Termigradation of Un-Compostible Parts of Major Weeds Prosopis *(Prosopis Juliflora)* and Ipomoea *(Ipomoea Carnea)*

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1 Introduction

As brought out earlier [1], quote—'anthropogenic processes for the treatment of biodegradable solid waste revolve round the use of aerobic, anaerobic, and facultative bacteria [2, 3]. Be it a sanitary landfill, a composting system, a solid-feed anaerobic digester, or a bioprocess of some other kind, bacterial digestion has been central to the treatment of biodegradable solid wastes [4–8]. The only exception to this general rule has been vermicomposting wherein the action of bacteria and enzymes on solid waste is mediated (and controlled) by earthworms. The animal ingests solid waste along with soil and deposits the digested material in the form of seed-like vermicast. During the passage through the worm gut, the feed is acted upon by the gut microflora and gets significantly stabilized. The resulting vermicast is a good soil conditioner and fertiliser [9–14].

But neither vermicomposting nor direct bacterial action during any of the economically viable solid waste degradation processes can handle lignin [5, 6]. 'Hard' biowastes such as coconut shells and woody biomass also defy swift biodegradation.

In an attempt to find a quicker and more widely applicable way to dispose large volumes of biowaste, especially the type of biowaste—mentioned above—which resists treatment methods currently in general use, we have begun exploring a new frontier: termigradation,"—unquote.

As further noted earlier [1], quote—' termites are among the nature's most powerful scavengers and earth movers, alongside earthworms and ants [15–17]. But

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unlike the other two, termites harbour in their midst microflora which have the special ability not possessed by other animals: ability to digest lignin [18]. In case of lower termites, ligneous material is masticated and ingested which is then digested by microflora present in certain species of protozoa living symbiotically in the termite gut [19, 20]. In case of higher termites, the microflora capable of digesting lignin is present directly in the animal gut [19, 20].

Other characteristics of termites which make them potential candidates for bioprocessing of solid waste are [21]: (a) their voracious appetite; (b) their ability to consume a wide variety of wastes; (c) diversity of their habitat preference which makes it possible to always find one or other species suitable for a given geo-climatic situation [22–24]; (d) their very fast rate of population growth; and (e) good quality of protein represented by termite bodies, making them ideal as poultry feed or source of chemicals such as biofuel [21, 25],'—unquote.

But,as noted earlier [1], quote—"any endeavour to develop bioreactors based on termites has to overcome a unique challenge. It lies in the fact that termites are 'eu-social' animals with well-defined and uncompromising social hierarchy [26]. Unlike earthworms, of which every single individual has the potential to reproduce sexually while it is feeding upon the waste in a bioreactor, the worker termites cannot breed. It is, therefore, not possible to inoculate a pile of waste with worker termites and expect that the workers would feed and breed till the entire waste is consumed. For any termireactor to function sustainably, it has to be ensured that the workers keep coming from termite nests where the workers are being born and reared continuously (along with, of course, other termites of higher caste viz soldiers),'—unquote.

To achieve this objective, we have developed two types of termite-based reactors:

(a) Developing life-size but captive termite colonies indoors as a kind of 'bioangines'. In them the termites are made to feed upon the waste that is supplied in specially designed reactors. These termigradation systems can be termed *ex-situ* processes.
(b) *In situ* systems wherein termireactors containing the waste are placed near pre-existing termite mounds. The reactors are designed to facilitate termite entry, feeding and exit while also protecting the waste from being disturbed by wind and other animals. Chambers have sufficient openings to allow access to termites but are otherwise closed from all sides. The reactors are provided with trails so that the scout termites who keep looking for food (so as to call others to the food source once it is located) are led to the reactors.

Termireactors of three sizes as were fashioned from 3mm thick aluminium sheets. The dimensions of the larger sized reactors of 432 L volume were as in Fig. 1. The smaller reactors of dimensions 63(L), 40(B), 28(H) cm and 48(L), 30(B), 23(H) cm, having 71 and 33 L volume, respectively, had similar shape and design.

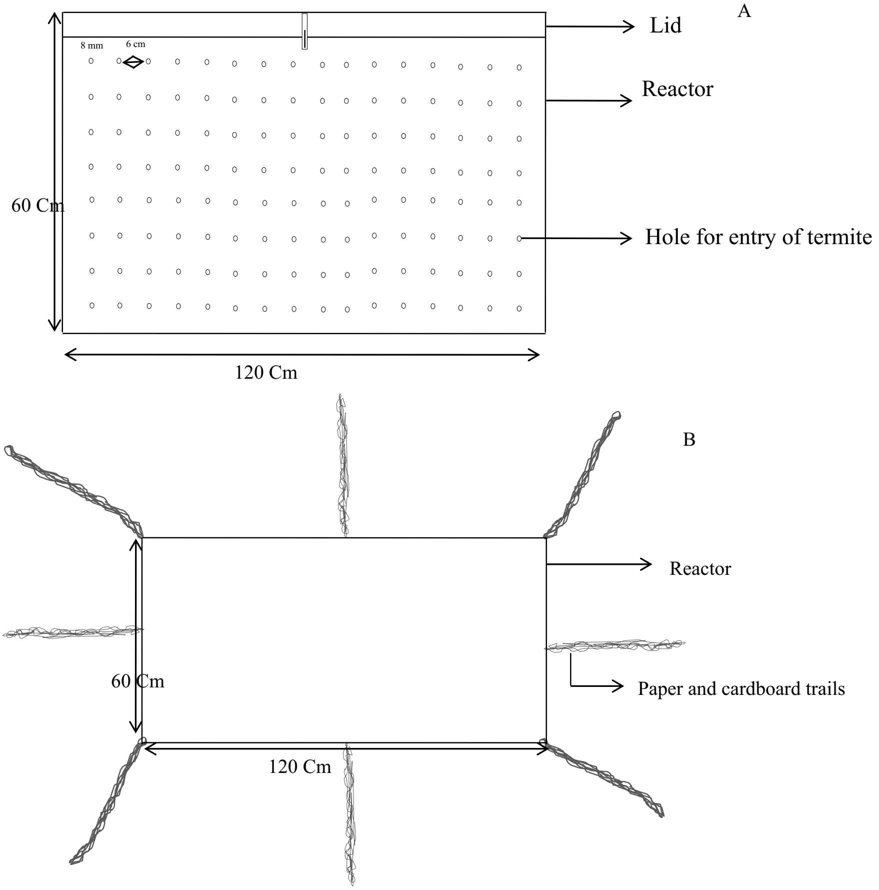

Fig. 1 (**a**) Sectional view of the termireactor and (**b**) top view of the reactor with trails made up of squeezed waste paper (to lead the termite food scouts to the reactor).The dimensions belong to the 71 L reactor; the other reactors deployed in the study have identical design but smaller sizes

2 Materials and Method

The substrates—'hard' branches of prosopis and ipomoea (parts too woody to be amenable to composting or vermicomposting yet not woody enough for use as fuel)—were collected from in and around Pondicherry University. After removing the debris and leaves of other species, dry weights of three randomly picked and pooled samples of either substrate were estimated by oven drying weighed samples at 105 °C to constant weight.

For *in-situ* experiments, active mounds were identified within the University campus and termireactors were placed inside holes dug near these mounds. To protect the reactors from rain and sunlight, they were covered with soil from all the four sides.

For *ex-situ* studies a captive termite colony of *Hypotermes obscuriceps,* developed in the laboratory, was used.

The experiments in the in situ mode were started with the two largest sized (71 L) reactors, each fed with 35 kg prosopis branches, and two 71 L reactors, each fed with 2 kg of ipomoea stem. Simultaneously *ex-situ* studies were commenced with two 33 L reactors, fed with 1 kg of prosopis and 500 g of ipomoea, respectively. The quantities differed because of difference in the density of the substrates.

Unlike what happens in vermicomposting, during which the substrate is converted to vermicast and the vermicast becomes the quantifiable and reproducible outcome of the vermicomposting process, there is no 'termicast' generated by the termites during termigradation. Most of the substrate consumed by the termites is metabolised and what little excreta termites do generate, they carry it to their nests wherein 'fungal gardens' are organised by them. In the 'fungal gardens' fungus is 'cultivated' by termites as a food source. The excreta is deposited in the fungal gardens to fertilize it. Hence almost nothing is left behind when termites feed upon prosopis or ipomoea (or any other substrate) in a termireactor. For this reason, the extent of degradation of the substrate has to be worked out on the basis of the unconsumed substrate present in the termireacotrs.

Accordingly the progress of termigradation in all reactors was assessed by taking out the unconsumed substrate once every 30 days, freeing it from termites and a few soil-like particles that result from termite foraging and movement, and quantifying it.

3 Results and Discussion

As explained earlier, termites tend to assimilate most of what they consume and take away the little excreta they might have generated. What remains in the termireactor is still-to-be-consumed substrate of which some part is finely fragmented by the termites in the course of their foraging activity. The reddish brown deposits over pieces of prosopis branches, seen in Fig. 2, represents that component. The situation in the ipomoea fed termireactor is as seen in Fig. 3. Earlier, in trial experiments, we had allowed termites to act on the substrate till no unconsumed substrate remained. In such termireactors only traces of the reddish-brown particulates were found. This indicates that by-and-by, the termites consume these particulates as well.

A close-up of a partly consumed prosopis branch is shown in Fig. 4 while Fig. 5 displays individuals of *H.obscuricaps* (tiny, milk-white animals) active near their mound.

The results of in-situ experiments with prosopis and ipomoea are presented in Tables 1 and 2, respectively. Despite the reactor contents being heterogeneous, and dependent upon termite behaviour, there is remarkable agreement between the duplicates; the relative error being well below 10% in all the assessments. We have encountered similar reproducibility in the past [26, 27, 28, 29] for different substrates and in different situations.

Fig. 2 Termite-worked branches of prosopis

Fig. 3 Termite-worked pieces of ipomoea stem

Fig. 4 Close-up of a partially consumed piece of prosopis

Fig. 5 Individuals of *H. obscuriceps* near their mound (colony)

In case of prosopis (Table 1), the maximum reactor utilization —21.1%—occurred during the first 30 days. In subsequent months the rate gradually declined. The pattern was similar with ipomoea (Table 2): 30.2% of all the substrate was consumed in the first 25% of the experiment duration.

Table 1 Extent of termigradation (%) of prosopis (35 kg) at 30-days intervals in in-situ reactors

Days	Reactors		Termigradation %	
	A	B	During each run	Cumulative
30	20.8	21.3	21.1 ± 0.4	21.1 ± 0.4
60	18.4	19.8	19.1 ± 1.0	40.2 ± 1.4
90	14.6	13.9	14.3 ± 0.5	54.4 ± 1.9
120	11.2	12.4	11.8 ± 0.8	66.2 ± 2.7

Table 2 Extent of termigradation (%) of ipomoea (2 kg) at 30-days intervals in in-situ reactors

Days	Reactors		Termigradation %	
	D	E	During each run	Cumulative
30	30.5	29.9	30.2 ± 0.4	30.2 ± 0.4
60	27.4	26.7	27.1 ± 0.5	57.3 ± 0.9
90	21.6	20.5	21.1 ± 0.8	78.4 ± 1.7
120	17.4	16.8	17.1 ± 0.4	95.5 ± 2.1

To understand these findings we have to consider the termite behaviour. The termite scouts, who keep looking for food source, are the ones who launch, and in a way control, the termigradation process. It is these scouts who, upon locating the food contained in the termireactors, send signals to their colonies. From there, and apparently based on the content of the singles, appropriate number of worker termites come out to the food source and consume it. Apparently, as the quantity of the source goes down the termites are able to sense it and give signals due to which lesser number of termites forage upon the remains. It also appears that for some reason, that we have not been able to fathom, termites never depute such a large number of foragers to any termireactor that they can finish off all the substrate content in a few hours or a few days. There is always a pattern whereby utilization of a food source is slowly rolled out with time. Perhaps they tend to go slower as the source of the food dwindles so as to enhance the duration of its availability—as a form of food security measure.

To benefit from this termite behaviour it appears advisable that instead of running the termireactors in batch mode—as we have done—they should be operated in a semi-continuous mode. The quantity of substrate consumed in the first 30 days should be augmented with equivalent quantity of fresh substrate.

The results of the *ex-situ* reactors operated with prosopis and ipomoea are shown in Tables 3 and 4, respectively. Due to the past experience of the authors, which had shown the high degree of reproducibility in termireactor performance, supported by similar reproducibility achieved in the present study on *in-situ* termigradation described above, we have deployed only one reactor each for the two weeds. It may be seen that the performance of the *ex-situ* reactors has been very similar to the performance of the *in-situ* reactors. Whereas in the *in-situ* reactors 21.1, 19.1,

Table 3 Extent of termigradation (%) of prosopis (1 kg) at 30-days intervals in ex-situ reactors

Days	Termigradation % in reactor –C	
	During each run	Cumulative
30	20.7	20.7
60	17.5	38.2
90	13.9	52.1
120	10.5	62.6

Table 4 Extent of termigradation (%) of ipomoea (500 gm) at 30-days intervals in ex-situ reactors

Days	Termigradation % in reactor -F	
	During each run	Cumulative
30	31.1	31.1
60	25.6	56.7
90	20.2	76.9
120	12.3	89.2

14.3 and 11.8% of prosopis was consumed by 30th, 60th, 90th and 120th day, the respective figures for the *ex-situ* reactors are 20.7, 17.5, 13.9 and 10.5%. Whereas the average cumulative prosopis consumption was 66.2% in the *in-situ* reactors, it was very similar—62.6%—in the *ex-situ* reactors. In a like fashion, the consumption by the 30th, 60th, 90th and 120th day of ipomoea, which was 30.2, 57.3, 78.4, and 95.5% in the *in-situ* reactors matched closely with the pattern in the ex-situ reactors—31.1, 56.7, 76.9 and 89.2%. Figure 6 brings this out graphically. And this level of match in performance was seen even though the capacities of the reactors were different while the reactor contents were heterogeneous.

The rate of termidegradation of ipomoea was over 20% greater than of prosopis perhaps because of the lesser content of lignin in ipomoea.

4 Summary and Conclusion

The paper recounts the concepts of ‘termigradation’—which represents termite-induced biodegradation—and associated technology, introduced and patented earlier by S. A. Abbasi and co-workers. The technology enables assimilative and eco-friendly disposal of such ligninous biowaste which defies conventional biodegradation processes such as anaerobic digestion, composting and vermicomposting. The paper also provides a gist of special challenges associated with the use of termites as bioagents. They stem from the highly eu-social character of termites. Similar to wasps, bees and ants termites have rigid hierarchy and social order wherein the worker termites do most of the work but have no ability to breed (except in rare and special cases). Also termites cannot survive for long if isolated from the colony to which they

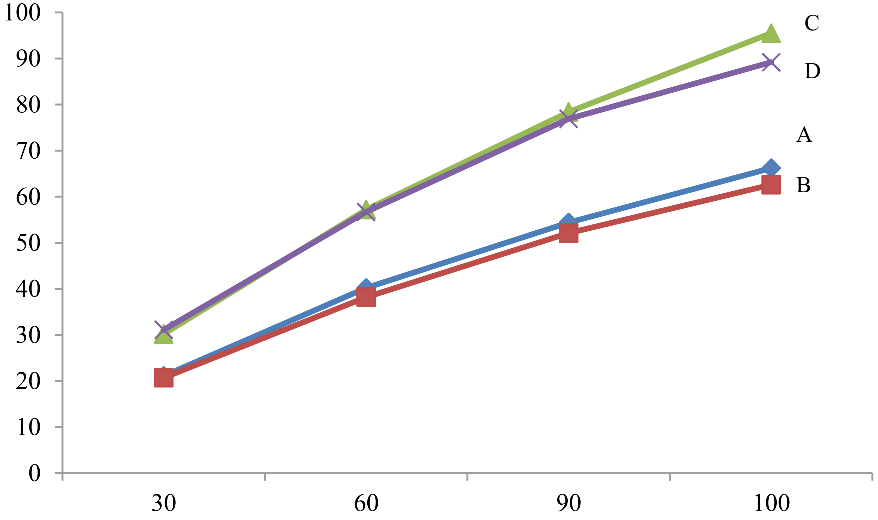

Fig. 6 Relative performance of the *in-situ* and the *ex-situ* reactors. Curves A and C pertain to *in-situ* termigradation of prosopis and ipomoea, respectively, while curves B and D pertain to *ex-situ* termigradation these weeds.

had belonged. The author's termigradation technology overcomes all these impediments while harnessing termites for the final disposal of those ligninous parts of harmful weeds like prosopis and ipomoea, which defy conventional bioprocesses.

The paper then describes experiments on the degradation of those ligninous constituents of prosopis and ipomoea which cannot be otherwise biodegraded. Utilization of *in-situ* and *ex-situ* termireactors has been described in experiments lasting 4 months on the trot. The results show that the most rapid termidegradation occurs during the first 30 days. The mechanism of the process and the use of the findings in process design, optimization and control have been described.

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