Pill millipede compost: a viable alternative to utilize urban organic solid waste

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Urban organic solid waste needs appropriate attention for transformation into compost or manure through bioconversion to reduce the landfill and to avoid waste-borne hazards. This study proposes the possibilities of using pill millipedes (*Arthrosphaera*) as saprophagous fauna for transformation of urban organic solid waste into compost. Pill millipedes transform solid organic waste into quality compost (neutral pH, low phenolics, narrow *C/N* ratio and elevated nitrogen and phosphorus contents) within a short-time frame. Pill millipedes can be maintained or reared in the laboratory conditions throughout the year by feeding mixed organic waste (leaf litter) and soil. Various containers are recommended for bench-scale and green house conditions with a model compost bin to generate compost form organic solid waste using pill millipedes. Solid organic waste processing model has been proposed for eco-friendly production of manure using pill millipedes and earthworms.

Keywords: Composting, degradation, pill millipede, organic solid waste.

Eco-friendly bioconversion of urban organic solid waste is one of the important issues to cut down waste accumulation. Depending on the rate of degradability, the organic matter could be divided into different categories. Tremier *et al.*[1] classified organic matter into fast degradable and slow degradable pools based on the rates of oxygen uptake. Sole-Mauri *et al.*[2] further classified organic matter into six categories (carbohydrates, proteins, lipids, hemicelluloses, cellulose and lignin). Even though the soluble fraction is degradable, recalcitrant components require mechanical or chemical treatment to hasten degradation. The rate of degradation of cellulosic fraction varies depending on its origin. Although biodegradability of organic matter is not clearly understood, some studies evaluated the mechanism of biochemical transformation of organic matter through composting[3–5].

Organic waste generated by avenue trees and parks (e.g. leaf litter, twigs, bark, flowers, pruned matter and grass shreds) constitutes appropriate feedstock along with soil for compost production[3]. Home and kitchen gardens are also the major sources of organic waste. Besides, urban-generated lignified materials like paper and cardboard shreds lacking nitrogen are also ideal for composting along with soil to compensate nitrogen requirement. Several economically viable strategies are available to utilize organic solid waste for food (mushroom cultivation), energy (biogas production), vermicompost (earthworm compost) production and natural bio-transformation (compost in pits or heaps)[6–9]. Region-specific technology is necessary for utilization of biodegradable organic waste as pill millipedes confined to specific region of southern India[10,11]. For instance, mushroom culture facilities, biogas production plants, vermicompost bins and natural compost facilities serve the purpose of ecofriendly organic waste recycling. Such approaches meet the demands of food, fuel and organic manure at household and community levels[12]. Moreover, these attempts reduce the accumulation of solid organic waste and waste-borne problems (e.g. landfill, incineration and spread of diseases) in municipal, semi-urban and urban localities[13,14].

Domestic or community composting is better than incineration as it lowers amount of waste in the waste stream and landfill[12]. The high C/N ratio of organic matter (lignin and cellulose) ensures greater recalcitrance of feedstock[15], which will be mineralized by carbon loss during composting, especially by microbial activity. Composting transforms biodegradable waste into organic manure valuable for agriculture by desired biochemical changes suitable to the soil.

Vermicompost production using earthworms is one of the most attractive, popular and cost-efficient approaches of organic waste processing and management. The most important requirement of organic matter processing is to increase the surface area by shredding to facilitate microbial colonization and in turn degradation. Earthworms being major saprophagous fauna, utilize decomposed organic matter along with soil, digest organic matter in the intestine with microbes and produce casts consisting of organic matter with more surface area for further conditioning by soil microbes.

Besides earthworms, millipedes are also suitable for bioconversion of organic matter into valuable compost[16]. Earthworms, millipedes and their combination serve the bio-transformation of plantation, forest and urban organic waste into compost[13,17–20]. It is known that the degradation of organic matter and recycling of detritus are favoured by the gut microflora of millipedes[21]. It is possible to harvest pill millipede compost within 1–2 weeks: it possesses pH close to neutral, low total phenolics, low organic carbon and narrow C/N ratio with significantly elevated total nitrogen as well as total phosphorus[19,22].

Compared to other millipedes, pill millipedes belonging to the genus *Arthrosphaera* are large-bodied, devoid of poison glands, do not release offensive odour and roll up into marble/table tennis ball/baseball size, facilitating easy handling in organic matter processing. Pill millipedes are known to have a long lifespan of 11 years[23]. Location-dependent dominance of *Arthrosphaera* is seen

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in the Western Ghats of India. *Arthrosphaera davisoni*, *A. disticta*, *A. fumosa* and *A. zebraica* dominate in high-altitude regions, whereas the foothill regions show dominance of *A. magna* or *A. dalyi*, and the coastal regions are rarely colonized by a few species[10,11,24–26]. Adult pill millipedes weigh between 0.6 and 28 g; each individual ingests about 0.3–3 g of organic matter per day and generates significant amount of faecal pellets throughout the year under *ex situ* conditions. One *Arthrosphaera* species in the high-altitude region of the Western Ghats of Karnataka is gigantic among the species known so far (62–80 × 26–40 mm, 20–28 g)[10].

In the Western Ghats, pill millipedes emerge after sufficient rainfall. The adults are active for five months (July–November) and the activity of young ones is restricted to four months (August–November) due to decline in soil moisture[27]. But in mixed plantations, adults are active for up to eight months (June–January), whereas the juveniles emerge during late July or early August are active up to four months and hibernate in November prior to the adults. A recent study[26] on four pill millipedes demonstrated that under laboratory conditions (26–28°C) with mixed leaf litter diet in glass tanks, survival rate during wet season (June–November) was up to 98%, whereas during dry season (December–May) it was between 75% and 86%. Besides, four out of six pill millipede species moulted and two species showed mating behaviour, indicating positive signs of suitable conditions that could be provided in a laboratory. In cooler conditions (21–24°C), *A. fumosa* laid eggs and juveniles emerged indicating the possibility of successful breeding under e*x situ* conditions.

Pill millipedes ingest conditioned (partially decomposed) plant detritus and transform into mineral-rich compost in the form of faecal pellets[26–28]. Faecal pellets of temperate pill millipedes (*Glomeris marginata*) are attractive to earthworms (*Lumbricus castaneus* and *Octolasion lacteum*) and those pellets were further mineralized[29,30]. Such assessments need to be performed in tropical pill millipedes and earthworms for duel processing of organic waste as manure. Organic matter in faecal pellets of pill millipedes fed with *Acacia*, banana, cashew and coconut leaf litter amended with soil was higher than those fed with only soil (70.1–75.8% versus 9.3%)[19], probably due to lack of sufficient organic matter in the soil. Increase in nitrogen, phosphate and potassium, decrease in C/N ratio and prevalence of neutral pH of faecal pellets of pill millipedes fed with mixed litter diet[22] support their ability to transform solid organic waste into valuable manure with the help of gut microflora. Increase in nitrogen and phosphorus contents and decrease in phenolics and C/N ratio in pill millipede compost on feeding organic matter in laboratory, forests and plantations are evident[22,28]. It is likely that polyphenol oxidase produced by the gut microflora facilitates decrease of phenolics in the faecal pellets.

Experiments on the dry pasture yield in black gram (*Phaseolus mungo*) and dry straw yield in finger millet (*Eleusine coracana*) grown with farmyard manure and farmyard manure amended with pill millipede compost produced by the mixed plantation leaf litter by *A. magna* showed better performance by the latter[31]. Compost produced by flower waste using pill millipedes showed higher biomass as well as fruit yield in capsicum (*Capsicum annuum*) than conventional manure and vermicompost[18]. Prabhas *et al.*[32] also showed that millipede compost is superior and has a positive impact on plant growth against vermicompost and conventional compost. The above findings reveal that the mixture of farmyard manure with millipede compost performs better in plant production. As pill millipedes prefer mixed litter rather than mono-litter diet[24,28], it would be ideal to mix different organic wastes in various proportions to produce good quality compost. It is likely that pill millipedes meet their requirement of minerals, especially Ca^{++} and Mg^{++} from the mixed leaf litter than mono-litter to build their tergites[33]. Organically managed plantations are ideal for colonization of pill millipedes, especially the basins of plantations (e.g. coconut, areca and cocoa) receiving mixed organic waste as compost.

To employ pill millipedes in the production of compost at the laboratory, domestic and greenhouse levels, different containers can be used[10,18,19,26]. Plastic bottles (30 × 10 cm; with holes on the sides and top) kept in a horizontal position require about 250 g mixed organic waste for 5–10 pill millipedes per bottle (Figure 1). Glass tanks (90 × 60 cm) require about 4 kg of mixed organic waste and accommodate 20–30 pill millipedes per tank for bench-scale production of compost. Circular cement tanks (60 × 60 × 60 cm) are ideal under greenhouse conditions, and hold up to 2 kg of solid waste with 10–20 pill millipedes per tank. However, the number of small-sized pill millipedes like *A. disticta* and *A. nitida* (20–28 × 0.9–12 mm; 0.6–1.6 g) could be doubled than the large-sized ones. The top of glass and cement tanks requires mesh cover to avoid escape of millipedes. A schematic model of a compost bin is shown in Figure 2. The organic waste offered to millipedes requires periodical water spray to wet the organic matter (once or twice per day). Excess water is not desirable as the faecal pellets dissolve and become difficult to handle. The production of millipede compost is rapid as it can be harvested within 1–2 weeks under ideal conditions.

It is feasible to mix decomposing leaf litter and soil along with urban organic wastes (e.g. shreds of paper, paper cardboard and palm sheath) in different proportions. If the organic waste is fresh, it is necessary to precondition on wetting up to 2–3 weeks before offering to millipedes. A pilot experiment was conducted to produce compost from leaf litter with urban organic waste (Mangalore city, Karnataka: 12°52′N, 74°50′E) using *A. fumosa* and *A. magna* in glass tanks. Each container with

Figure 1. Containers to process solid waste by pill millipedes: plastic bottles (***a***), glass tank (***b***) and cement tank (***c***) for household, bench-scale and greenhouse conditions respectively.

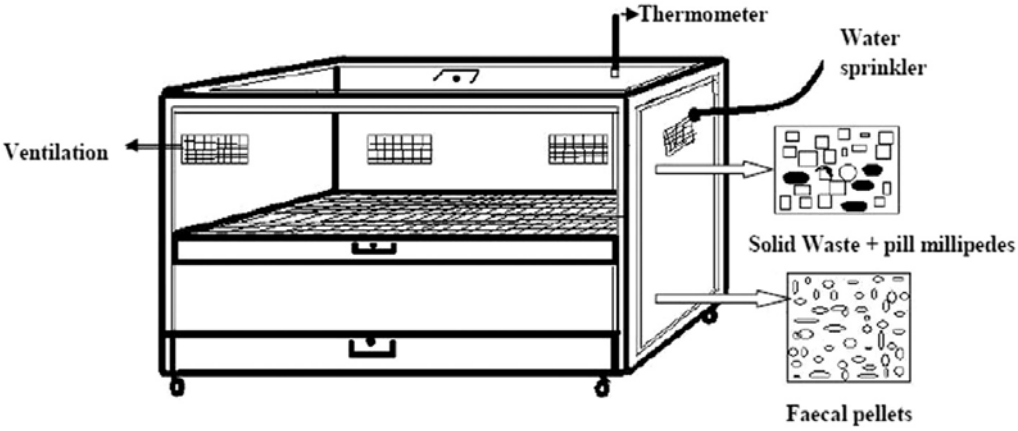

Figure 2. Improved bin model useful for compost production by pill millipedes.

10 cm soil bed was loaded with 1 kg each of fallen and dried leaf litter (*Lagerstroemia microcarpa*), waste paper, paper cardboard (packing material) and palm sheath. Twenty pill millipedes were allowed to feed on waste material up to one week. Shredding of urban organic waste and production of faecal pellets by pill millipedes are shown in Figure 3. Glass tanks without central mesh and 15 cm soil bed in the bottom will facilitate millipedes to burrow, hibernate and construct moulting chambers using organic matter and faecal material and in turn help long-term maintenance under laboratory conditions. The improved bin is useful for offering the organic solid waste to pill millipedes and to collect the faecal pellets as manure (Figure 2).

Further value-addition of pill millipede compost can be achieved by mixing inoculum of plant protectants like *Rhizobium* and *Trichoderma* prior to packing and distribution. As earthworms also feed on organic matter as well as faecal pellets of millipedes, strategies need to be set for dual processing for compost generation. It is also feasible to provide some amount of soil along with organic waste during composting. In the laboratory set-up, either cocoons or juveniles of earthworms present in decomposing organic waste and soil, grow up and process the organic matter along with pill millipedes, showing the compatibility of these fauna.

Urban organic waste provides suitable feedstock for transformation into compost. Such transformation could be a hobby in domestic or community centres of urban locations resulting in substantial cut down of solid waste accumulation and landfill. The compost generated serves the purpose to raise terrace garden (vegetable, fruit plants and flowering plants), hanging garden (orchids and ferns) and also kitchen garden. Such approaches pave the way for large-scale production, transport and utilization of millipede compost in organic farming.

Pill millipedes should be acclimatized to feeding mixed leaf litter diet and these could be supplied for compost production on a large scale. Secondly, suitable feedstock of solid organic waste and proportions of components

Figure 3. ***a***, Pill millipedes (*Arthrosphaera fumosa*) shredding solid waste in a bin. ***b***, Faecal pellets of *A. fumosa* fed on solid wastes. Pattern of consumption of various organic solid wastes (***c***, Leaf litter; ***d***, Paper; ***e***, Paper cardboard; ***f***, Palm sheath) by *A. fumosa* – (top panel) before feeding and (bottom panel) after feeding respectively.

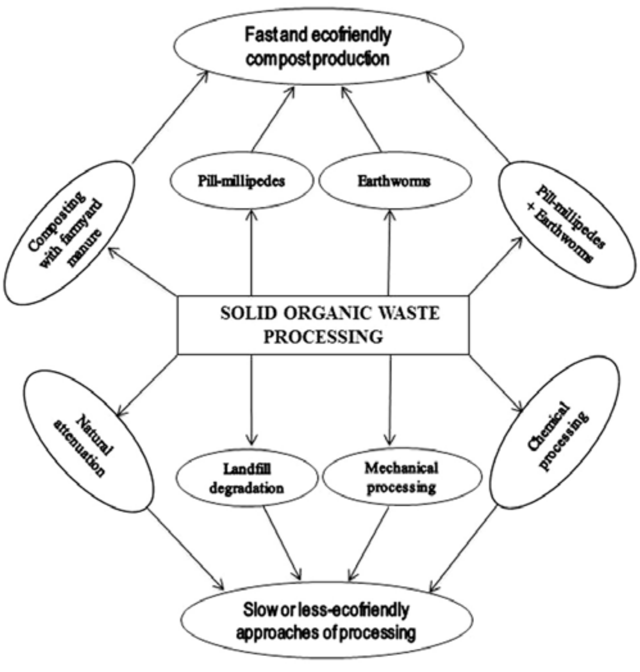

Figure 4. Schematic representation of organic solid waste processing for production of compost.

need to be identified and offered to the pill millipedes (or pill millipedes + earthworms). Some pill millipedes perform better in high elevation in the Western Ghats (800 m and above; e.g. *A. davisoni*, *A. disticta* and *A. zebraica*), while some perform better at mid-elevation (250–500 m; e.g. *A. dalyi* and *A. magna*). Although low-altitude coastal locations possess a few pill millipedes, they need special attention for rearing and utilization under fairly elevated temperature regimes (e.g. during summer). Our study showed that it is possible to cost-effectively maintain pill millipedes under laboratory conditions in the coastal region for compost production throughout the year. We propose a solid waste compost model to employ pill millipedes and pill millipedes + earthworms for eco-friendly manure production as one of the measures of urban organic solid waste processing (Figure 4). The rate of organic waste turnover and product generation consists of various sub-processes that are influenced by geographic and environmental variables. The proposed model requires mathematical validation and calibration to identify and quantify the organic waste transformation and organic waste management in urban localities. The sensitivity of the model to variations in the input of organic matter (either individual or in combination) needs validation for further progress to develop small-scale or large-scale or community-scale compost plants.

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