Indian Journal of Biotechnology
Vol 3, October 2004, pp 486-494

Earthworms and vermicomposting

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Received 24 January 2003; accepted 15 October 2003

A review is presented summarizing the global state-of-the-art, including the gist of the studies conducted by the authors, on vermicomposting. Studies on the impact of vermicast on plant growth are also reviewed. The paper brings out the suitability or otherwise of different species of earthworms to 'bioprocess' different types of organic waste. The paper also presents the gist of the studies–which are surprisingly few and far between–on the impact on plant growth of vermicasts produced in reactors fed with aquatic weeds or agrowaste.

Keywords: earthworms, vermicomposting, *Eudrilus eugeniae, Perionyx excavatus, Lampito mauritii, Drawida willsi*

IPC Code: Int. Cl.[7] C 05 F 3/00, 9/04

Introduction

Vermicomposting is the term given to the process of conversion of biodegradable matter by earthworms into vermicast. In the process, the nutrients contained in the organic matter are partly converted to more bioavailable forms. Vermicast is also believed to contain hormones and enzymes which it acquires during the passage of the organic matter through the earthworm gut. The hormones and enzymes are believed to stimulate plant growth and discourage plant pathogens. All-in-all, the vermicast is believed to be very good organic fertilizer and soil conditioner. Recent experiments by the authors[1,2] confirm the earlier reports that vermicompost has more beneficial impact on plants than compost. In this paper, the authors present a review of vermicomposting in the background of the attributes of the main agents behind vermicomposting–the earthworm.

Earthworms

Earthworms are invertebrates belonging to the phylum *Annelida* and class *Oligochaeta*. Earthworms are so called because they are almost always terrestrial and burrow into moist-rich soil, emerging at night to forage. The earthworms are long, thread-like, elongated, cylindrical, soft bodied animals with uniform ring like structures all along the length of their body. These bodies consist of segments, arranged in linear series, and outwardly highlighted by circular grooves called annuli. The body segmentation is merely an external feature but exists internally too. At the sides of the body on the ventral surface of each segment are four pairs of short, stubby bristles, or *setae*. The *setae* provide traction for movement and also enable the worms to cling to their burrows when predators try to pull them out. There is no well-marked head but a preoral called the *prostomium* is present. Earthworms have an opening at each of its ends, the opening at the anterior end is the mouth and the one at the posterior is the anus. The body is always kept moist by the secretion of the body wall and also by the body fluids that come out at regular intervals from very minute pores in the worms' body surface. The earthworms do not have any specific organ of sight, hearing or olfaction, but special cells exist all along the length of their bodies to take up these sensory functions.

Earthworms possess both male and female gonads. They deposit eggs in a cocoon without the free larval stage. At maturity, a cover-like tissue is developed just behind the anterior segments, called the *clitellum*.

In damp weather, the earthworms stay near the surface, often with mouth or anus protruding from the burrow, while during dry weather, they burrow to several feet underground, coil up and become dormant[3]. Charles Darwin, and numerous scientists before and after him, have described earthworms as great benefactors of soil and agriculture[4]. Earthworms continuously till and aerate the soil, supply it with

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organic matter, and help moisture reaching it via the burrows they make[5]. Barring a few exceptions, most species of earthworms reduce plant pathogens, and are believed to release enzymes and hormones in their excreta beneficial to plant growth. In recent years earthworms have been increasingly employed in vermicomposting biodegradable solid wastes[3,6-9].

Geographical Distribution

Earthworms are found in most parts of the world with the exception of deserts (where they are rare), areas under constant snow and ice, mountain ranges, areas bereft of soil and vegetation. Such features are natural barriers against the spread or migration of earthworm species, and so are the seas, because most species cannot tolerate salt water even for a short period or the areas influenced by salt water intrusion[3].

Some species are widely distributed. Michaelsen[10] has used the term *peregrine* to describe such species. Such of the species which occur only in specific areas and are not able to spread widely have been termed *endemic*.

Ecological Classification

Ecological classification of earthworms based on interspecific variations has been attempted by several workers.

a) Classification Based on Habitat

Evans and Guild[11] have distinguished earthworms into surface dwelling and deep dwelling species. Graff[12] inferred that a deep pigmented surface living variety generally occurs predominantly in habitats with sufficient organic matter. Byzova[13] was the first to distinguish surface living smaller worms with high metabolic rate from deep dwelling larger worms with less metabolic rate. Bouche[14] proposed an ecological classification of earthworms into 3 generalised life forms: (i) epigeics, (ii) anecics and (iii) endogeics. Table 1 gives the summary of the characteristics used to distinguish ecological types of earthworms. The epigeics have greater potentiality for degrading organic wastes and endogeics have better capacity of protein conservation, whereas anecics remain in between[14].

(i)*Epigeics*. Epigeics are the species that live above the mineral soil surface[15]. They are phytophagous and generally have no effect on the soil structure as they cannot dig into the soil [7]. They are small in size with uniform colouration[16].

(ii)*Anecics*. Anecics are the species that live in burrows in mineral soil layers, but come to the surface to feed on dead leaves, which they drag into their burrows. They play an important role in burying surface litter[15]. They ingest plant matter as well as soil; in other words they are geophytophagous[7]. They construct vertical tunnels[16] .

(iii)*Endogeics*. Endogeics are the species that inhabit mineral soil horizons feeding on soil more or less enriched with organic matter[15]. They are geophagous[7]. They construct horizontal branching burrows[16].

b)Classification Based on Nature of Diet

Perel classified earthworms, which feed on plant debris that is only slightly decomposed as *humus formers* and those which feed on plant debris that is already much decomposed as *humus feeders*[15].

Table 1—Summary of characteristics used by Bouche to distinguish ecological type of earthworms

	Ecological type		
Character	Epigeics	Anecics	Endogeics
Body	small	moderate	large
Burrowing	reduced	strongly developed	developed
Longitudinal contraction	nil	developed	least developed
Hooked chetae	absent	present	absent
Sensitivity to light	feeble	moderate	strong
Mobility	rapid	moderate	feeble
Skin moistening	developed	developed	feeble
Pigmentation	homochromic	dorsal and anterior	absent
Fecundity	high	moderate	limited
Maturation	rapid	moderate	slow
Respiration	high	moderate	feeble
Survival of adverse	as cocoons	true diapause	by quiescence

Another classification is also based on the nature of the diet. Earthworms that feed on a high proportion of raw humus have been termed *detrivorous* and those that feed on amorphous humus and mineral material *geophagous*[15].

Factors Responsible for Earthworm Distribution

The factors responsible for distribution are:

i) physico-chemical (soil, temperature, moisture, *p*H, inorganic salts, aeration and texture),
ii) available food (herbage, leaf litter, dung, consolidated organic matter), and
iii) reproductive potential and dispersive power of the species[17].

i) Soil Acidity

Earthworms are very sensitive to hydrogen ion concentration. Thus, the soil *p*H sometimes limits their distribution, number and species that live in a particular soil. Most species prefer soils with a *p*H close to 7.0[17].

ii) Soil Moisture

Earthworms do not thrive in dry soils and avoid drought either by migrating to lower layers several feet deep or by entering a state of diapause in which they roll up inside spherical earthen cells lined with mucus. They are much more active in moist soils than dry ones and during periods of heavy rain, individuals of some species such as *Lumbricus terrestris* come out on to the soil surface at night. Most species cannot survive flooding, though a fair number can do so, provided water is aerated. Excess water lowers the *p*H and this proves fatal to some species.

iii) Temperature

The activity, metabolism, growth, respiration and reproduction of earthworms are all greatly influenced by temperature. Fertility and the growth period from hatching to sexual maturity are also dependent on temperature.

iv) Cycles of Activity

The cycles of earthworm activities are mainly determined by the temperature and water regimes in the soil and the availability of food. Usually, temperature is the most dominant limiting factor in temperate and cold regions; shortage of food and soil moisture (such as in summer) may also be important limiting factors.

Burrowing

Earthworms create tunnels through the soil as they move. They first push their anterior portion into a crevice and then bore in by expanding their segments and forcing apart the obstacles. When the soil is very compact, they literally eat their way through. Burrows range from 3 to 12 mm in diam, but it is not certain whether worms increase the size of their burrows as they grow, or make new ones. During very dry days, earthworms can go several feet underground. At the bottom of each burrow, a wide space is formed so that they may take turns in the burrow. The entrance of the burrow is often covered with bits of leaves, faecal matters, and some pebbles to stop in flow of the water and keep off predators. The burrows are cemented internally by secretion of the worms' cutaneous glands.

Feeding

Earthworms mainly feed upon the decaying organic matter found in the soil. They also feed on leaf and other plant material obtained on the soil surface. They do not feed to any great extent on the leaf material *in situ*, but first pull it into the mouth of the burrow, to a depth of 2.5-7.5 cm, so forming a plug, which may protrude from the burrow. The food is first moistened by an alkaline enzymatic secretion, which digests starch, making it easier to tear it into shreds. Leaves may be torn by holding them by the edge between the prostomium and the mouth and pushing the pharynx forward. Alternatively, small portions may be sucked in by first pressing the mouth against the leaf and then withdrawing the pharynx, thus creating suction.

Casting

After passing through the animal, the food emerges as a compact, concentrated mass termed as casting. Some species cast within their burrows and others on the surface. The form of casting may vary from individual pellets (as in *Pheretima posthuma*) to short threads (as in *Perionyx milardi*). *Eutyphoenus waltoni*, an Indian species, produces casts that look like a twisted coiled tube and the African species *Eudrilus eugeniae* Kinberg produces casts that take the form of pyramids of very finely divided soil[17].

Earthworm casts contain microorganisms, inorganic minerals and organic matter in a form available to plants. Casts also contain enzymes such as protease, amylase, lipase, cellulase and chitinase, which continue to disintegrate organic matter even after they have been excreted.

Species Suitable for Vermicomposting

The criteria for selection are:

(i) Easy to culture;
(ii) High affinity for the substrate to be vermicomposted; and
(iii) High rate of vermicast output per worm and per unit digester volume.

Species Advocated for Vermicomposting

It is generally known that epigeic species have a greater potential as waste decomposers than anecics and endogeics. This is due to predominantly humus consuming surface dwelling nature of the epigeics. The commonly used epigeic species are *E. eugeniae*, *Eisenia foetida* and *Perionyx excavatus* Perrier[16,18-22].

All the above three species are prolific feeders and can feed upon a wide variety of degradable organic wastes. They exhibit high growth rate. But *E. foetida* has a wider tolerance for temperature than *E. eugeniae* and *P. excavatus* which allows the species to be cultivated in areas with high temperature (often as high as 43°C as well as those with lower soil temperature (often below 5°C).

Species used in India

Some experts recommend the use of surface dwelling epigeic species for vermicomposting, while others recommend the burrowing anecics and endogeics. A status report prepared by CAPART[16] recommends epigeic species such as *E. eugeniae*, *E. foetida*, *P. excavatus* and *P. sansibaricus* as good converters of waste. Of these, *P. excavatus* and *P. sansibaricus* are endemic species. *E. foetida* is probably the species best suited for vermicomposting throughout the country, whereas *E. eugeniae*, *P. excavatus* and *P. sansibaricus* are better suited for the southern parts of the country, where the summer temperature does not rise as high as in Central and North India.

The Institute of Natural Organic Agriculture (INORA) in Pune, also advocates the use of surface worms because they consume all types of garbage and multiply quickly[23].

The use of endogeics and anecics that are native to the local soil has been recommended by many others[7,24,25]. Though surface dwellers are capable of working hard on the litter layer and convert all the organic waste into manure, they are of no significant value in modifying the structure of the soil[7]. The anecics, however, are capable of both organic waste consumption as well as modifying the structure of the soil. Earthworms comprising the epigeic and anecic varieties, for the combined process of litter and soil management have been recommended, although *P . excavatus* and *Lampito mauritii* Kinburg together take care of litter and other organic waste; *L. mauritii* being an anecic also helps in rejuvenating the soil by burrowing through it. The local endogeics recommended in the status report of CAPART for maintenance of soil fertility include *L. mauritii*, *Pontoscolex corethrurus, Pheretima posthuma, Octochaetona serrata* and many others[16].

In the study conducted by Gajalakshmi *et al*[26] four species of detritivorous (humus-former) earthworms were tested for their ability to vermicompost paper waste blended with cowdung in 6:1 (w/w) ratio. The species used were *E. eugeniae*, *P. excavatus*, *L. mauritii* and *Drawida willsi* Michaelsen.

As mentioned earlier, *E. eugeniae* and *P. excavatus* are classified as epigeics or humus feeder earthworms. They typically inhabit humus-laden upper layers of garden earth and manure-pits. They have higher frequency of reproduction and faster rate of growth to adulthood than most other species; these two factors make them efficient utilizers of humus, manure, and other forms of organic carbon. Further, as they do not burrow into the soil, the vermireactors based on them need not contain deep bed of soil. This has the potential of contributing towards saving on reactor volume, in turn contributing to favourable economics. For all these reasons *E. eugeniae* and *P. excavatus* have been extensively used in vermicomposting throughout the world [27-29] and have proved to be efficient converters of organic feed, especially manure, into vermicast.

The anecics, *L. mauritii* and *D. willsi* are geophytophagous but known to be voracious feeders of humus in preference to soil. They burrow into the soil but such burrows are shallow; hence, it was felt that a thin layer of soil may be adequate for them in the vermireactors. Further, *D. willsi* is endemic to southern India–the region where these studies have been conducted–and its choice was influenced by the possibility that by virtue of this factor the species may prove more adopted and resilient, hence, 'robust'[26] .

It was found that *L. mauritii* and *E. eugeniae* were more efficient vermicast producers than the other two species, converting ~52% of the feed against ~46% achieved by the other two species. *E. eugeniae* has been the most reproductive, followed by *L. mauritii*.

D. willsi and *P. excavatus* have each produced significantly lesser number of offsprings[26] .

Another study was conducted by the authors[30] employing the same earthworm species to vermicompost water hyacinth. It revealed that in terms of the efficiency of vermiconversion of water hyacinth (as reflected in the mass of vermicasts produced per unit time for the given rate of feed input), the animal species followed the trend *E. eugeniae* > *P. excavatus* > *L. mauritii* > *D. willsi*. Similar trends were observed for increase in animal biomass, and number of offsprings produced, with the exception that in the latter aspect *L. mauritii* was indistinguishable from *D. willsi.*

It was observed that with waste paper as the principal feed, it was found that the geophytophagous *L. mauritii* was not only the most efficient producer of vermicasts but also generated more offsprings during the six-month long trials. In the case of water hyacinth, the phytophagous *E. eugeniae* and *P. excavatus* were seen to score over the two geophytophagous, or anecic, species. Besides the fact that water hyacinth is a phytomass and ought to be naturally preferred by phytophagous species, the relative 'hardness' of waste paper feed may be a reason why geophytophagous worms were able to feed upon it more voraciously than the phytophagous species.

Conventional Steps Involved in Vermicomposting

Vermicomposting can be done either in pits or concrete tanks or well rings or in wooden or plastic crates appropriate to a given situation[7]. If done in pits, it is preferable to select a composting site under shade, in the upland or an elevated level, to prevent water stagnation in pits during rains.

Any set-up for producing vermicompost should have the following attributes:

a) It should have adequate provision for earthworms to live, feed, and breed; such provision should confirm to the habits of the earthworm species used in the set-up.
b) It should be kept optimally moist and close to neutral *p*H.
c) It should safeguard against insects and predators so as to prevent harm to the earthworms.
d) It should have adequate provision for periodic harvesting of vermicast and renewal of feed.

According to Ismail[7], a typical vermicomposting unit may be set up by first placing a basal layer of vermibed comprising broken bricks or pebbles (3-4 cm) followed by a layer of coarse sand to a total thickness of 6-7 cm to ensure proper drainage. This may be followed by a 15 cm moist layer of loamy soil. Into this soil may be inoculated about 100 locally collected earthworms (about 50 surface and 50 subsurface varieties).

Small lumps of cattledung (fresh or dry) may then be scattered over the soil and covered with a 10 cm layer of hay. Water may be sprayed till the entire set up is moist but not wet. Less water kills the worms and too much chases them away. The unit may be kept covered with broad leaves like those of coconut or palmyrah. Old jute bags can also be used for covering. Watering the unit should be continued and the unit monitored for 30 days. The appearance of juvenile earthworms by this time may be taken as a healthy sign. Organic refuse may be added from the thirty-first day as a spread on the bed after removing the fronds. The spread should not exceed 5 cm in thickness at each application. Though addition of this amount of matter can be done everyday. According to Ismail [7] it is advisable for a beginner to spread the feed only twice a week, watering to requirement. After a few applications, the refuse may be turned once without disturbing the bed. The day enough refuse has been added into the unit, watering may be done and 45 days later the compost would be ready for harvest.

As the organic refuse changes into a dark brown compost, addition of water should be stopped (42^{nd} day). This would move the worms into the vermibed. The compost may be harvested and the harvested compost placed in the form of a cone on ground in bright sunlight. This will facilitate worms present in the compost to move to the lower layers. The compost pile may be spread for about 24 to 36 hrs, and the worms may be removed from the lower layers of the compost[31].

Vermireactors, which are essentially tanks in which earthworms are made to feed upon animal manure and/or other biodegradable solid wastes, do not require continuous inputs of other forms of energy for their operation. As such, the cost of the tanks constitutes the major component of cost input in a vermireactor. In order to maximise benefit from such reactors, it is essential to minimize the reactor volume for a given vermicast output[26].

In a study conducted by the authors, vermireactors with two kinds of vermibeds–reactors with conventional vermibed and reactors with modified vermibed–were operated. In the reactors with conventional vermibed, circular, 4 l plastic containers were filled from bottom up with successive layers of sawdust, river sand and soil of 1, 2 and 4 cm, respectively. In reactors with modified vermibed, a layer of moist cloth and the feed constituted the vermibed.

Both the types of reactors were operated in two modes: low and high rate. The low rate reactors consisted of 20 worms and 75g (dry weight) of the feed, whereas the high rate reactors were operated with 12.5 times more earthworm density and feed loading rates[26,30].

The vermicast recovery per unit digester volume was 3% more in reactors with modified vermibed in the low rate reactors and 6.1 % better in the high rate reactors. Eventhough the performance was only a little (3-6%) better in vermireactors with modified vermibeds, it indicates the feasibility and application of these reactors to be run by the common household people.

Factors Influencing Culturing of Earthworms

Several factors control the culturing and maintenance of healthy earthworm populations, of which the most important are: i) Food; ii) Moisture; iii) Temperature; iv) Light; v) *p*H and vi) Protection from predators.

i) Food

One of the most important factors that control the establishment and continuity of earthworm populations is food and its quantity. Higher nitrogen ratios help in faster growth and greater production of cocoons. Fresh green matter is not easily fed upon. Decomposition by microbial activity is essential before earthworms can feed on fresh waste. The C/N ratio is the critical factor that limits earthworm populations. When the C/N ratio of the feed material increases, it becomes difficult to extract enough nitrogen for tissue production. Earthworms find it difficult to survive when the organic carbon content of the soil is low.

ii) Moisture

Moisture levels have to be maintained at around 50% so that the microbial activity is high and the food matter is easy to feed upon. Excess water leads to anaerobic conditions, which in turn lowers the *p*H and creates acidic conditions. Acidic conditions reduce productivity and cause migration.

iii) Temperature

Temperature affects metabolism, growth and reproduction. Soils exposed to the sun lose moisture quickly and are usually devoid of earthworms. Earthworms maintain lower body temperatures than the surrounding soil or organic matter by their metabolic adjustments.

iv) Light

Earthworms are very sensitive to light. The photoreceptor cells detect light and the earthworms moves away to avoid strong light. The deep burrowing anecics and other species emerge at the surface only at night for this reason.

v) *p*H

Earthworms are sensitive to changes in *p*H. They prefer conditions of neutral reaction. Earthworms find it difficult to survive if the *p*H falls below 6 and thus they migrate or are killed.

vi) Predators

Earthworms are preyed upon by many species of ants, birds, toads, salamanders, snakes, moles, cats, rats, dogs, etc. Moles catch earthworms, bite off three to five anterior segments to prevent locomotion and keep them in their burrows. A variety of invertebrates also feed on earthworms. These include flatworms, centipedes, staphylinid beetles, etc.

Benefits of Vermicompost

In India—as also many other parts of the world—vermicasts are believed to have several components, which improve the soil to which they are applied[7,15,32,33]. The perceived, sometimes demonstrated benefits include improvement in the water retention capability of the soil, and better plant availability of the nutrients in the vermicasts compared to the 'parent' (pre-vermicomposted) material[34,35]. The magnitude of the transformation of phosphorus forms was found to be considerably higher in the case of earthworm-inoculated organic wastes, showing that vermicomposting may prove to be an efficient technology for providing better phosphorus nutrition from different organic wastes[36,37]. The studies carried out by Basker[38] under field conditions indicated that the castings of earthworms contained two to three times more available potassium than the surrounding soil. Earthworm castings have a higher ammonium concentration and water-holding capacity than bulk soil samples, and they constitute sites of high dentrification potential[39]. According to Parkin and Beery[40], earthworm castings are enriched in mineral N, and compared with the surrounding soil, vermicompost has lower C/N ratio and *p*H than normal compost irrespective of the source of organic waste. Microbial population is also considerably higher in vermicompost than in compost[41].

In Bangalore, earthworms successfully decomposed sugar factory residuals and turned them into a soil nutrient that allowed farmers using the material to reduce chemical fertilizers by 50%[42].

Vermicasts are believed to contain enzymes and hormones that stimulate plant growth and discourage pathogens[7,43,44]. Vermicompost added to various container media significantly inhibited the infection of tomato plants by *Fusarium oxysporium* f. sp. *lycopercisi*, the protective effect increased in proportion to the rate of application of vermicompost[44].

Whereas vermicast generated from animal dung is universally believed to be beneficial to soil and plants, there are no reports giving evidence that the same may be true of vermicasts generated from other sources. To explore this area, the authors have conducted three studies on the impact of the application of water hyacinth and neem compost/ermicompost on plants[1,2,45].

The first experiment was qualitative, done at the kitchen gardens of five farmers[1]. In each location ~ 4 m^2 plots were marked out and the following common vegetables were planted: lady's finger (*Abelmoschus esculentus*), brinjal (*Solanum melongena*), cluster bean (*Cyamopsis tetragonoloba*), chilli (*Capsicum annum*), and tomato (*Lycopersicon esculentum*). Three of the plots were treated with water hyacinth vermicompost and two of the plots with equal quantity of water hyacinth compost. As these were qualitative studies basically to see whether the water hyacinth compost/vermicompost discourages plant growth, no controls of unfertilized plots were studied. Observations on the five kitchen gardens revealed total absence of any harmful effect of compost/vermicompost. Rather, the farmer's view was that the vegetables grew better than normal on the treated plots.

In the second experiment, saplings of *Crossandra undulafolia* were grown with and without the presence of water hyacinth compost/vermicompost[1]. *C. undulaefolia*, is an angiosperm and a free-branching perennial herb[46]. It is an ornamental plant, and is marketed as such. It was found that the pots containing soil amended with water hyacinth compost had crossandra plants achieving significantly better height, larger number of leaves, more favourable shoot : root ratio, greater biomass per unit time and larger length of inflorescence. In terms of root length, quicker onset of flowering and harvest index too, the treated plants on an average performed better than the controls but the enhancement was not statistically significant. The positive impact was more pronounced in plants treated with vermicompost; indeed in respect of all the nine parameters there was statistically significant (at $\geq$ 95% confidence level) enhancement in performance. Of particular interest is the enhancement in the flower yield and harvest index by vermicompost as these attributes directly enhance the benefits from the cultivation of crossandra.

The third experiment was conducted to study the impact of the application of vermicompost obtained from neem (*Azadirachta indica*) on the growth and yield of the brinjal plant, *S. melongena*[2]. Morphological and yield attributes were studied in brinjal saplings treated with neem vermicompost as compared to the untreated saplings. The plot supplemented with neem vermicompost had plants achieving significantly better height, root length, greater biomass per unit time, quicker onset of flowering, and enhancement in fruit yield. In terms of fertility coefficient and harvest index too, in treated plots, there was statistically significant enhancement in performance. With the supplementation of neem vermicompost after 2 months in control plots, there was increase in plant height, root length, total biomass and number of flowers and fruits produced.

Deolalikar and Mitra[47] have used vermicompost prepared from paper mill solid waste for fertilizing aquacultural tanks and found an increase in net primary productivity from 32.08 to 220.83 mg C/m/h. Vermicompost application also showed better growth of Rohu fish (*Labeo rohita*) when compared with other commercially availalable organic manures[48].

Acknowledgement

The authors thank the All India Council for Technical Education for providing equipment support under the MODROBS scheme. SG thanks Council of Scientific and Industrial Research, New Delhi for a Senior Research Fellowship.

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