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Transformation of toxic and allelopathic lantana into a benign organic fertilizer through vermicomposting

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ABSTRACT

In a first study of its kind, the composition of vermicompost derived solely from the toxic and allelopathic weed lantana has been investigated using UV–visible and Fourier transform infrared (FT-IR) spectroscopy, thermogravimetric (TG) and differential scanning calorimetry (DSC), gas chromatography–mass spectometry (GC–MS), and scanning electron microscopy (SEM). The studies reveal that a sharp reduction in humification index, substantial mineralization of organic matter and degradation of complex aromatics such as lignin and polyphenols into simpler carbohydrates and lipids occur in the course of vermicomposting. GC–MS analysis shows significant fragmentation, bio-oxidation and molecular rearrangements of chemical compounds in vermicompost in comparison to those in lantana. SEM micrographs of vermicompost reflect strong disaggregation of material compared to the much better formed lantana matrices. The phenols and sesquiterpene lactones which are specifically responsible for the toxicity and allelopathy of lantana are seen to get significantly degraded in the course of vermicomposting — turning it into a plant-friendly organic fertilizer. The study leads to the possibility that the millions of tons of phytomass that is generated annually by lantana can be gainfully utilized in producing organic fertilizer via vermicomposting.

1. Introduction

Lantana (*Lantana camara*), a species of tropical American origin, has now spread across tropical and sub-tropical Africa, Asia and Australia and in over 60 countries [18], becoming one among the world's ten worst weeds [51,57]. It has infested millions of hectares of natural and cultivated lands, including forests [49], causing great ecological and economic damage [63]. Due to its tolerance for adverse environmental conditions and its high growth rate, it is able to out-compete other plants for space, water and nutrients, thereby catastrophically harming biodiversity [14]. Besides destroying the habitat of several species of animals, its roots exude toxic chemicals to the surrounding soil which kill or repel other plants.

There have been efforts to find possible ways of utilizing lantana, which include employing lantana as a source of cellulose [64], ethanol [38,44], drugs [56], biogas [55], materials for furniture [45] and compost mulch [58,64]. But none of these efforts have proved economically viable and lantana continues to invade more and more landscapes even as the ever–increasing biomass of lantana remains unutilized.

In nature both epigeic (phytophagous) and anecic (geophytophagous) groups of earthworm species scavenge on leaf litter and other bits of plant debris. The vermicast they deposit is known to rejuvenate and fertilize the soil by making its physical attributes and chemical composition plant-friendly [2,20]. Together the epigeic earthworms — who specialize in feeding on phytomass — and anecics, who feed on phytomass as well as soil, process billions of tons of phytomass per year. But even as controlled vermicomposting of animal manure has been economically viable and is done across the world [20], phytomass-based vermicomposting has never gone beyond laboratory experiments [1]. Among several reasons for it have been the need for pre-composting; reliance on manure supplementation; and low reactor efficiency, which, together, had made vermicomposting of phytomass too slow, cumbersome, and expensive to be utilizable [1,41]. These constraints had also prevented the exploration of possible utilization of lantana — indeed any other weed — as a substrate for generating vermicompost.

The problem has been recently overcome with the development of the concept of high-rate vermicomposting and associated technology by S.A. Abbasi and coworkers [1,3,4,24,25,59,60]. This has made it possible to vermicompost lantana and other forms of phytomass without any pre-composting or manure supplementation [1,26,42]. Moreover, the vermicomposting is achieved at a rate which is 3–4 times faster than the rate possible hitherto.

These developments have also made it possible to vermicompost lantana speedily, and in a potentially cost-effective manner. But before lantana can be put to use as a source of fertilizer, it is necessary to first check whether lantana vermicompost is helpful to other species of plants or is hostile as the lantana plants are. In two recent studies [30,35] which cover several species of plants and several concentrations of

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lantana vermicompost, we have confirmed that lantana vermicompost is as plant-friendly in enhancing germination success, fruit yield, and pathogen control as manure-based vermicomposts are known to be [20].

The present paper reports extensive investigations we have since carried out with the support of UV–visible and FTIR spectrometry, thermogravimetric and differential thermal analysis, GS-MS analysis, and scanning electron microscopy to identify the changes which are responsible for destroying the toxicity of lantana and giving plant-friendly attributes to its vermicompost.

2. Experimental

2.1. General

Alkali-resistant and temperature resistant borosilicate glassware and deionized, double distilled, water were employed throughout. All other chemicals were of analytical reagent grade, unless otherwise specified.

Plants of lantana were collected from its natural growth in the Pondicherry University campus. The leaves were plucked and washed with water to remove dust. After gently wiping off adhering water the leaves were charged directly in vermireactors employing *Eisenia fetida*. The vermireactors were operated in pulse-fed, high-rate, mode as detailed earlier [26,42]. There was no pre-composting or any manure supplementation. The vermicast was periodically harvested in each pulse. It was distinguished as a clear and precisely quantifiable product of the vermireactors. The quantities of the substrate and the vermicast were recorded on the basis of dry weights obtained by oven drying the samples to constant weight at 105 °C.

2.2. C:N ratio

The C:N ratio was computed on the basis of total organic carbon and Kjeldahl nitrogen determined by the dichromate redox [29] and Kjeldahl [34] methods respectively, using Kel Plus semi-automated digesters.

2.3. UV–visible spectroscopy

To measure the degree of humification that may be occurring due to vermicomposting, the method of Zbytniewski and Buszewski [67]) was employed. For it, 1 g each of the initial substrate and the vermicompost were taken in separate 250-mL polyethylene flasks and extracted with 50 mL of 0.5 M NaOH by shaking for 2 h. The contents of each flask were left undisturbed overnight and then centrifuged at 3000 rpm for 25 min. The absorbance (A) of each supernatant was measured at 472 nm (A_{472}) and 664 nm (A_{664}). Of these, the absorbance at 472 nm reflects the organic material at the beginning of humification and the absorbance at 664 nm is an indicative of the humified material [27, 53]. The degree of humification — often called the 'humification index' ($Q_{4/6}$) — is calculated by the ratio of A_{472} and A_{664}.

2.4. FT-IR spectrometry

For FT-IR spectrometry, the samples were prepared by oven drying, finely grounding, and mixing thoroughly of either lantana or its vermicompost with KBr (spectroscopic grade), homogenized in an agate mortar, and pelletizing at a pressure of about 1 MPa. The FT-IR spectra were recorded at a frequency of 0.5 cm/s on a Nicolet iS50 FT-IR spectrometer.

2.5. Thermal analysis

For thermogravimetric (TGA) and differential thermal analysis (DTA), performed with a TG analyzer model SDT Q600 V20.9 Build 20, the samples (20 mg) were ground in an agate mortar and sieved to ≤2 mm pore size. A temperature range of 30 °C–800 °C was explored in a nitrogen atmosphere at a heating rate of 10 °C/min. The manometric pressure was maintained at 101 kPa.

2.6. GC–MS analysis

Equal masses (5 g) of lantana and its vermicompost were separately mixed with 100 mL of methanol–water (9:1) (v/v), mixtures in 250-mL sterilized conical flasks. They were equilibrated overnight and filtered through Whatman no. 42 (Maidstone) filters. Each extract was evaporated to dryness and the residue was collected, quantified and dissolved in spectroscopic grade methanol. From it, 1 μl samples were injected into the gas chromatograph part of the GC–MS system Agilent 7890A GC interfaced with Agilent 5975C MS. The signals were associated with compounds in the samples by comparing the peaks obtained from the samples with the National Institute of Standards and Technology (NIST) library database [36].

2.7. Scanning electron microscopy (SEM)

Lantana leaves and its vermicompost were separately powdered and sputtered with gold. Their surface morphology was recorded using Hitachi, S-3400N electron microscope.

3. Results and discussion

3.1. C:N ratio

The results (Fig. 1) reveal that the C/N ratio of lantana (22.7) falls sharply to 8.1 as it gets vermicomposted. A C/N ratio of less than 20 is indicative of significant stabilization and a level of acceptable maturity, while a ratio of 15 or less is deemed preferable for agronomic use of the compost [16,40]. Hence the extent of reduction in C/N ratio achieved during vermicomposting of lantana reflects lantana's transformation into a nitrogen rich fertilizer. The fall in C/N ratio is essentially due to the loss of carbon content in lantana through microbial respiration. Some of the organic nitrogen is also likely mineralized by the earthworms and added to the vermicompost in the form of mucus and excreta.

3.2. UV–visible spectroscopy

The humification index ($Q_{4/6}$) values of lantana (8.38) were seen to have reduced sharply (to 2.03) as it got vermicomposted (Fig. 2). A humification index value less than 5 is indicative of high level of organic

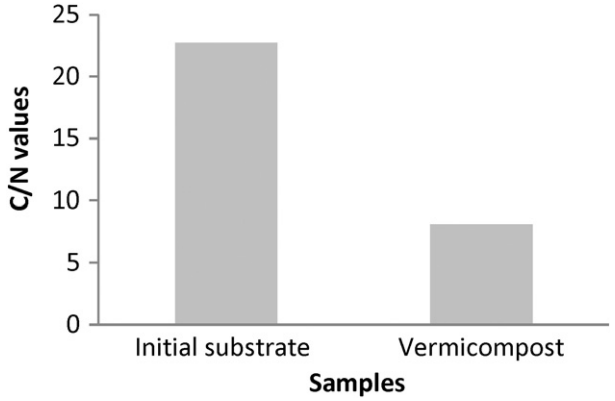

Fig. 1. C/N ratio of initial substrate (lantana leaves) and corresponding vermicompost.