followed by Indonesia (54.6 MT) are the biggest producer of rice in the world.[1,2] This leads to larger production of paddy straw, a major agricultural by-product of rice cultivation. India being second largest producer of rice estimated to generate more than 100 million tons of paddy straw on a yearly basis.[3] This large quantity of produced straw is generally either left in fields or get burnt in to open, emitting greenhouse gases hence, causing severe air pollution.[4] Gadde *et al*.,[5] reports that India contributes 0.05% of total greenhouse gas emission through open field burning of rice straw. In India, Punjab, Uttar Pradesh, West Bengal, Haryana and Madhya Pradesh are the major rice producing states which faces grievous air pollution due to burning of paddy stubble left after its harvesting. Though paddy straw is a potential roughage to the livestock, the higher amount of silica (>9.0%), phytoliths (>0.9%) and lignocellulosic content are its major limitations.[4,6] Paddy straw has found applications in thatch houses, domestic fuel, handicrafts, crop mulches, particle boards, mushroom,[3] as fillers in poly lactic acid,[7] bioethanol and biochar.[8] Among the different applications, composting of paddy straw receives more attention due to its inherent nature of on-farm utilization and recycling of nutrients. Being a rich source of nutrients like N (0.5%-0.8%), P (0.16%-0.27%), K (1.4%-2.0%), production of compost from the paddy straw provides the biggest advantages by recycling nutrients and enhancing soil organic carbon content hence, improving the fertility of soil.[9] But due to high levels of lignocellulosic content and higher C:N (90:1) ratio the rate of bioconversion of paddy straw with the help of natural microflora is very slow.[4] Therefore, there is a need to deploy potential microbial consortia externally, which can accelerate the process of rice straw decomposition for proper management of stubble left after its cultivation as well as enrichment of soil nutrients.

Composting facilitated by microbial consortia is very helpful by significantly decreasing the composting period and being an environment friendly advent in the management of agriculture residues.[4] The literature showed that microbial inoculants used for composting were in the form of consortia consisting of two or more organism rather than a single kind of organism.[10,11] The lignocellulolytic fungi viz., *Trichoderma harzianum*, *Phanerochaete chrysosporium*, *Pleurotus* spp., *Aspergillus* spp., *Penicillium* spp. etc., are often reported for rapid composting of agricultural residues. Some of the bacterial strains used in composting are *Bacillus* spp., *Streptomyces* spp., *Actinomyces* spp., etc. The factors which affect the efficiency of microbial consortia are size and composition of feedstock, moisture content, aeration, time of inoculation and the composition of the microbial cultures used. The use of microbial inoculants in co-composting of agricultural residues with farm animal manures facilitate the biodegradation and produce the mature compost in a short period (2-3 months).[10] Therefore, it is imperative that bioformulation based rapid composting technique is promising in bioconversion of paddy straw into quality compost in an efficient manner. In recent years, several decomposers for rapid composting of paddy straw or other agricultural waste have been developed.[12] However, there is no scientific data available on their comparative efficacy. The present study was carried out to assess the efficacy of five different microbial consortia (BIO-FAST, BIO-COMPOST, NCOF, PUSA and TEJAS) in rapid composting of paddy straw and their ability to produce the quality compost by using bioconversion bags.

MATERIALS AND METHODS

Raw materials & bioconversion bags

The paddy straw was obtained from ICAR-Indian Institute of Seed Science farm, Mau, Uttar Pradesh in November 2021. The paddy straw was chopped into 3-4 cm. The Bioconversion bags of the dimension [12 (L) x 4 (B) x 3 (H) feet] were used for composting.

Microbial consortium/decomposers

The different microbial consortium/ decomposers evaluated for rapid composting of paddy straw are BIO-FAST, BIO-COMPOST, TEJAS, PUSA and NCOF. The microbial consortia, type of formulation and their source is given in Table 1. The microbial consortia used were of liquid formulation except, TEJAS which was solid.[2] The BIO-FAST consortium consists of the combination of two hyper ligno-cellulolytic fungi viz., *Phanerochaete chrysosporium* V-1 and *Pleurotus flabellatus* M-1.[13-15] The BIO-COMPOST consortium consists of four fungal cultures *viz., Phanerochate chrysosporium, Trichoderma virdie, Aspergillus awamori and Pleurotus florida.*[16] The commercial formulations *viz*., M/s TEJAS (https://www.indobioagri.in/biofertilizer-tejas.php accessed on 28 April 2024), M/s NCOF[17] and M/s PUSA[18] was used as positive check. The consortia, PUSA and NCOF was obtained in gel and scaled up to liquid formulation as per manufacturers instruction. A control was maintained in which none of the microbial consortium was added.

Experimental trial

The experimental trials on rapid composting of paddy straw was taken at ICAR-NBAIM, Kushmaur, Mau, Uttar Pradesh, India during the period February to April 2022. There were six treatments and the treatment details are given in Table 1. The treatments, MC-1, MC-2, MC-3, MC-4, MC-5 and their respective consortium are BIO-FAST, BIO-COMPOST, TEJAS, PUSA and NCOF. A control was maintained in which no microbial consortium was added. Each treatment consists of 100 kg Paddy straw + 10% cow dung + 1% Urea+ 0.1% jaggery. The moisture content was maintained at 50-60%. The MC/decomposer was added at the rate of 0.1% (solid/liquid). There were three replications under each treatment. Therefore, 18 bioconversion bags were used under the study (Figure 1). The turnings were made at the interval of 7 days to provide aeration. The outline of the methodology used in the study is depicted in Figure 2. The samples of paddy straw from bioconversion bags during composting process were drawn at different time intervals [0, 10, 20, 30, 40, 50 and 60 days after initiation (DAI)]. Collected samples were analyzed for various physico-chemical and biological characterization (Figure 3). The fresh samples were used for pH, EC, moisture content and biochemical analysis (enzymatic and microbial population). The samples were dried at 65°C for

Table 1. Treatment details

Treatment	Microbial Consortium (MC)/ Decomposer	Type of formulation	Source of procurement
MC-1	BIO-FAST	Liquid	Microbial Technology Lab, ICAR-National Bureau of Agriculturally Important Microorganisms, Mau
MC-2	BIO-COMPOST	Liquid	ICAR-National Bureau of Agriculturally Important Microorganisms, Mau
MC-3	TEJAS	Solid	M/s Indore Biotech, Indore
MC-4	PUSA	Gel to Liquid (as per manufacturer instruction)	ICAR- Indian Agricultural Research Institute, New Delhi
MC-5	NCOF	Gel to Liquid (as per manufacturer instruction)	National Centre for Organic Farming, Ghaziabad, India
Control	No MC/ Decomposer		

Note: MC: Microbial Consortium; Each treatment consists of 100 kg Paddy straw + 10% cow dung + 1% Urea+ 0.1% jaggery. The moisture content was maintained at 50-60%. The MC/decomposer was added at the rate of 0.1% (solid/liquid). Number of replications in each treatment-3. The turnings were made at the interval of 7 days to provide aeration.

24 h grounded and passed through 0.5 mm mesh size sieve. The fine powdered samples were used for chemical analysis (Total N, P, K, Organic carbon and micronutrients)

Physico-chemical characterisation of paddy straw during composting process

The change in the pattern of temperature in the compost pile during the composting process was noted on daily basis using garden thermometer. Five grams of the sample was mixed with 25 ml distilled water and pH and EC were estimated. The moisture content (%) was calculated based on the difference in weight of initial sample (g) and the final sample (g) after drying at 105°C for 3-4 h. The moisture content was estimated using the formula (initial weight-final weight/initial weight x 100). The dried samples were used for analysing the primary and micronutrients. The total nitrogen content (%) was estimated by micro-kjeldhal method,[19] while the total phosphorus content (%) was estimated by vanadate-molybdate method,[20] and potassium content (%) by flame photometer (SYSTRONICS Flame Photometer 128).[15] The organic carbon (OC) content of the bio-compost were evaluated

Figure 1. Experimental trial set-up of rapid composting of paddy straw using bioconversion bags

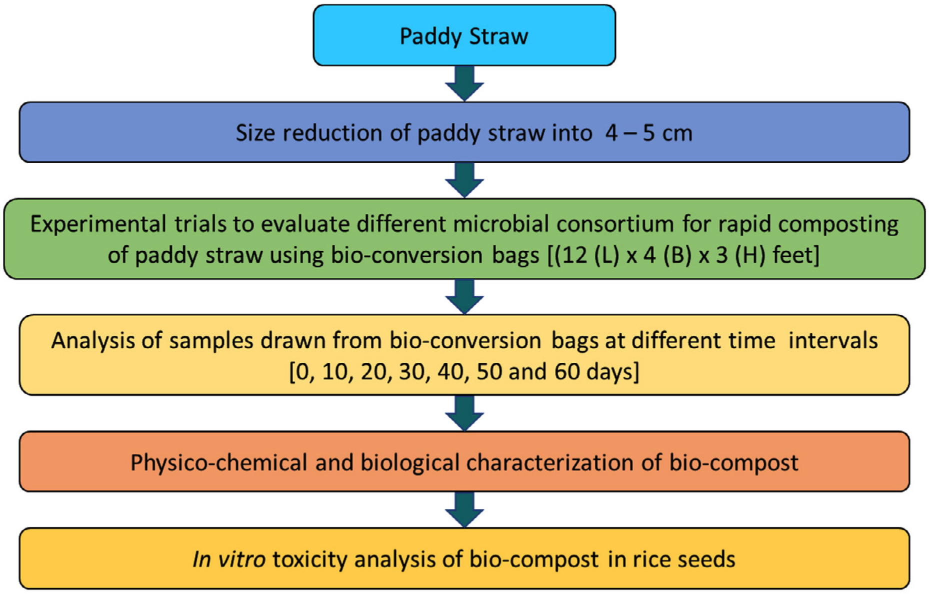

Figure 2. Methodology followed in the study

by using Walkley-Black method.[21] The C:N ratio of the paddy straw during the composting process was determined by taking the ratio between carbon and nitrogen content in the samples. The micronutrients (Fe and Zn) in ppm in the final sample (60 DAI) were estimated using Atomic Absorption Spectrophotometer.[15]

Biological Characterization of paddy straw during composting process

The fresh samples were used for biochemical analysis such as enzymatic activity and microbial population. The enzymatic activities Cellulase, Xylanase, Amylase and Peroxidase in the samples at different intervals were calculated

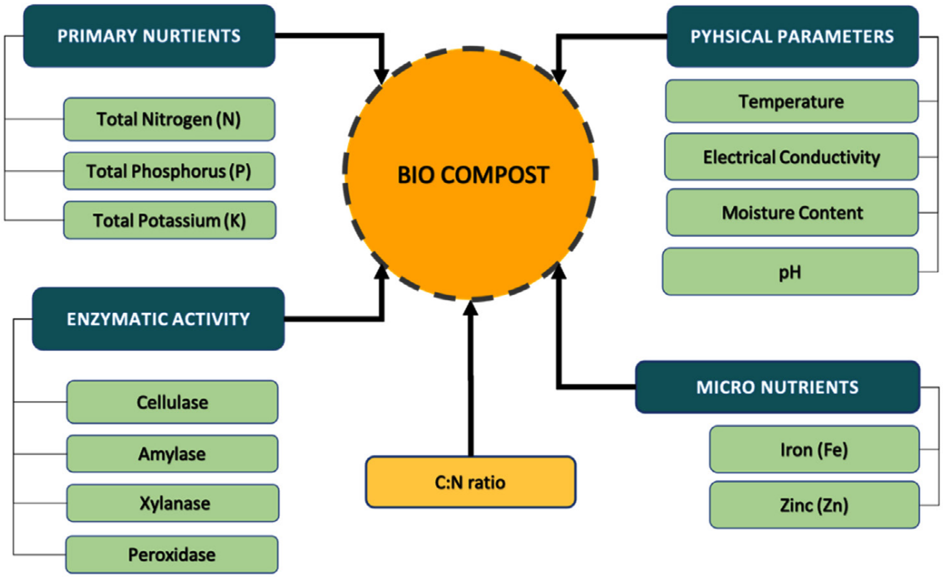

Figure 3. Physico-chemical and biological characterization of bio-compost

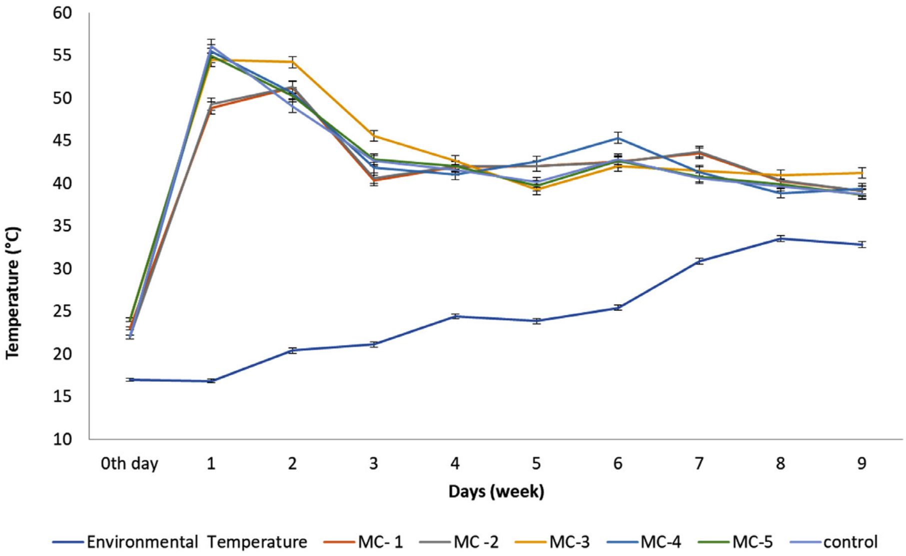

Figure 4. Dynamics of temperature during paddy straw composting

Table 2. Dynamics of % Total Nitrogen (N) during paddy straw composting

Treatment	DAI						
	0	10*	20	30	40	50	60
MC-1	0.55 (4.25)^{ab}	0.63 (4.55)	0.67 (4.69)^{b}	0.82 (5.19)^{b}	0.94 (5.56)^{bc}	1.37 (6.72)	1.65 (7.37)^{a}
MC-2	0.59 (4.40)^{ab}	0.63 (4.52)	0.67 (4.69)^{b}	0.78 (5.07)^{b}	1.22 (6.32)^{a}	1.14 (6.13)	1.37 (6.72)^{ab}
MC-3	0.51 (4.09)^{b}	0.51 (4.09)	0.65 (4.69)^{b}	1.02 (5.79)^{b}	1.06 (5.91)^{ab}	1.14 (6.05)	1.21 (6.29)^{bc}
MC-4	0.63 (4.55)^{a}	0.67 (4.69)	0.78 (5.07)^{b}	0.86 (5.32)^{b}	0.86 (5.32)^{c}	0.94 (5.56)	0.98 (5.67)^{cd}
MC-5	0.51 (4.09)^{b}	0.59 (4.58)	0.78 (5.07)^{b}	1.02 (5.79)^{a}	1.06 (5.90)^{ab}	1.33 (6.57)	1.69 (7.45)^{a}
Control	0.43 (3.76)^{c}	0.74 (4.95)	0.74 (4.95)^{b}	0.78 (5.07)^{b}	0.86 (5.32)^{c}	0.88 (5.38)	0.93 (5.53)^{d}
CV	4.37	6.32	3.68	3.73	5.10	10.90	6.42

DAI: Days After Initiation; MC: Microbial Consortium; CV: Coefficient of Variation. Treatment values having a common superscript letter(s) (a, b, c, d, ab, bc and cd) are not significantly different at P=0.05 as analyzed by one-way ANOVA. *NS: Not Significant. Figures in parentheses are arc sign transformed values.

according to the method as described by Ghose and Bisaria.[22] One g of sample was taken in 10 ml of acetate buffer (pH 4.8, 0.05 M) and extracted for 30 min. The extract was centrifuged at 5000 rpm for 10 min. The filtrate was used for enzyme assay. The enzyme activity of Cellulase, Xylanase and Amylase was expressed in mg/ml/h while peroxidase was expressed in Units/L. The microbial population in the samples were enumerated based on serial dilution technique. One g of sample was taken in 9 ml sterile blank and serial dilutions were prepared. The serial dilutions (bacteria- 10^{-6} to 10^{-8}; fungi- 10^{-1} to 10^{-3}; actinomycetes- 10^{-4} to 10^{-6}) were plated on nutrient agar, rose bengal agar and kenknight's agar, respectively. The microbial population was expressed in colony forming units (CFU)/g on dry weight basis.

In vitro toxicity analysis of bio-compost of paddy straw in rice seeds

The phytotoxicity and bio compost maturity of paddy straw compost was assayed.[23,24] To test the phytotoxicity and bio-compost maturity; seed germination, relative root elongation and germination index of rice seeds were assessed under laboratory conditions. One g compost was taken in 10 ml of sterile distilled water and extracted for 1 hrs. The slurry was filtered using the Whatman's filter paper No. 1 and the filtrate was used for toxicity assay. The three different concentrations of extract tested for seed germination assay were 100%, 50% and 20%, respectively. The germination assay was conducted in square Petri plates (120 mm). In each of the Petri plate, sterilized (autoclaved) filter paper (12 x 12 cm) was placed. Five ml of extract was added in each Petri plate while 5 ml of distilled water added in control. Twenty rice seed (cv. BPT 5204) was placed in each Petri plate. Five replications were maintained in both control and treatments. The Petri plates were incubated at 25°C in the dark for 5 days. The relative seed germination (SG), relative root elongation (RE) and germination index (GI) were calculated as follows:

$$SG\% = \frac{\text{Number of seeds germinated in extract}}{\text{Number of seeds germinated in control}} \times 100$$

$$RE\% = \frac{\text{Mean root length in extract}}{\text{Mean root length in control}} \times 100$$

$$GI\% = \frac{SG\% \times RE\%}{100}$$

Statistical analysis

The data was analysed in a completely randomized design (CRD) using one-way analysis of variance (ANOVA) (WASP.1; ICAR research complex, Goa). For all analysis, the differences were considered to be significant at P ≤ 0.05. The standard error mean (SEM) was determined by using MS Excel 2019.

RESULTS

Physico-chemical properties

The temperature of the heap of paddy straw in bioconversion bags during the composting process was observed on daily basis from start to 60 days of composting. The temperature was recorded on 5 different spots in each bioconversion bags and the average were taken. The record of temperature on weekly basis is depicted in Figure 4. The results showed that in the active phase of composting, temperature was raised to the maximum of 55 to 60°C in first week and the temperature was maintained at thermophilic phase (40-45°C) till week 7. After that, the temperature reached to mesophilic phase (30-40°C) equivalent to environmental temperature. The pH of the paddy straw during composting process was observed at 10 days interval. The result showed that there is an increase in the pH from neutral (6.5 to 7.0) to alkaline (8.0 to 8.75) irrespective of the treatments (Figure 5). Due to intermittent addition of moisture, the moisture content of the bio compost heaps was maintained between 50 to 60% (results not shown). The electrical conductivity (EC) (mS/cm) of the paddy straw during composting process was observed at 10 days interval. The EC has been increased in all the treatments from the range (0.72 to 1.61) to (3.24 to 3.91) (Figure 6).

The total N, P and K of the paddy straw during composting process was analysed at the

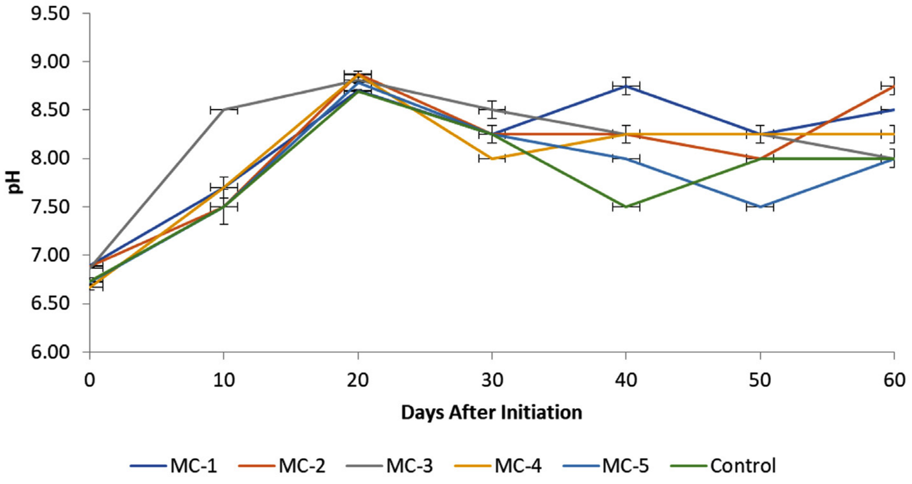

Figure 5. Dynamics of pH during paddy straw composting

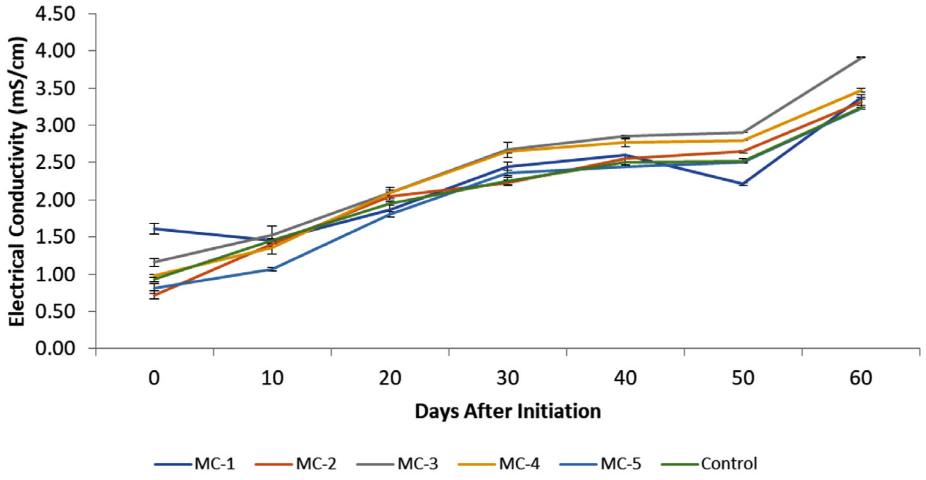

Figure 6. Dynamics of Electrical Conductivity during paddy straw composting

Table 3. Dynamics of % Total Phosphorus (P) during paddy straw composting

Treatment	DAI						
	0	10	20	30	40	50	60
MC-1	0.19 (2.52)	0.23 (2.77)^{bc}	0.29 (3.07)^{bc}	0.38 (3.53)^{a}	0.35 (3.41)^{a}	0.36 (3.42)	0.44 (3.82)^{a}
MC-2	0.21 (2.63)	0.25 (2.87)^{a}	0.29 (3.07)^{bc}	0.26 (2.87)^{d}	0.36 (3.44)^{a}	0.36 (3.46)	0.44 (3.80)^{a}
MC-3	0.21 (2.63)	0.22 (2.69)^{d}	0.26 (3.03)^{c}	0.28 (2.96)^{cd}	0.34 (3.34)^{a}	0.37 (3.47)	0.43 (3.75)^{a}
MC-4	0.21 (2.63)	0.24 (2.83)^{ab}	0.29 (3.24)^{a}	0.32 (3.09)^{bc}	0.35 (3.39)^{a}	0.37 (3.49)	0.35 (3.38)^{b}
MC-5	0.20 (2.56)	0.22 (2.69)^{d}	0.30 (3.16)^{ab}	0.30 (3.14)^{b}	0.31 (3.17)^{b}	0.38 (3.52)	0.34 (3.34)^{b}
Control	0.21 (2.61)	0.23 (2.73)^{cd}	0.30 (3.16)^{ab}	0.27 (3.00)^{bcd}	0.33 (3.29)^{ab}	0.35 (3.39)	0.35 (3.39)^{b}
CV	2.18	1.26	1.87	2.95	2.69	2.21	4.40

DAI: Days After Initiation; MC: Microbial Consortium; CV: Coefficient of Variation. Treatment values having a common superscript letter(s) (a, b, c, d, ab, bc, cd and bcd) are not significantly different at P = 0.05 as analyzed by one-way ANOVA. Figures in parentheses are arc sign transformed values.

Table 4. Dynamics of % Total Potassium (K) during paddy straw composting

Treatment	DAI						
	0	10	20	30	40	50	60
MC-1	0.54 (4.20)^{a}	1.10 (6.02)^{c}	1.59 (7.24)^{a}	1.62 (7.31)^{b}	1.82 (7.75)^{a}	1.69 (7.46)^{a}	1.63 (7.34)^{a}
MC-2	0.52 (4.15)^{a}	1.25 (6.41)^{a}	1.59 (7.24)^{a}	1.44 (6.88)^{cd}	1.91 (7.94)^{a}	1.58 (7.22)^{a}	1.53 (7.10)^{ab}
MC-3	0.53 (4.17)^{a}	1.12 (6.08)^{bc}	1.48 (6.99)^{a}	1.75 (7.61)^{a}	1.96 (8.05)^{a}	1.70 (7.48)^{a}	1.46 (6.93)^{b}
MC-4	0.53 (4.18)^{a}	1.16 (6.18)^{b}	1.59 (7.24)^{a}	1.53 (7.11)^{bc}	1.77 (7.64)^{ab}	1.68 (7.44)^{a}	1.53 (7.11)^{ab}
MC-5	0.40 (3.62)^{b}	1.07 (5.94)^{cd}	1.34 (6.65)^{b}	1.51 (7.06)^{cd}	1.57 (7.20)^{bc}	1.02 (5.72)^{b}	1.49 (7.01)^{b}
Control	0.37 (3.48)^{b}	1.03 (5.82)^{d}	1.26 (6.44)^{b}	1.41 (6.82)^{d}	1.38 (6.75)^{c}	1.51 (7.06)^{a}	1.32 (6.60)^{c}
CV	3.49	1.51	2.22	1.91	3.34	7.23	1.98

DAI: Days After Initiation; MC: Microbial Consortium; CV: Coefficient of Variation. Treatment values having a common superscript letter(s) (a, b, c, d, ab, bc and cd) are not significantly different at P = 0.05 as analyzed by one-way ANOVA. Figures in parentheses are arc sign transformed values.

interval of 10 days. In general, the total nitrogen content of the paddy straw has been increased from 0 to 60 days (Table 2). At 0th day the total N (%) was recorded lower in control (0.43) and higher in microbial consortia applied paddy straw. Among them, MC-4 was recorded highest (0.63). The total N was found higher in microbial consortium added compost than the control during composting process (10-60 days). At 60 days of composting the total N was found higher ($p < 0.05$) in MC-5 added compost (1.69) followed by MC-1 (1.65) when compared to control (0.93). The total P (%) of paddy straw during composting process at different intervals (0-60 days) were estimated. The results showed that at 0th day of composting the total P content was the range 0.19-0.21. The total P content was increased from 0th day to 60 days irrespective of all the treatments. At 60th day, the total P was higher ($p < 0.05$) in MC-1(0.44), MC-2 (0.44) and MC-3 (0.43) compared to control (0.35) (Table 3). The total K (%) of paddy straw during composting process at different intervals (0-60 days) were estimated. In general, the total K was found increased with respect to the increase to the days of composting. Similarly, the K content was found higher in microbial consortium added paddy straw than the control in all days of composting. At 0th day of composting, the lower K content was recorded in control (0.37) and the higher K content was recorded in MC-1 (0.54). At 60th day of composting the higher K content was recorded in microbial consortia added paddy straw than the control. Among microbial consortia, MC-1 added paddy straw recorded higher K content (1.63) compared to control (1.32) at $p < 0.05$ (Table 4). The organic carbon [(OC)%] in paddy

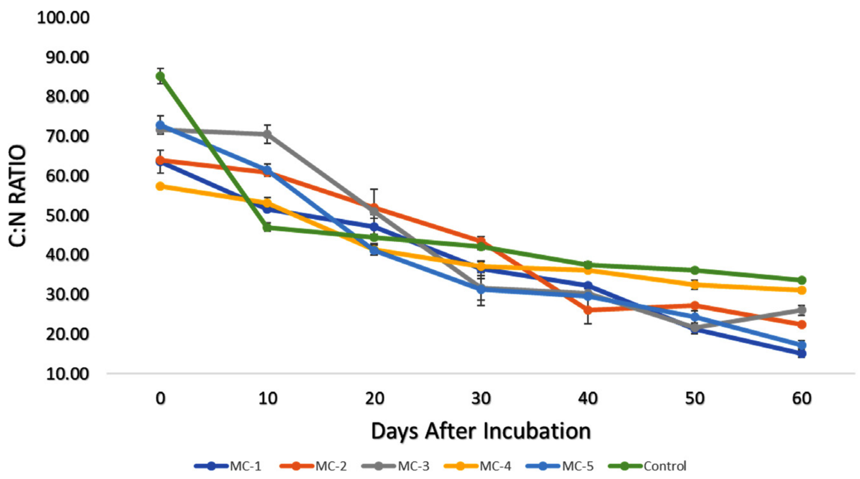

Figure 7. Dynamics of C:N ratio during paddy straw composting

straw during composting process was recorded at different intervals (0 to 60 days) (Table 5). It was found that OC was decreasing with the increase in days of composting. The OC content at 0th day of composting was in the range of (34.50-37.65). At 60 days of composting, the lowest OC was recorded in MC-1 (24.75) followed by MC-5 (28.65) and the highest value was recorded in control (31.35) at $p < 0.05$.

C:N ratio

The C:N ratio of the paddy straw was recorded during composting process at different intervals (0 to 60 days) (Figure 7). At 0th day of composting C:N ratio was recorded higher in control (85.31) and lower (57 to 73) in microbial consortia applied paddy straw. Among them, MC-4 recorded lowest (57.4). With the increase in days of composting, the C:N ratio was found decreasing. The results showed that C:N ratio was reached to <20 at 60 days in the treatments (MC-1 and MC-5) and the corresponding values were (15.11 and 17.11), respectively. The C:N ratio recorded in control at 60 days was 33.71.

Physico-chemical parameters of paddy straw compost

The physicochemical parameters of bio-compost prepared from paddy straw after 60 days of composting has been given in Table 6. The total N, P, K (%) was found higher in microbial consortium added compost than the control at $p < 0.05$. The total N, P, K content (3.72) was recorded higher in MC-1 (BIO-FAST) added compost and the corresponding values were (1.65, 0.44 and 1.63), respectively. Next to MC-1 the N, P, K content (3.52) was recorded higher in MC-5 (NCOF) and the corresponding values were (1.69, 0.34 and 1.49), respectively. The micronutrients (Fe and Zn) in ppm was recorded higher in microbial consortium added compost than the control. The micronutrient (Fe) was higher ($p < 0.05$) in MC-1 (2135.00) while, Zn in MC-5 (138.65) (Table 6).

Biological properties

The dynamics of microbial population during composting of paddy straw is given in Table 7. There was an increase in the microbial population with the progress of composting. The bacterial population was higher even at the start of composting (10^9 CFU/g), increased to 10^{10} CFU/g and reached again to 10^9 CFU/g at the end of composting period. The fungal population had been increased steadily from 10^2 CFU/g at 0 DAI to 10^9 CFU/g at 60 DAI. Similarly, the actinomycetes population also increased steadily from 10^5 CFU/g at 0 DAI to 10^7 CFU/g at 60 DAI. There were no differences found in microbial population among the treatments. The cellulase, amylase, xylanase and peroxidase activities of paddy straw during composting process was recorded at different intervals (0 to 60 days). The cellulase activity

Table 5. Dynamics of % organic carbon (OC) during paddy straw composting

Treatment	DAI						
	0	10	20	30	40	50	60
MC-1	34.50 (35.97)	32.55 (34.79)^{b}	31.50 (34.14)	30.00 (33.20)^{c}	30.30 (33.38)	28.95 (32.55)	24.75 (29.80)^{b}
MC-2	37.65 (37.85)	36.30 (37.05)^{a}	34.65 (36.06)	33.90 (33.86)^{bc}	31.20 (35.61)	31.05 (33.59)	30.60 (33.59)^{a}
MC-3	36.45 (37.14)	35.85 (36.78)^{a}	33.00 (34.51)	32.25 (35.06)^{a}	32.10 (34.60)	31.05 (33.86)	30.45 (33.49)^{a}
MC-4	36.15 (36.96)	35.55 (36.60)^{a}	32.25 (34.60)	31.65 (34.23)^{abc}	30.90 (33.77)	30.45 (33.40)	30.30 (33.40)^{a}
MC-5	37.05 (37.49)	36.15 (36.96)^{a}	32.10 (34.51)	31.80 (34.33)^{ab}	31.05 (33.86)	30.15 (33.30)	28.65 (32.36)^{a}
Control	36.60 (37.22)	34.95 (36.24)^{a}	33.00 (35.06)	32.85 (34.97)^{ab}	32.10 (34.51)	31.50 (34.14)	31.35 (34.05)^{a}
CV	1.85	1.39	2.00	1.82	2.35	1.63	3.17

DAI: Days After Initiation; MC: Microbial Consortium; CV: Coefficient of Variation. Treatment values having a common superscript letter(s) (a, b, c, ab, bc and abc) are not significantly different at P=0.05 as analyzed by one-way ANOVA. Figures in parentheses are arc sign transformed values.

(mg/ml/h) was found to be increasing with the increase in composting days and the maximum value was recorded at 50 and 60 days. At sixty days of composting the maximum cellulase activity (2.99 ± 0.09) was recorded in MC-1 and the lowest value was recorded in MC-5 (2.68 ± 0.01) (Table 8). The amylase activity (mg/ml/h) was recorded higher at 10 days of composting and thereafter decreasing trend was observed. The maximum amylase activity was recorded in MC-1, MC-3 and control and corresponding values were 3.23 ± 0.05, 3.23 ± 0.12 and 3.22 ± 0.04, respectively (Table 9). Similar to amylase, the xylanase activity (mg/ml/h) was higher at 10 days of composting thereafter a decreasing trend was observed. The maximum xylanase activity (29.38) in MC-4 applied compost (Table 10). The peroxidase activity of paddy straw compost was higher at 10 DAI and the maximum peroxidase activity was observed in MC-1 applied compost as given in Table 11.

Phytotoxicity and maturity

The *in vitro* toxicity to assess the phytotoxicity and the maturity of compost was done through seed germination (%), relative root elongation (%) and germination index (%). The seed germination was found to be insignificant at $p < 0.05$. The seed germination was recorded more than 90% in all the treatments. The relative root elongation was significantly higher in MC-3 (66.31) followed by MC-1 (58.33) when compared to control (41.79) at $p < 0.05$. Similarly, the germination index was significantly higher in MC-3 (59.66) followed by MC-1 (56.67) when compared to control (38.71) at $p < 0.05$ (Table 12). The 100% extract of the compost had lower germination index than the dilute (50% and 20%).

DISCUSSION

The present study was attempted to evaluate the microbial consortia on rapid composting of paddy straw using bioconversion bags. The different microbial consortia evaluated were BIO-FAST, BIO-COMPOST, TEJAS, PUSA and NCOF. The samples were drawn from bioconversion bags at different intervals (0, 10, 20, 30, 40, 50 and 60 days) to analyze for physico-chemical and biological parameters. The different physico-chemical parameters observed were temperature, pH, EC, moisture content, total N, P, K, organic carbon and C:N ratio. The temperature in the heap was increased between 55 to 60°C during first week of composting and maintained thermophilic phase (40 to 45°C) till seventh week. The rise in temperature might be due to the onset of higher microbial activity to decompose the sugar, starch and proteins present in composting pile which increases the heat dissipation due to the respiration of micro-organisms, eventually increasing the temperature initially.[11] In another study, Haug,[25] reports that higher composting temperature (above 55°C) for continuous three days helps to eradicate the pathogens present in

Table 6. Physiochemical parameters of paddy straw compost at 60 DAI

Treatment	% Total Nitrogen (N)	% Total Phosphorus (P)	% Total Potassium (K)	% Organic carbon (OC)	Iron (Fe)	Zinc (Zn)
MC-1	1.65 (7.37)^{a}	0.44 (3.82)^{a}	1.63 (7.34)^{a}	24.75 (29.80)^{b}	2135.00^{a}	88.30^{b}
MC-2	1.37 (6.72)^{ab}	0.44 (3.80)^{a}	1.53 (7.10)^{ab}	30.60 (33.59)^{a}	1695.00^{b}	82.95^{b}
MC-3	1.21 (6.29)^{bc}	0.43 (3.75)^{a}	1.46 (6.93)^{b}	30.45 (33.49)^{a}	1582.50^{b}	81.45^{b}
MC-4	0.98 (5.67)^{cd}	0.35 (3.38)^{b}	1.53 (7.11)^{ab}	30.30 (33.40)^{a}	635.00^{c}	106.78^{ab}
MC-5	1.69 (7.45)^{a}	0.34 (3.34)^{b}	1.49 (7.01)^{b}	28.65 (32.36)^{a}	570.00^{cd}	138.65^{a}
Control	0.93 (5.53)^{d}	0.35 (3.39)^{b}	1.32 (6.60)^{c}	31.35 (34.05)^{a}	320.00^{d}	72.85^{b}

MC: Microbial Consortium; Treatment values having a common superscript letter(s) (a, b, c, d, ab, bc and cd) are not significantly different at P=0.05 as analyzed by one-way ANOVA. Figures in parentheses are arc sign transformed values.

Table 7. Dynamics of microbial population (CFU/g) during paddy straw composting

Treatment	DAI						
	0	10	20	30	40	50	60
				Bacteria			
MC-1	33.68×10^{9}	41.00×10^{9}	42.00×10^{9}	28.97×10^{10}	34.56×10^{10}	46.37×10^{10}	17.10×10^{10}
MC-2	39.60×10^{9}	64.27×10^{9}	86.03×10^{9}	30.63×10^{10}	39.92×10^{10}	44.63×10^{10}	10.96×10^{10}
MC-3	42.20×10^{9}	53.45×10^{8}	23.35×10^{10}	57.09×10^{10}	65.21×10^{10}	68.22×10^{10}	42.32×10^{9}
MC-4	42.34×10^{9}	15.15×10^{9}	21.59×10^{9}	35.30×10^{10}	39.18×10^{10}	44.65×10^{10}	39.13×10^{9}
MC-5	38.96×10^{9}	70.71×10^{9}	79.94×10^{9}	95.16×10^{9}	35.86×10^{10}	51.18×10^{10}	97.19×10^{8}
Control	42.75×10^{9}	53.77×10^{9}	56.99×10^{9}	48.36×10^{10}	50.86×10^{10}	58.14×10^{10}	82.90×10^{9}
				Fungi			
MC-1	18.80×10^{2}	21.70×10^{3}	25.93×10^{4}	28.73×10^{4}	55.66×10^{7}	45.73×10^{9}	34.96×10^{9}
MC-2	25.83×10^{2}	13.08×10^{4}	09.78×10^{4}	11.98×10^{4}	44.68×10^{7}	39.63×10^{9}	10.96×10^{10}
MC-3	63.88×10^{2}	12.67×10^{4}	28.82×10^{4}	37.26×10^{4}	24.36×10^{8}	28.76×10^{9}	42.32×10^{9}
MC-4	13.50×10^{2}	13.38×10^{4}	16.43×10^{4}	11.80×10^{4}	13.80×10^{7}	33.92×10^{9}	39.13×10^{9}
MC-5	19.42×10^{2}	11.04×10^{4}	12.89×10^{4}	15.27×10^{4}	45.16×10^{8}	56.23×10^{8}	97.19×10^{8}
Control	25.80×10^{2}	19.61×10^{4}	36.51×10^{4}	71.44×10^{4}	48.94×10^{7}	51.74×10^{9}	82.90×10^{9}
				Actinomycetes			
MC-1	10.55×10^{5}	19.54×10^{5}	36.46×10^{6}	48.62×10^{6}	54.25×10^{6}	69.90×10^{7}	20.61×10^{7}
MC-2	11.87×10^{5}	17.43×10^{5}	23.85×10^{6}	36.64×10^{6}	41.33×10^{6}	11.53×10^{7}	13.56×10^{7}
MC-3	27.77×10^{5}	29.42×10^{5}	32.42×10^{6}	41.31×10^{6}	43.54×10^{6}	73.04×10^{6}	16.53×10^{7}
MC-4	35.41×10^{5}	38.84×10^{5}	47.16×10^{6}	58.47×10^{6}	62.29×10^{6}	11.91×10^{7}	11.20×10^{7}
MC-5	28.81×10^{5}	72.59×10^{5}	23.64×10^{6}	36.84×10^{6}	44.16×10^{6}	91.52×10^{6}	64.56×10^{7}
Control	31.34×10^{5}	38.34×10^{5}	13.44×10^{6}	23.48×10^{6}	29.86×10^{6}	52.52×10^{6}	57.74×10^{7}

DAI: Days After Initiation; MC: Microbial Consortium the pile. The thermophilic phase (40 to 45°C) from second to seventh week and mesophilic phase 30 to 40°C after 7th week denotes the succession of microbial activity due to changes in the organic matter pattern in compost.[26]

The pH and EC were recorded increasing over the composting period. The pH was changed from neutral (6.5 to 7.0) to alkaline (8.0 to 8.70) at the end of composting. Similarly, the EC was changed from (0.72 to 1.61) to (3.23 to 3.91) at

Table 8. Dynamics of cellulase activity during paddy straw composting

Treatment	DAI						
	0	10	20	30	40	50	60
MC-1	1.013 ± 0.00^{a}	1.08 ± 0.00^{ab}	1.32 ± 0.01^{c}	2.71 ± 0.01	2.79 ± 0.06^{a}	2.81 ± 0.01	2.99 ± 0.09^{a}
MC-2	0.95 ± 0.09^{a}	1.05 ± 0.06^{ab}	1.37 ± 0.22^{c}	2.78 ± 0.09	2.80 ± 0.04^{a}	2.78 ± 0.03	2.92 ± 0.00^{ab}
MC-3	0.957 ± 0.08^{a}	0.89 ± 0.04^{bc}	2.08 ± 0.06^{c}	2.76 ± 0.06	2.85 ± 0.01^{a}	3.15 ± 0.16	2.86 ± 0.03^{b}
MC-4	0.953 ± 0.07^{a}	0.83 ± 0.03^{c}	1.60 ± 0.16^{b}	2.85 ± 0.02	2.63 ± 0.01^{b}	2.83 ± 0.04	2.93 ± 0.01^{ab}
MC-5	0.637 ± 0.02^{b}	1.11 ± 0.14^{a}	2.82 ± 0.00^{a}	2.79 ± 0.03	2.78 ± 0.05^{a}	2.89 ± 0.00	2.68 ± 0.01^{c}
Control	1.01 ± 0.04^{a}	1.16 ± 0.01^{a}	2.64 ± 0.05^{a}	2.72 ± 0.05	2.79 ± 0.00^{a}	3.02 ± 0.11	2.85 ± 0.03^{b}
CV	11.25	11.28	9.94	3.18	2.29	4.95	2.34

DAI: Days After Initiation; MC: Microbial Consortium; CV: Coefficient of Variation. Treatment values having a common superscript letter(s) (a, b, c, ab and bc) are not significantly different at P=0.05 as analyzed by one-way ANOVA

Table 9. Dynamics of amylase activity during paddy straw composting

Treatment	DAI						
	0	10	20	30	40	50	60
MC-1	3.42 ± 0.01^{a}	3.23 ± 0.05	2.83 ± 0.09^{bc}	1.38 ± 0.02^{c}	1.42 ± 0.02	1.42 ± 0.02^{ab}	1.05 ± 0.00
MC-2	2.93 ± 0.00^{b}	3.08 ± 0.09	2.56 ± 0.07^{cd}	1.48 ± 0.01^{ab}	1.43 ± 0.02	1.33 ± 0.00^{c}	1.33 ± 0.00
MC-3	2.52 ± 0.02^{d}	3.23 ± 0.12	3.23 ± 0.16^{a}	1.47 ± 0.01^{ab}	1.38 ± 0.01	1.38 ± 0.01^{bc}	1.00 ± 0.31
MC-4	2.92 ± 0.01^{b}	3.05 ± 0.11	2.77 ± 0.06^{bcd}	1.54 ± 0.00^{a}	1.46 ± 0.02	1.31 ± 0.03^{c}	1.31 ± 0.03
MC-5	2.63 ± 0.07^{c}	3.15 ± 0.07	2.48 ± 0.04^{d}	1.41 ± 0.02^{bc}	1.39 ± 0.05	1.38 ± 0.06^{bc}	1.38 ± 0.06
Control	2.69 ± 0.00^{c}	3.22 ± 0.04	2.89 ± 0.17^{b}	1.39 ± 0.05^{c}	1.48 ± 0.02	1.48 ± 0.02^{a}	1.34 ± 0.03
CV	1.84	4.76	6.66	2.77	3.02	3.51	18.16

DAI: Days After Initiation; MC: Microbial Consortium; CV: Coefficient of Variation; Treatment values having a common superscript letter(s) (a, b, c, d, ab, bc, cd and bcd) are not significantly different at P=0.05 as analyzed by one-way ANOVA

Table 10. Dynamics of xylanase activity during paddy straw composting

Treatment	DAI						
	0	10	20	30	40	50	60
MC-1	15.26 ± 2.42	27.42 ± 0.02^{d}	23.04 ± 0.00	18.12 ± 1.92^{a}	15.08 ± 3.16	13.22 ± 0.42^{c}	6.40 ± 0.12^{d}
MC-2	12.36 ± 0.84	28.88 ± 0.32^{b}	19.02 ± 0.94	18.12 ± 1.80^{a}	16.50 ± 0.02	15.28 ± 0.60^{a}	10.48 ± 1.04^{ab}
MC-3	14.22 ± 0.58	28.20 ± 0.24^{c}	26.26 ± 4.98	16.90 ± 1.66^{a}	15.64 ± 1.64	14.16 ± 0.72^{b}	8.92 ± 0.68^{bc}
MC-4	12.66 ± 0.26	29.38 ± 0.34^{a}	23.10 ± 0.34	19.06 ± 0.82^{a}	15.88 ± 1.48	13.18 ± 0.46^{c}	8.28 ± 0.56^{cd}
MC-5	14.44 ± 0.68	28.04 ± 0.36^{c}	24.00 ± 2.12	14.40 ± 0.44^{b}	13.10 ± 0.74	13.08 ± 0.44^{c}	11.08 ± 2.44^{a}
Control	14.20 ± 0.09	27.94 ± 0.02^{c}	22.02 ± 2.18	17.06 ± 0.86^{a}	15.16 ± 0.56	13.84 ± 0.32^{bc}	7.60 ± 0.12^{cd}
CV	8.47	0.91	10.55	7.93	10.63	3.700	13.00

DAI: Days After Initiation; MC: Microbial Consortium; CV: Coefficient of Variation; Treatment values having a common superscript letter(s) (a, b, c, d, ab, bc and cd) are not significantly different at P=0.05 as analyzed by one-way ANOVA the end of composting. The increase in pH and EC was due to the release of ions in the mineralization process of composting. The composting process requires sufficient moisture usually 50 to 60% for the biodegradation to take place. However, moisture content more than 60 to 65% creates the

Table 11. Dynamics of peroxidase activity during paddy straw composting

Treatment	DAI				
	0	10	20	30	40
MC-1	3.65 ± 0.67	9.46 ± 0.99^{a}	2.78 ± 0.30	2.73 ± 0.25^{a}	1.54 ± 0.30^{a}
MC-2	2.73 ± 0.25	5.72 ± 0.25^{b}	2.98 ± 0.00	2.16 ± 0.32^{b}	0.00^{c}
MC-3	3.36 ± 0.38	4.32 ± 0.59^{c}	2.73 ± 0.25	2.48 ± 0.00^{ab}	1.54 ± 0.30^{a}
MC-4	2.41 ± 0.57	4.35 ± 0.62^{c}	2.73 ± 0.25	1.54 ± 0.30^{c}	0.92 ± 0.33^{b}
MC-5	2.98 ± 0.50	4.32 ± 0.00^{c}	2.48 ± 0.00	2.16 ± 0.32^{b}	1.54 ± 0.30^{a}
Control	3.20 ± 1.71	3.36 ± 0.38^{c}	2.98 ± 0.00	0.92 ± 0.33^{d}	0.00^{c}
CV	27.23	10.78	6.81	13.91	27.12

DAI: Days After Initiation; MC: Microbial Consortium; CV: Coefficient of Variation; Treatment values having a common superscript letter(s) (a, b, c, d and ab) are not significantly different at P=0.05 as analyzed by one-way ANOVA

Table 12. Phytotoxicity and maturity analysis of paddy straw bio-compost in rice seeds

Treatments*	Seed germination SG (%)	Relative root elongation RE (%)	Germination Index GI (%)
		100 %	
MC-1	97.50 (82.11)	58.33 (49.84)^{a}	56.67 (48.86)^{ab}
MC-2	90.00 (71.95)	41.67 (40.20)^{b}	37.60 (37.80)^{c}
MC-3	90.00 (71.95)	66.31 (54.52)^{a}	59.66 (50.58)^{a}
MC-4	92.50 (74.25)	45.00 (42.13)^{b}	41.60 (40.16)^{c}
MC-5	95.00 (79.00)	48.69 (44.24)^{b}	46.76 (43.10)^{bc}
Control	92.50 (76.56)	41.79 (40.27)^{b}	38.71 (38.46)^{c}
CV	8.970	21.224	23.33
		50%	
MC-1	97.50 (82.11)^{ab}	77.41 (61.71)^{c}	75.36 (60.26)^{b}
MC-2	97.50 (82.11)^{ab}	86.75 (68.68)^{bc}	84.63 (67.02)^{b}
MC-3	95.00 (77.08)^{b}	83.35 (65.95)^{bc}	79.19 (62.88)^{b}
MC-4	95.00 (77.08)^{b}	82.24 (65.17)^{bc}	78.13 (62.18)^{b}
MC-5	100.00 (88.34)^{a}	97.11 (81.65)^{a}	97.11 (81.65)^{a}
Control	97.50 (82.109)^{ab}	88.49 (72.22)^{ab}	86.54 (70.79)^{ab}
CV	4.973	8.275	9.10
		20%	
MC-1	100.00 (88.35)	95.67 (78.44)^{a}	95.67 (78.17)^{a}
MC-2	95.00 (79.00)	71.52 (58.52)^{bc}	68.80 (57.03)^{b}
MC-3	100.00 (88.35)	75.46 (60.37)^{a}	75.46 (60.39)^{b}
MC-4	97.50 (82.11)	75.32 (60.88)^{ab}	73.10 (59.31)^{b}
MC-5	100.00 (88.35)	72.21 (58.62)^{a}	72.21 (58.53)^{b}
Control	92.50 (74.25)	70.90 (57.43)^{c}	65.74 (54.16)^{b}
CV	5.21	11.95	12.40

* Treatment values having a common superscript letter(s) (a, b, c, ab and bc) are not significantly different at P=0.05 as analyzed by one-way ANOVA

anaerobic condition by filling the pores of compost hence retarding the process of decomposition.[27,28] In this study, the moisture content of 50 to 60% was maintained throughout the process as described by Nghi *et al*.[29]

The N, P, K content was significantly higher in microbial consortium added compost than control $p < 0.05$. The increasing trend of N, P, K content was observed invariably in all the treatments. Increase in content of nitrogen in microbial consortium added compost than control is similar to the trend observed by Jusoh *et al*.[11] According to Viel *et al*.[30] the loss of organic C in the form of CO_2 causes the net loss in dry mass which increase the amount of N during composting. Another study defines the activity of nitrogen fixing bacteria which generally occurs at the end of composting and might play role in increasing the values of N.[31] Increasing trend of P in the compost inoculated with consortia was in contrast with the results of Jusoh *et al*.[11] and in accordance to the results of Arumugam *et al*.,[32] Increased levels of P were recorded may be due to increased production of organic acids caused by mineralization of N which in turn induces the micro-organisms mediated P solubilization in the compost.[33,34] Phosphate level increment in the treatments is supported by the findings of Khankhane *et al*.,[35] and is might be due to the activities of microbial consortia added for compositing which induces the solubilization of phosphate in the pile of paddy straw. Lower levels of N, P and K in control (where none of the microbial consortia added) was due to reduced mineralization of N which in turn decreased the availability of nitrogen, phosphate and potassium in compost.[9,32]

The decreasing trend of organic carbon was observed during the composting process might be due to the action of microbial consortia over composting of paddy straw and hence causing mature rapidly.[4] The biodegradation of crop residues results in decrease in organic carbon content and increase in mineral content. The microbial consortia applied paddy straw had lower initial C:N ratio compared to control. This might be due to the addition of residual nitrogen from the liquid/solid consortium to the paddy straw. The microbial augmented and nitrogen fortified agricultural residues with initial C:N ratio of 60-70 accelerate the composting process by enhanced mineralization.[10, 36-38] The analysis of C:N ratio showed the decreasing trend and the C:N ratio was reached to <20 at 60 days in MC-1 (BIO-FAST) followed by MC-5 (NCOF) applied compost. The C:N ratio is the indicator of composting process and the decrease in C:N ratio represents the progress of composting. The maturity of the compost is indicated by the C:N ratio reached to <20.[11] Thus, the results of the present study showed the application of microbial consortia (BIO-FAST/NCOF) accelerate the composting process and the mature compost is prepared within 60 days. The total N, P, K content was higher in MC-1 (3.72) followed by MC-5 (3.52). The iron (Fe) and zinc (Zn) content of the mature compost was observed to be higher in MC-1 and MC-5 applied compost, respectively. The concentration of micronutrients, Zn and Fe is supported by previous studies which indicate that the accumulation of such metals is correlated with the maturity and stability of paddy straw compost inoculated with microbial consortia.[11]

The biological parameters such as microbial population and enzymatic activities (cellulase, amylase, xylanase and peroxidase) were analysed at different intervals of composting. Though the microbial population (bacteria, fungi and actinomycetes) had been increased during the composting process, there were no differences were found among the treatments. The cellulase activity was recorded higher at 50 and 60 days of composting while the amylase and xylanase activity were recorded higher at 10 days of composting. The enzymatic activity was found to insignificant between the control and treatments at $p < 0.05$ which was similar to the results of earlier work.[4,36] Increased activity of cellulase during active phase of composting was might be due to the action of β-1,4 endoglucanase over cellulose, opening up the reactive sites for the action of exoglucanase hence increasing the activity of cellulase.[37] Decreased assimilation of organic acid was also a reason for increasing the activity of amended microorganisms to produce hydrolytic enzymes for the degradation of high molecular weight compounds like cellulose, hemicellulose and lignin which in turn enhances their cellulase enzyme activity.[38] Increment in the activity of xylanase and peroxidase during the initial phase of composting was may be related to the depolymerisation of alkali soluble carbon (mineralisation of C) with the help of microbial consortia added as treatment.[4] The seed germination assay to evaluate the Phytotoxicity and the maturity of compost showed that the relative root elongation (%) and germination index (%) was significantly higher in MC-3 (TEJAS) followed by MC-1 (BIO-FAST) when compared to control. Increased levels of seed germination in treatments MC-1 followed by MC-5, over control depicts that microbial consortia used in these treatments resulted to produce mature composts without imparting any phytotoxicity over germination of rice seeds.[39] Many studies reported that a GI higher than 80% indicates the absence of phytotoxins in composts.[40, 41] According to Selim *et al*.,[42] GI ranging from 66 to 100 indicates absence of phytotoxicity. Results of current study show that the diluted extract (50% and 20%) of compost had higher germination index and no phytotoxicity effect.

CONCLUSION

Paddy straw is available in abundance. However, they are mostly burnt in the field itself due to the short window that exist between rice-wheat cropping system. Among the different applications, rapid composting of paddy straw is gaining importance as they provide on-farm utilization solutions and avoid logistics problems. The microbial consortia applied paddy straw has lower initial C:N ratio (57-73) and showed rapid mineralization. The primary nutrients and the micronutrients were significantly higher in BIO-FAST followed by NCOF applied compost. However, the microbial population and the enzymatic activity were not significant between the treatments and control. The toxicity analysis showed that the compost was matured in TEJAS followed by BIO-FAST applied treatments. Among the microbial consortia evaluated, BIO-FAST followed by NCOF were found to be best for rapid composting of paddy straw. Thus, the study offers the better utilization practice of paddy straw for recycling of nutrients under field conditions.

ACKNOWLEDGMENTS

The authors are thankful for financial assistance received from the project Establishment of Biotech KISAN Hub at ICAR-NBAIM (Project No. 1011258) funded by the Department of Biotechnology, Govt. of India to carry out this work. The authors are also thankful to the Director, ICAR-NBAIM, Mau, for the support and guidance.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORS' CONTRIBUTION

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

FUNDING

None.

DATA AVAILABILITY

All datasets generated or analyzed during this study are included in the manuscript.

ETHICS STATEMENT

Not applicable.

REFERENCES

1. Singh Y, Sharma S, Kumar U, et al. Strategies for economic utilization of rice straw residues into value-added by-products and prevention of environmental pollution. *Sci Total Environ*. 2024;906:167714. doi: 10.1016/j.scitotenv.2023.167714
2. Zaidi ST. Rice Crop Residue burning and alternative measures by India: A Review. *J Sci Res.* 2021;65(02):132-137.
3. Veena SS, Pandey M. Paddy straw as a substrate for the cultivation of Lingzhi or Reishi medicinal mushroom, *Ganoderma lucidum* (W.Curt.:Fr.) P. Karst. in India. *Int J Med Mushrooms.* 2011;13(4):397-400.
4. Sharma A, Sharma R, Arora A, et al. Insights into rapid composting of paddy straw augmented with efficient microorganism consortium. *Int J Recycl Org Waste Agricult.* 2014;3(2):54. doi: 10.1007/s40093-014-0054-2
5. Gadde B, Menke C, Wassmann R. Rice straw as a renewable energy source in India, Thailand, and the Philippines:Overall potential and limitations for energy contribution and greenhouse gas mitigation. *Biomass Bioenergy.* 2009;33(11):1532-1546.

6. Kauldhar BS, Yadav SK. Turning waste to wealth:A direct process for recovery of nano-silica and lignin from paddy straw agro-waste. *J Clean Prod.* 2018;194:158-166.
7. Yaacab ND, Ismail H, Ting SS. Potential use of paddy straw as filler in poly lactic acid/paddy straw powder biocomposite:Thermal and thermal properties. *Procedia Chem*. 2016;19(2):757-762.
8. Bhattacharyya P, Bhaduri D, Adak T, et al. Characterization of rice straw from major cultivars for best alternative industrial uses to cutoff the menace of straw burning. *Ind Crops Prod.* 2020;143:111919.
9. Vijayaprabhakar A, Durairaj SN, Hemalatha M, Joseph M. Study on residue management options in combine harvested rice field in relation to yield and economic benefits of succeeding rice crop. *Agric Sci Dig.* 2021;41(1):85-88.
10. Greff B, Sziget J, Nagy A, Lakatos E, Varga L. Influence of microbial inoculants on co-composting of lignocellulosic crop residues with farm animal manure:A review. *J Environ Manage.* 2022;114088. doi: 10.1016/j.jenvman.2021.114088
11. Jusoh MLC, Manaf LA, Latiff PA. Composting of rice straw with effective microorganisms (EM) and its influence on compost quality. *Iranian J Environ Health Sci Eng*. 2013;10:1-9. doi: 10.1186/1735-2746-10-17
12. Maheshwari HS, Mahapatra SS, Bharti A, Rajput LS, Kumar S. Rapid decomposition of paddy straw:A overview. *Food Sci Rep.* 2020;1(12):58-61.
13. Mageshwaran V, Ashtaputre NM, Hasan H, et al. A rapid process for preparation of bio-enriched compost from cotton stalks, in:Symposium Papers "Future Technologies:Indian Cotton in the next Decade. 2015:469-478.
14. Hasan H, Sardar A, Asthaputre NM, Mageshwaran V. Storability of bio enriched compost prepared from cotton stalks. *J. Cotton Res. Dev*. 2020;34 (2):301-308.
15. Velmourougane K, Manikandan A, Blaise D, Vellaichamy M. Cotton Stalk Compost as a Substitution to Farmyard Manure Along with Mineral Fertilizers and Microbials Enhanced Bt Cotton Productivity and Fibre Quality in Rainfed Vertisols. *Waste Biomass Valor.* 2022;13:2847-2860. doi: 10.21203/rs.3.rs-780420/v1
16. Pandiyan K, Singh A, Saxena AK. Bio Compost Technology. Creating wealth from agricultural waste. Indian Council of Agricultural Research, New Delhi. 2020.
17. Mooventhan P, Singh SRK, Venkatesan P, Singh U. Waste Decomposer to improve soil and plant health:A Success from the tribal belt of Chattisgarh under the farmer's first initiative. *Harit Dhara*. 2021;4(1):7-9.
18. Shabnam and Rimpika. Pusa Decomposer: An effective curb to crop residue problem. *Just Agriculture*. 2021;1(11):1-3.
19. Humpires, EC. Mineral composition and ash analysis. In:Modern methods of plant analysis Vol.1 (eds.) K. Peach and M.V. Tracy Springer Verlag, Berlin, 1956:468-502. doi: 10.1007/978-3-642-80530-1_17
20. Jackson ML. Soil Chemical Analysis. Wisconsin Prentice Hall of India Pvt. Ltd., New Delhi 46. 1967.
21. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Sci.* 1934;37(1):29-38.
22. Ghose TK, Bisaria VS. Measurement of hemicellulase activities:Part I Xylanases. *Pure Appl Chem*1987;59(12):1739-1751. doi:10.1351/pac198759121739
23. Jagadabhi PS, Wani SP, Kaushal M, Patil M, Vemula AK, Rathore A. Physico-chemical, microbial and phytotoxicity evaluation of composts from sorghum, finger millet and soybean straws. *Int J Recycl Org Waste Agricult.* 2019;8:279-293.
24. Moharana, PC, Biswas DR. Assessment of maturity indices of rock phosphate enriched composts using variable crop residues. *Bioresour Technol.* 2016;222:1-13.
25. Haug RT. The practical handbook of compost engineering. Routledge, Editon 1st. 2017. doi: 10.1201/9780203736234
26. Omar HM, Mahmoud YI, El-Haggar SM. Sustainable bio-conversion of rice straw waste into high quality organic fertilizer. *J Environ Prot* (Irvine, Calif) 2020;11:315-331.
27. Cooperband L. The art and science of composting. Center for Integrated agricultural systems. Madison. 2002:1-14.
28. Pace MG, Miller BE, Farrell-Poe KL. The Composting Process. Utah State University:Logan, UT, USA. 1995.
29. Nghi NT, Romasanta RR, Hieu NV, et al. Rice straw-based composting, In:Sustainable Rice Straw Management. Springer, Cham, 2020:33-41.
30. Viel M, Sayag D, Peyre A, Andre L. Optimization of in-vessel co-composting through heat recovery. *Biological Wastes.* 1987;20(3):167-185.
31. Bishop PL, Godfrey C. Nitrogen transformations during sludge composting. *Biocycle.* 1983;24:34-39.
32. Arumugam K, Seenivasagan R, Kasimani R, Sharma NK, Babalola OO. Enhancing the post-consumer waste management through vermicomposting along with bioinoculumn. *Int J Eng Trends Technol.* 2017;44:179-182.
33. Ponnamperuma FN. Straw as a source of nutrients for wetland rice. Organic matter and rice. International Rice Research Institute, Philippines. 1984;117:136.
34. Singh M, Sidhu HS, Singh Y, Blackwell J. Effect of rice straw management on crop yields and soil health in rice-wheat system. *Conserv Agric Newsl.* 2011;18.
35. Khankhane PJ, Barman KK, Varshney JG. Effect of rice residue management practices on weed density, wheat productivity and soil fertility in a swell-shrink soil. *Indian J Weed Sci.* 2009;41:41-45.
36. Pandey AK, Gaind S, Ali A, Nain L. Effect of bioaugmentation and nitrogen supplementation on composting of paddy straw. *Biodegradation* 2009;20:293-306.
37. Gaind S, Nain L, Patel VB. Quality evaluation of cocomposted wheat straw, poultry droppings and oil seed cakes. Biodegradation 2008;20(3):307-317. doi: 10.1007/s10532-008-9223-1
38. Gaind S, Nain L. Chemical and biological properties of

wheat soil in response to paddy straw incorporation and its biodegradation by fungal inoculants. *Biodegradation* 2007;4(4):495-503. doi: 10.1007/s10532-006-9082-6

39. Goyal S, Sindhu SS. Composting of rice straw using different inocula and analysis of compost quality. *Microbiol J.* 2011;1(4):126-138. doi: 10.393/mj.2011.126.138

40. Abdel-Rahman MA, El-Din MN, Refaat BM, Abdel-Shakour EH, Ewais EED, Alrefaey HMA. Biotechnological application of thermotolerant cellulose-decomposing bacteria in composting of rice straw. *Ann Agric Sci*. 2016;61(1):135-143. doi: 10.1016/j.aoas.2015.11.006

41. Sanchez-Monedero MA, Roig A, Paredes C, Bernal MP. Nitrogen transformation during organic waste composting by the Rutgers system and its effects on pH, EC and maturity of the composting mixtures. *Bioresour Technol.* 2001;78(3):301-308.

42. Selim SM, Zayed MS, Atta HM. Evaluation of phytotoxicity of compost during composting process. *Nat Sci (East Lansing).* 2012;10(10(2)):469-477.