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TEMPERATURE RESPONSES OF BIOMASS–MANURE MIXTURES DURING VERMICOMPOSTING: TREATMENT AND SEASONAL COMPARISONS

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ABSTRACT
Temperature is a practical process indicator in vermicomposting because it reflects the balance between microbial heat generation and heat loss and influences earthworm activity. This study described weekly substrate temperature in seven biomass–animal dung mixtures during two 12-week vermicomposting batches at Jorhat, Assam, India, in 2022 (Season I, June–August; Season II, October–December). Biomass (*Eichhornia crassipes*, *Ipomoea carnea* and banana pseudostem, with rice stubble replacing 30% of the biomass in three treatments) and animal dung (cow dung, poultry litter or their mixtures) made up 60% and 40% of each mixture by weight, and *Eisenia fetida* was used. The experiment comprised seven substrate treatments, each maintained in three replicate tanks (21 tanks in total). Substrate temperature was recorded separately in each replicate tank twice daily, and treatment-wise mean temperatures were calculated. The overall mean temperature was 28.14°C in Season I and 25.78°C in Season II, a difference of 2.36°C. Treatment-averaged temperature peaked in week 5 in Season I (29.77°C) and in week 6 in Season II (27.47°C), then declined to 26.21°C and 22.74°C by week 12. Differences among treatments were small (≤0.62°C) but consistent: the 12-week mean increased with the poultry-litter share of the dung fraction, T_4 (poultry litter only) exceeded T_1 (cow dung only) in all 12 weeks of both seasons, and replacing 30% of the biomass with rice stubble changed the mean by no more than 0.08°C. Substrate temperature remained between 22.0 and 30.4°C, and the seasonal difference in substrate temperature was far smaller than the difference of about 6.8°C in ambient air temperature between the two periods. The recorded temperature range of 22.0–30.4°C roughly indicated a predominantly moderate-temperature processing environment, with no sustained high-temperature phase observed in either season. However, the mean temperature throughout the production cycle increased with the poultry-litter share of the dung fraction in both seasons.

KEYWORDS: vermicomposting; substrate temperature; poultry litter; cow dung; rice stubble; seasonal variation; Assam

1. INTRODUCTION
Vermicomposting is a biological waste-processing approach in which earthworms and microorganisms act together to convert biodegradable organic materials into a more stable product. It can support the recycling of agricultural residues and animal wastes, but process performance depends on the properties of the feedstock and the physical environment in which decomposition takes place (Lim et al., 2016; Katiyar et al., 2023). Temperature is a practical process variable because it integrates the heat produced by microbial metabolism with the heat lost through the substrate surface to the surroundings. Its trajectory therefore carries information about changing biological activity, although temperature alone is not a direct measure of decomposition rate or maturity.
Substrate temperature is shaped by microbial activity, feedstock composition, moisture, aeration, reactor dimensions and ambient conditions. A rise may thus indicate net heat production, whereas a later fall may reflect reduced heat generation, greater heat loss, changing weather, or a combination of these. Interpretation is most reliable when the full time series is examined together with ambient temperature and moisture records rather than a single temperature value (Lim *et al*., 2016; Katiyar *et al.,* 2023).
Temperature control is especially important because vermicomposting is not interchangeable with thermophilic composting. Earthworm activity can be constrained by excessive heat, whereas cooler conditions can slow decomposition and stabilisation. Controlled-temperature studies with *Eisenia fetida* show that temperature affects earthworm responses and vermicompost characteristics, with the response depending on substrate and experimental conditions (Zhang *et al.,* 2020; Zhou *et al*., 2021). Zhang *et al*. (2020) compared 15, 20 and 25°C

during vermicomposting of dewatered sludge and reported the fastest stabilisation at 25°C in that system, while Zhou *et al.* (2021) examined pig manure over a wider temperature range and found that about 30°C favoured several measured biological responses. These values should not be taken as universal optima across feedstocks.
Feedstock formulation may also affect the thermal response. Plant residues influence structure and aeration, whereas animal manures differ in moisture content and readily degradable organic matter, and reactor geometry and operating conditions further modify process performance (Katiyar *et al*., 2023). The carbon-to-nitrogen ratio of mixtures containing poultry manure has been manipulated by blending chicken manure with waste paper, which produced a good-quality vermicompost with minimal toxicity at an intermediate C/N ratio (Ravindran and Mnkeni, 2016), and rice straw has been vermicomposted with cow dung and neem leaves to produce a material evaluated on tomato growth (Yadav and Parveen, 2023). Even so, the direction and size of the temperature response of a given mixture must be established by measurement rather than inferred from its list of ingredients.
This study describes the weekly temperature patterns of seven biomass–animal dung mixtures, built from locally available weeds, banana pseudostem, rice stubble, cow dung and poultry litter, during two production seasons at Jorhat, Assam. The objectives were to (i) describe temperature changes over the 12-week series; (ii) compare temperature patterns among the seven treatments, including the effects of poultry-litter share and rice-stubble substitution; and (iii) quantify the difference between the June–August and October–December batches and place it in the context of ambient air temperature.

2. MATERIALS AND METHODS

2.1 Study location and production seasons

The experiment was conducted at the Livestock and Poultry Farm, Assam Agricultural University, Jorhat, Assam, India (26°45′ N, 94°12′ E; altitude 87 m), during 2022. Season I ran from June to August 2022 and Season II from October to December 2022. In each season the tanks were filled and earthworms introduced at the beginning of the first month (June or October), and the vermicompost was harvested towards the end of the third month (August or December).

2.2 Substrate composition and treatment structure

The experiment consisted of seven substrate treatments, each maintained in three replicate tanks, resulting in a total of 21 experimental tanks. Each concrete tank measured 110 × 100 × 75 cm and contained 350 kg of substrate on a dry-weight basis. Biomass constituted 60% and animal dung constituted 40% of the total mixture by weight. The same set of 21 physical tanks was used for both production seasons. After completion of the first production cycle and harvesting of vermicompost, the tanks were emptied and fresh substrate corresponding to the respective treatments was introduced for the second production cycle.

Table 1. Composition of the seven substrate mixtures used in the vermicomposting experiment.

Treatment	Composition within biomass fraction (60% of total mixture)	Composition within animal-dung fraction (40% of total mixture)	Rice stubble (% of mixture)	Poultry litter (% of mixture)
T_1	100% biomass	100% cow dung	0	0
T_2	100% biomass	50% cow dung + 50% poultry litter	0	20
T_3	100% biomass	30% cow dung + 70% poultry litter	0	28
T_4	100% biomass	100% poultry litter	0	40
T_5	70% biomass + 30% rice stubble	50% cow dung + 50% poultry litter	18	20
T_6	70% biomass + 30% rice stubble	30% cow dung + 70% poultry litter	18	28
T_7	70% biomass + 30% rice stubble	100% poultry litter	18	40

The percentages in column 2 and 3 indicate the percentage of the fraction that is made up of the listed elements. Sixty percent of the substrate mixture is the biomass fraction, and 40% is the animal-dung fraction. The percentages of the mixture of rice stubble and poultry litter are given in columns 4 and 5. For instance, 30% rice stubble of biomass fraction equals 18% of the total mixture, 50% poultry litter of animal dung fraction equals 20% of total mixture.

2.3 Temperature monitoring

Substrate temperature was measured using a soil thermometer twice daily, at 06:00 and 18:00 h, beginning the day after earthworm introduction. Measurements were recorded separately for each of the three replicate tanks under every treatment, at the centre of the substrate and at a depth of 0–15 cm. Weekly mean temperatures were first calculated for each replicate tank from the twice-daily observations. The three replicate values were then averaged to obtain the treatment-wise mean temperature for each week. The same procedure was followed for both production seasons.

2.4 Ambient meteorological data

Monthly maximum and minimum air temperature, relative humidity, total rainfall and bright sunshine hours for June–December 2022 were obtained from the Department of Agrometeorology, Assam Agricultural University, Jorhat (Appendix B). Mean ambient temperature for each season was approximated as the average of the monthly maximum and minimum temperatures over the three months of that season; September, which fell between the two batches, was excluded.

2.5 Data summary and analysis

Weekly mean substrate temperatures were calculated for each replicate tank using the twice-daily observations recorded at 06:00 and 18:00 h. For each treatment, the weekly mean temperature was obtained by averaging the values from its three replicate tanks. The 12-week mean, minimum temperature, maximum temperature, peak week and week-12 temperature were calculated from the weekly treatment-wise means. Weekly seasonal means were calculated as the arithmetic mean of the seven treatment-wise means for each week. Seasonal overall means were calculated across the 84 treatment-week means (seven treatments × 12 weeks). The data were summarized descriptively to examine temporal temperature patterns, differences among treatments and seasonal variation.

The treatment weeks means of 84 treatment weeks (per season) were descriptive summary values and were not independent experimental replicates. Three replicate tanks were used for each treatment and the same 21 physical tanks were used for the second production season.

3. RESULTS

3.1 Temperature dynamics in Season I

The overall mean across all treatments and weeks in Season I was 28.14°C (Table 3). The treatment-averaged temperature rose from 27.31°C in week 1 to a maximum of 29.77°C in week 5, a gain of 2.46°C, stayed close to this level in week 6 (29.66°C), and then declined steadily to 26.21°C in week 12 (Figures 1a and 2). Individual values ranged from 25.9°C (T_1, week 12) to 30.4°C (T_7, week 6). Temperature peaked in week 5 in T_1, T_2, T_3, T_5 and T_6 and in week 6 in T_4 and T_7 (Table 2). Twelve-week treatment means ranged from 27.81°C (T_1) to 28.43°C (T_4).

3.2 Temperature dynamics in Season II

The overall mean in Season II was 25.78°C. The treatment-averaged temperature increased from 25.23°C in week 1 to 27.47°C in week 6, a gain of 2.24°C, and all seven treatments peaked in week 6. Unlike Season I, the subsequent decline was not monotonic: the mean fell to 26.56°C in week 7, recovered slightly to 26.80°C in week 8, and then dropped to 22.74°C in week 12, 4.73°C below the peak. The week-7 fall was concentrated in T_2, T_3, T_5, T_6 and T_7 (1.0–1.3°C below week 6), whereas T_1 and T_4 fell by only 0.3°C; these five treatments partly recovered in week 8 (+0.4 to +0.7°C). The highest value was 27.7°C (T_4 and T_7, week 6) and the lowest 22.0°C (T_1, week 12). Treatment means ranged from 25.53°C (T_1) to 26.03°C (T_4).

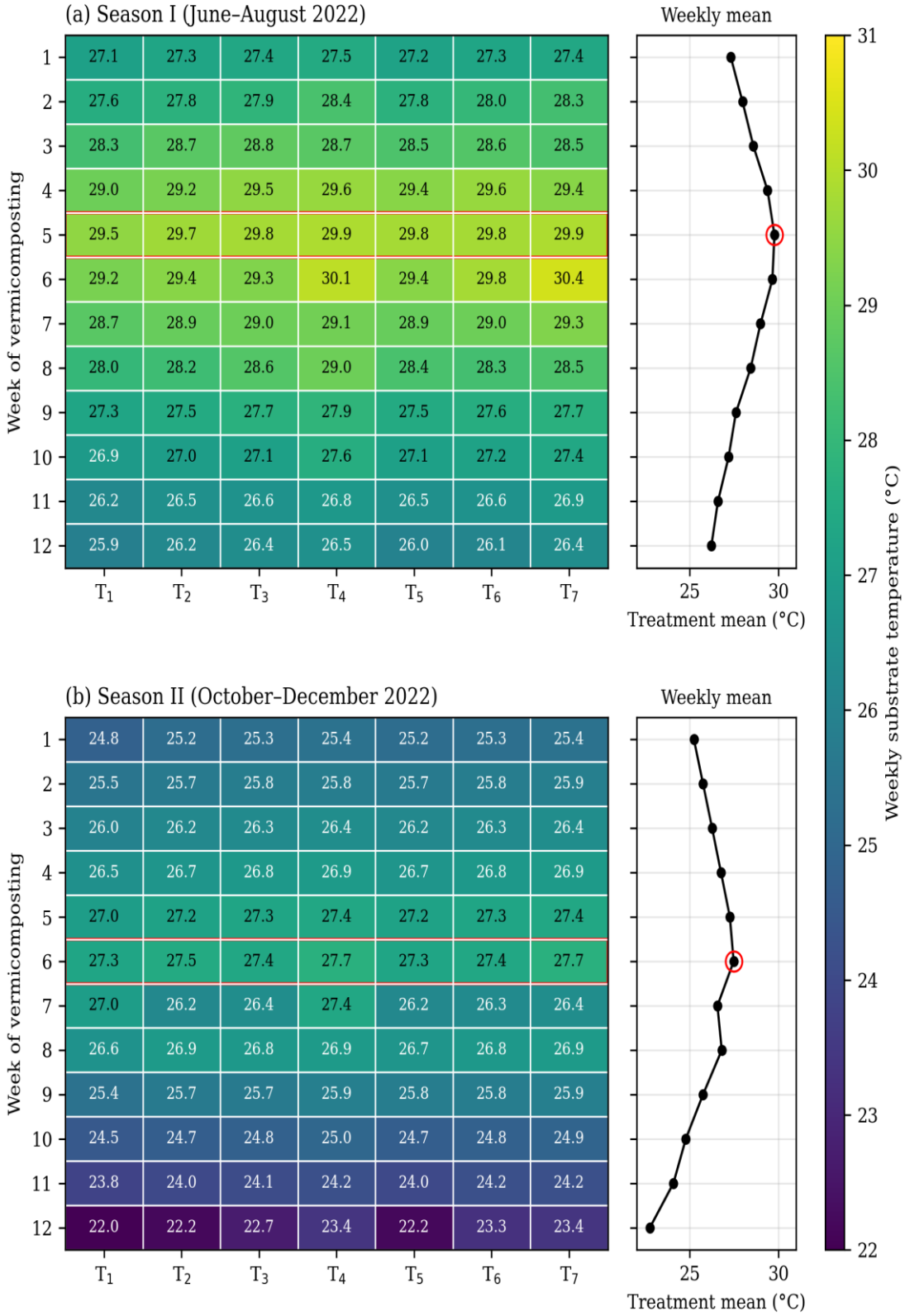


Figure 1. Weekly substrate temperature (°C) of seven biomass–animal dung mixtures during (a) Season I (June–August 2022) and (b) Season II (October–December 2022). Rows are weeks of vermicomposting and columns are treatments; cell values are weekly means and the colour scale is common to both panels. The red outline marks the week in which the treatment-averaged temperature was highest. The right-hand panel of each plot shows the mean across the seven treatments for each week.
Values represent means of three replicate tanks for each treatment.

Table 2. Treatment-wise descriptive summaries of weekly substrate temperature.

Season	Treatment	12-week mean (°C)	Minimum (°C)	Maximum (°C)	Peak week	Week 12 (°C)
Season I	T_1	27.81	25.9	29.5	5	25.9
	T_2	28.03	26.2	29.7	5	26.2
	T_3	28.18	26.4	29.8	5	26.4
	T_4	28.43	26.5	30.1	6	26.5
	T_5	28.04	26.0	29.8	5	26.0
	T_6	28.16	26.1	29.8	5	26.1
	T_7	28.34	26.4	30.4	6	26.4
Season II	T_1	25.53	22.0	27.3	6	22.0
	T_2	25.68	22.2	27.5	6	22.2
	T_3	25.78	22.7	27.4	6	22.7
	T_4	26.03	23.4	27.7	6	23.4
	T_5	25.66	22.2	27.3	6	22.2
	T_6	25.84	23.3	27.4	6	23.3
	T_7	25.95	23.4	27.7	6	23.4

Values represent treatment-wise mean temperatures calculated from three replicate tanks.
Values were recalculated from the weekly observations in Appendix A. Where the maximum occurred in two weeks (T_6, Season I: weeks 5 and 6), the earlier week is given.

Table 3. Season-level summary derived from the weekly observations.

Season	Overall mean (°C)	Minimum (°C)	Maximum (°C)	Peak week of weekly mean	Peak weekly mean (°C)	Week 12 mean (°C)
Season I	28.14	25.9	30.4	Week 5	29.77	26.21
Season II	25.78	22.0	27.7	Week 6	27.47	22.74

Overall means represent the arithmetic mean of 84 treatment-week means (seven treatments × 12 weeks). Each treatment-week mean was calculated from three replicate tanks.

3.3 Comparison among treatments

The ranking of treatments was similar in the two seasons. T_4, which contained poultry litter as the only animal-dung component, had the highesT12-week mean in both seasons (28.43°C and 26.03°C) and T_1, which contained cow dung only, had the lowest (27.81°C and 25.53°C). The spread among treatment means was small: 0.62°C in Season I and 0.50°C in Season II. T_4 was warmer than T_1 in all 12 weeks of both seasons (mean weekly difference 0.62°C and 0.50°C), and T_1 was the coolest or equal-coolest treatment in all 12 weeks of Season I and in 11 of 12 weeks of Season II (the exception was week 7, when T_1 was 0.6–0.8°C above the other treatments except T_4).

When treatments were pooled by the poultry-litter share of the dung fraction, the 12-week mean increased progressively from 0% to 100% poultry litter in both seasons (Table 4). The effect of replacing 30% of the biomass with rice stubble was negligible and had no consistent direction: mean differences relative to the matched treatments without rice stubble were +0.01°C (T_5 vs T_2), −0.02°C (T_6 vs T_3) and −0.08°C (T_7 vs T_4) in Season I, and −0.02°C, +0.06°C and −0.08°C, respectively, in Season II.

Table 4. Twelve-week mean substrate temperature pooled by poultry-litter share of the animal-dung fraction.

Poultry litter share of dung fraction	Treatments pooled	Poultry litter (% of mixture)	Season I mean (°C)	Season II mean (°C)
0% (cow dung only)	T_1	0	27.81	25.53
50%	T_2, T_5	20	28.04	25.67
70%	T_3, T_6	28	28.17	25.81
100% (poultry litter only)	T_4, T_7	40	28.38	25.99

Pooled values are the average of the 12-week treatment means of the treatments listed (T_5–T_7 contain rice stubble; see Table 1).

3.4 Seasonal comparison

The overall mean was 28.14°C in Season I and 25.78°C in Season II, a difference of 2.36°C. The treatment-averaged difference between seasons ranged from 1.63°C (week 8) to 3.47°C (week 12) and widened in the last weeks because Season II cooled faster than Season I (Figure 2). The week-12 treatment-averaged temperature was 26.21°C in Season I and 22.74°C in Season II. This comparison is between two production batches and fresh substrate, used for treatment, was added to the same substrate tanks for the second production batch. Season is not the only factor affecting the variation in temperatures observed; other factors such as batch, weather, and management practices could have also influenced the difference.

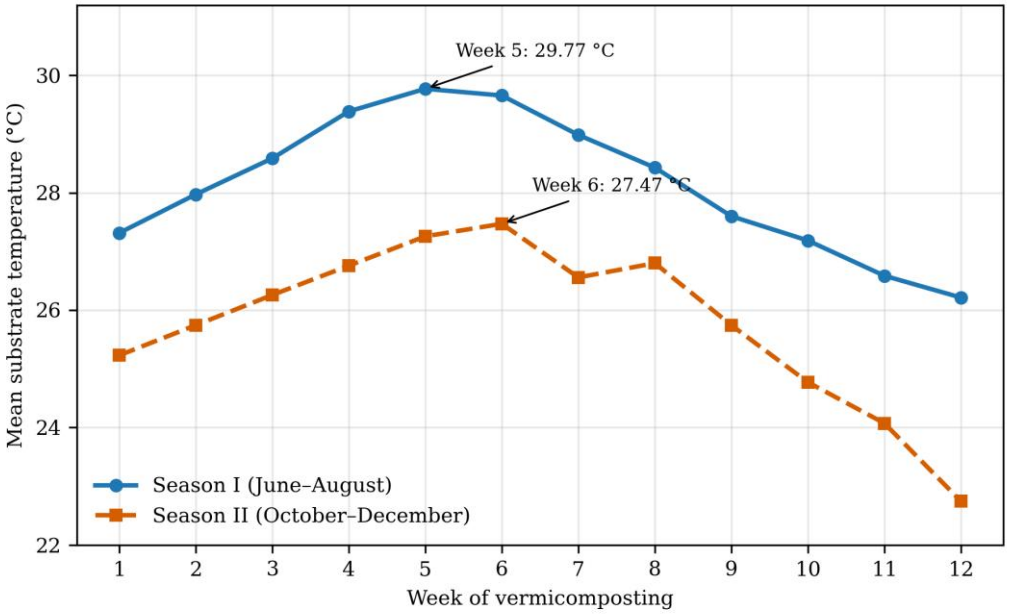


Figure 2. Mean substrate temperature across the seven treatments by week and season. Values are arithmetic means of the seven treatment values for each week.

Values represent means of three replicate tanks for each treatment.

3.5 Substrate temperature in relation to ambient temperature

Ambient air temperature differed much more between the two periods than substrate temperature did (Table 5; Appendix B). The mean of the monthly maximum and minimum temperatures was 28.73°C for June–August and 21.97°C for October–December, a difference of 6.76°C compared with 2.36°C for the substrate. The substrate overall mean was 0.59°C below this ambient midpoint in Season I and 3.82°C above it in Season II. The lowest weekly substrate temperature (22.0°C) was well above the monthly minimum air temperatures recorded in November (14.1°C) and December (11.4°C). In Season I, monthly ambient temperature rose from June (27.58°C) to August (29.48°C), while substrate temperature declined after week 5–6; in Season II, ambient temperature fell from October (25.80°C) through November (21.50°C) to December (18.60°C), in parallel with the decline in substrate temperature.

Table 5. Substrate temperature compared with ambient air temperature during the two seasons.

Season	Mean of monthly maximum air temperature (°C)	Mean of monthly minimum air temperature (°C)	Ambient midpoint (°C)	Substrate overall mean (°C)	Substrate minus ambient (°C)
Season I (Jun–Aug)	32.81	24.65	28.73	28.14	−0.59
Season II (Oct–Dec)	28.37	15.57	21.97	25.78	+3.82

Ambient values are averages of the monthly maximum and minimum temperatures for the three months of each season (Appendix B); the ambient midpoint is the average of these two values. Monthly meteorological data do not capture conditions within the tanks.

4. DISCUSSION

4.1 Overall thermal trajectory

In both seasons, treatment-averaged substrate temperature increased by approximately 2.2–2.5°C during the first five to six weeks before declining. This pattern is consistent with initial microbial heat production during organic matter decomposition, followed by reduced net heat accumulation as readily degradable substrates become depleted and heat losses continue (MacGregor *et al*., 1981).

However, temperature alone cannot distinguish changes in microbial activity from heat exchange with the surrounding environment. In Season I, substrate temperature declined after week 6 despite rising or near-maximum monthly ambient temperatures, suggesting that ambient cooling alone was insufficient to explain the decline. Reduced heat generation may have contributed, although this interpretation remains provisional. In Season II, declining ambient temperatures coincided with substrate cooling, making the relative contributions of biological activity and environmental heat loss difficult to separate.

Controlled studies show that temperature affects microbial communities, earthworm responses and stabilisation in vermicomposting, with responses depending on feedstock and conditions (Zhang *et al*., 2020; Zhou *et al*., 2021). The substrate temperatures recorded here (22.0–30.4°C) overlap the 25–30°C range at which favourable earthworm responses were reported in those studies, although the feedstocks differed from those used in this work.

4.2 Differences among substrate treatments

The 12-week mean temperature increased with the poultry-litter share of the dung fraction in both seasons, with T_4 recording the highest and T_1 the lowest values. This consistent pattern suggests an association between substrate composition and thermal dynamics. Poultry litter provides nitrogen and organic substrates that can support microbial decomposition, potentially contributing to heat generation; however, the extent of this effect depends on feedstock characteristics and process conditions (Atkinson *et al*., 1996; Finore *et al.,* 2023). The influence of the C/N ratio and moisture conditions on compost temperature has also been demonstrated in chicken-litter composting (Ogunwande *et al*., 2008). Nevertheless, the observed differences were small (maximum 0.62°C) and should be interpreted cautiously, particularly given potential thermometer measurement error. Rice-stubble substitution showed no consistent temperature response (−0.08 to +0.06°C), indicating that the present data do not support a general warming or cooling effect of rice stubble under the tested conditions.

4.3 Seasonal contrast

Substrate temperature was 2.36°C higher in Season I than in Season II, but the corresponding difference in ambient temperature was about 6.8°C. The substrate therefore tracked the seasonal shift in air temperature only partly. In the cooler Season II the substrate averaged about 3.8°C above the ambient midpoint and never fell below 22.0°C, whereas in the warmer Season I it averaged slightly below the ambient midpoint. This is consistent with the substrate mass buffering ambient temperature and, in the cooler season, retaining or generating some heat, but the data cannot show which of these dominated because tank exposure, shading and tank-level heat balance were not measured. The comparison of ambient temperature also uses monthly values and an approximate midpoint, and the two batches differ in more than season. Temperature dynamics during vermicomposting are also influenced by seasonal conditions and substrate characteristics (Garg & Gupta, 2011). Furthermore, differences in tank exposure, shading, ventilation and heat transfer may have contributed to the observed variation (Khater *et al*., 2014).

4.4 Relevance to vermicomposting management

No sustained high-temperature phase occurred in either season, and the recorded range is consistent with a moderate-temperature processing environment. Temperature is relevant to earthworm activity, but a moderate profile does not by itself establish that the final material is mature, stable, free of pathogens or agronomically effective. Published studies assess temperature together with other process and product indicators, and temperature responses vary across substrates and species (Zhang *et al.,* 2020; Zhou *et al*., 2021; Katiyar *et al.,* 2023). Monitoring of this kind is therefore best used as a low-cost companion to measurements of moisture, pH, C/N ratio, earthworm biomass and compost maturity.

5. CONCLUSION

In the 12-week series, substrates in both production seasons showed early warming followed by cooling; the substrate temperature dynamics were influenced by production season and substrate composition. The overall mean substrate temperature was 28.14°C in Season I and 25.78°C in Season II, a difference of 2.36°C, and the treatment-averaged weekly maximum occurred in week 5 in Season I (29.77°C) and week 6 in Season II (27.47°C). Despite a considerable difference in ambient air temperature between the two seasons, the variation in substrate temperature was comparatively smaller, suggesting that the substrate provided some buffering against seasonal temperature fluctuations.

Temperature increased with the share of poultry litter in the dung fraction, T4 recorded the highest and T1 generally the lowest 12-week mean temperatures in both seasons, whereas rice-stubble substitution had a negligible effect, these differences were small. No sustained high-temperature phase occurred, and the range of 22.0–30.4°C is consistent with a moderate-temperature process. These observations suggest that the proportion of poultry litter in the substrate mixture may have contributed to differences in heat generation during decomposition, although the underlying mechanisms require confirmation through complementary measurements of microbial activity and substrate characteristics. However, the underlying mechanisms need validation by other measurements of microbial activity and substrate properties.

The observed temperature patterns may reflect changes in microbial metabolism and organic matter decomposition across treatments and seasons. The comparatively higher temperatures in poultry-litter-enriched substrates may be associated with greater microbial activity supported by readily decomposable organic compounds and nutrients. Microbial respiration and extracellular enzyme activities, particularly those involved in cellulose and protein degradation, may have contributed to the initial warming, while the subsequent cooling may indicate changes in substrate availability and decomposition rates. However, these mechanisms were not directly assessed. Future studies incorporating microbial community profiling, enzyme assays and molecular analyses of functional genes could elucidate the microbial processes underlying temperature variations and improve understanding of organic matter transformation during vermicomposting.

REFERENCES

1. Atkinson, C. F., Jones, D. D., & Gauthier, J. J. (1996). Biodegradability and microbial activities during composting of poultry litter. *Poultry Science*, *75*(5), 608-617.
2. Finore, I., Feola, A., Russo, L., Cattaneo, A., Di Donato, P., Nicolaus, B., ... & Romano, I. (2023). Thermophilic bacteria and their thermozymes in composting processes: a review. *Chemical and Biological Technologies in Agriculture*, *10*(1), 7.
3. Garg, V. K., & Gupta, R. (2011). Effect of temperature variations on vermicomposting of household solid waste and fecundity of Eisenia fetida. *Bioremediation Journal*, *15*(3), 165-172.
4. Katiyar, R. B., Sundaramurthy, S., Sharma, A. K., Arisutha, S., Khan, M. A., & Sillanpää, M. (2023). Optimization of engineering and process parameters for vermicomposting. *Sustainability*, *15*(10), 8090.
5. Khater, E. S. G., Bahnasawy, A. H., & Ali, S. A. (2014). Mathematical model of compost pile temperature prediction. *Journal of Environmental & Analytical Toxicology*, *4*(6), 1.
6. Lim, S. L., Lee, L. H., & Wu, T. Y. (2016). Sustainability of using composting and vermicomposting technologies for organic solid waste biotransformation: Recent overview, greenhouse gases emissions and economic analysis. *Journal of Cleaner Production*, *111*, 262–278.
7. MacGregor, S. T., Miller, F. C., Psarianos, K. M., & Finstein, M. S. (1981). Composting process control based on interaction between microbial heat output and temperature. *Applied and environmental microbiology*, *41*(6), 1321-1330.
8. Ogunwande, G. A., Osunade, J. A., & Ogunjimi, L. A. O. (2008). Effects of carbon to nitrogen ratio and turning frequency on composting of chicken litter in turned-windrow piles. *Agricultural Engineering International: The CIGR Ejournal, 10*, 1–16. Manuscript EE 07 016.
9. Ravindran, B., & Mnkeni, P. N. S. (2016). Bio-optimization of the carbon-to-nitrogen ratio for efficient vermicomposting of chicken manure and waste paper using Eisenia fetida. *Environmental Science and Pollution Research*, *23*(17), 16965-16976.
10. Yadav, S., & Parveen, K. (2023). Influence of vermicompost derived from rice straw, neem leaves, and cow dung on plant growth parameters of *Solanum lycopersicum* (tomato). *Indian Journal of Science and Technology*, *16*, 989–997.
11. Zhang, H., Li, J., Zhang, Y., & Huang, K. (2020). Quality of vermicompost and microbial community diversity affected by the contrasting temperature during vermicomposting of dewatered sludge. *International Journal of Environmental Research and Public Health*, *17*(5), 1748.
12. Zhou, Y., Zhang, D., Zhang, Y., Ke, J., Chen, D., & Cai, M. (2021). Evaluation of temperature on the biological activities and fertility potential during vermicomposting of pig manure employing *Eisenia fetida*. *Journal of Cleaner Production*, *302*, 126804.

Appendix A. Weekly substrate temperature observations (°C)

Table A1. Season I (June–August 2022).

Week	T_1	T_2	T_3	T_4	T_5	T_6	T_7
1	27.1	27.3	27.4	27.5	27.2	27.3	27.4
2	27.6	27.8	27.9	28.4	27.8	28.0	28.3
3	28.3	28.7	28.8	28.7	28.5	28.6	28.5
4	29.0	29.2	29.5	29.6	29.4	29.6	29.4
5	29.5	29.7	29.8	29.9	29.8	29.8	29.9
6	29.2	29.4	29.3	30.1	29.4	29.8	30.4
7	28.7	28.9	29.0	29.1	28.9	29.0	29.3
8	28.0	28.2	28.6	29.0	28.4	28.3	28.5
9	27.3	27.5	27.7	27.9	27.5	27.6	27.7
10	26.9	27.0	27.1	27.6	27.1	27.2	27.4
11	26.2	26.5	26.6	26.8	26.5	26.6	26.9
12	25.9	26.2	26.4	26.5	26.0	26.1	26.4

Weekly temperature values represent the arithmetic means of three replicate tanks for each treatment. Temperature observations were recorded twice daily at 06:00 and 18:00 h.

Table A2. Season II (October–December 2022).

Week	T_1	T_2	T_3	T_4	T_5	T_6	T_7
1	24.8	25.2	25.3	25.4	25.2	25.3	25.4
2	25.5	25.7	25.8	25.8	25.7	25.8	25.9
3	26.0	26.2	26.3	26.4	26.2	26.3	26.4
4	26.5	26.7	26.8	26.9	26.7	26.8	26.9
5	27.0	27.2	27.3	27.4	27.2	27.3	27.4
6	27.3	27.5	27.4	27.7	27.3	27.4	27.7
7	27.0	26.2	26.4	27.4	26.2	26.3	26.4
8	26.6	26.9	26.8	26.9	26.7	26.8	26.9
9	25.4	25.7	25.7	25.9	25.8	25.8	25.9
10	24.5	24.7	24.8	25.0	24.7	24.8	24.9
11	23.8	24.0	24.1	24.2	24.0	24.2	24.2
12	22.0	22.2	22.7	23.4	22.2	23.3	23.4

Weekly temperature values represent the arithmetic means of three replicate tanks for each treatment. Temperature observations were recorded twice daily at 06:00 and 18:00 h.

Appendix B. Meteorological data

Table A3. Meteorological data observed during the period of experimentation (Jorhat; latitude 26°45′ N, longitude 94°12′ E, altitude 87 m).

Month	Max. temp. (°C)	Min. temp. (°C)	Max. RH (%)	Min. RH (%)	Total RF (mm)	BSSH (h)
June 2022	31.19	23.96	94.27	80.33	202.9	1.98
July 2022	33.38	24.89	92.45	72.65	321.8	5.59
August 2022	33.85	25.10	92.84	71.61	166.5	6.24
September 2022	36.00	28.60	83.00	65.00	175.6	4.6
October 2022	30.4	21.2	97.0	74.00	235.8	4.9
November 2022	28.9	14.1	98.0	56.00	0.0	8.6
December 2022	25.8	11.4	99.0	58.00	0.9	6.4

Max. and Min. temp., maximum and minimum air temperature; Max. and Min. RH, maximum and minimum relative humidity; RF, rainfall; BSSH, bright sunshine hours. September 2022 fell between the two batches. Source: Department of Agrometeorology, Assam Agricultural University, Jorhat 785013.