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Value added product recovery from sludge generated during gum arabic refining process by vermicomposting

Veena Das · Sanjeev Satyanarayan · Shanta Satyanarayan

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Abstract Gum arabic is multifunctional and used in food products, pharmaceutical, confectionery, cosmetic, printing and textile industry. Gum arabic has an excellent market and its production is being increased to meet the market demand. In the process, huge quantity of solid waste is generated during its refining process. An attempt has been made to vermicompost this organic waste using *Eudrilus eugeniae*. This research work is first of its kind. Literature on this substrate has not been reported anywhere else for vermicomposting. Results were excellent with volatile solid reduction of 51.34 %; C/N ratio reduced to 16.31 % indicating efficient loss of carbon as carbon dioxide during vermicomposting period. Manurial value, i.e. nitrogen, phosphorus and potassium content in the range, required for the plants also increased. Porosity of 67.74 % and water holding capacity of 65.75 % were observed. The maturity of the vermicompost was evaluated through scanning electron microscopy wherein the complete conversion of large raw material particles into finer particles forming a uniform matrix with more surface area was observed indicating its efficient conversion. Microbial quality of vermicompost was also studied. The final vermicompost is free of fungal cells and pathogenic bacteria.

Keywords *Eudrilus eugeniae* · Gum arabic sludge · Percent volatile solids reduction · Refining · Vermicompost

V. Das
CSIR-NEERI, Nagpur, Maharashtra 440020, India

S. Satyanarayan
IRG Systems South Asia P. Ltd., New Delhi, India

S. Satyanarayan (✉)
CSIR-NEERI, 71, Friends Layout No. 4, Deendayal Nagar, Nagpur, Maharashtra 440022, India
e-mail: dr_shantasa@rediffmail.com

Introduction

Increasing industrialization, population growth and affluence are exerting enormous pressure on environment due to solid waste generation. Disposal of solid waste has become a major problem in both urban and rural areas due to a shortage of dumping sites followed by strict environmental rules and regulations. As a result, more emphasis is now being given to eco-friendly and sustainable management techniques. Scientific investigations have established the use of earthworms for the conversion of biomasses into manure, as a low-cost technology system.

Vermicomposting is a well-known composting technique for stabilizing different degradable organic wastes (Hanc and Vasak 2015; Lim et al. 2016; Wu et al. 2014). During vermicomposting, earthworms maintain an aerobic condition in the organic wastes, ingest solids and convert them into vermicast. Vermicomposting has an advantage of reducing the total volume and particle size of the biomass waste and side by side increases its relative manurial value. Furthermore, the availability of macronutrients and micronutrients is generally higher in vermicompost than in the traditional compost and inorganic fertilizer, indicating that vermicompost is a better supplement to improve and stimulate plant growth (Lim et al. 2015b).

Many waste biomasses have been successfully converted by vermicomposting. In early years, water hyacinth, a weed, was used for vermicomposting. This weed is one of the most productive and hardy of all the weeds, and no attempt to control this weed or destroy it by chemical, biological, mechanical or hybrid means has ever achieved total success (Reddy and Smith 1987; Ramaswamy 1997 and Abbasi et al. 1997).

Combined vermicomposting of crop residues and cattle dung with *Eisenia foetida* has been reported (Bansal and Kapoor 2000). A nitrogen deficient pulp and paper industry sludge were vermicomposted by mixing it with nitrogen rich wastes like pig manure, poultry droppings and sewage sludge (Elvira et al. 1996). It is further reported that, individually, the sludge from pulp and paper industry does not support earthworm growth and activity, but nitrogen rich waste amendment with the waste results in better bioconversion.

Vermicomposting process also depends on the earthworm species utilized. Weed parthenium is very dangerous and creates severe allergy in humans and cannot be treated easily. This weed grows rampantly everywhere and creates health problems. Its disposal poses great problems. Report on its use in biogas plant has been reported (Banerjee 1987). But recently, this weed has been vermicomposted using earthworms *Eudrilus eugeniae*. This is one of the best solutions to get rid of this notorious weed which crept into India from USA. The problem with this weed is that it contains a toxin called parthenin along with phenols. This toxin can be eradicated by vermicomposting technique when mixed with optimum quantity of cow dung. Report further says that around 30–35 % organic carbon and 32–48 % phenol contents are reduced (Rajiv et al. 2013). Vermicompost plays a major role in improving the growth and yield of different agricultural products. Vermicomposting is an appropriate alternative for the safe, hygienic and cost-effective disposal of many degradable waste materials. Cellulose rich banana tree peels have been effectively vermicomposted. In addition, *E. eugeniae* was used successfully in vermicomposting of various agricultural wastes, such as soy bean husk (Lim et al. 2011), rice husk (Lim et al. 2012a, b), rice residues (Shak et al. 2014), palm oil mill effluent (Lim et al. 2015a,b; Lim and Wu 2015), empty fruit bunches (Lim et al. 2015a) and other wastes.

Many animal wastes like pig, cow dung, poultry and even human wastes are reported to have been converted successfully into nutrient rich manure by vermicomposting (Chan and Griffiths 1988; Manuel et al. 2002; Giraddi and Meenatchi 2008 and Yadav Kunwar et al. 2010). Thus, diseases creating pathogens are also eradicated.

Some special wastes like arca nut and coconut leaves, which are very hard and rich in lignin, have been tried for vermicomposting. It is reported that pre-decomposed arca nut and coconut leaves in combination with cattle dung could be efficiently vermicomposted (Chaudappa et al. 1999 and CPCRI Report 2009). It is also found that vermicomposting could be used as an efficient technology to convert empty fruit bunches into nutrient rich organic fertilizers, if the wastes were mixed with cattle dung in an appropriate ratio (Lim et al. 2015a). Guar gum industry waste also had the potential utilization in vermicomposting (Suthar 2006). Rubber tree leaves, which are very thick and contain sticky latex, have also been used for vermicomposting (Chaudhari et al. 2001). Some plants which grow only in some specialized areas like cocoa plants, its leaves, have also been utilized for vermicomposting. Based on the literature it was observed that 'gum arabic' refining waste sludge has not been used for vermicomposting till date. Hence, an attempt has been made to study the feasibility of this forest residue—gum arabic refining sludge for vermicomposting.

Gum arabic is a kind of resinous material, exudes from the stem and branches of the tree. Spray drying is the process by which raw gum is dissolved in water, centrifuged to remove the impurities, pasteurized and sprayed in hot air to evaporate water. Spray drying produces free-flowing powder with high solubility. Spray drying process is similar to milk powder production. During refining of gum arabic, a dark brown to black coloured thick waste sludge is produced. Gum arabic is multifunctional and is used in food, pharmaceutical, confectionery, cosmetic, printing and textile industry.

The only plant available in Asia, which produces spray-dried gum arabic, is situated in a place called Pandurna around 90 km from Nagpur city, Maharashtra, India. Raw gum arabic is imported from Sudan. Huge amount of solid waste is generated during the gum refining. This sludge poses a disposal problem. On analysis of this solid waste, it was found that it contains around 89.46 % volatile solids of total solids indicating good degradable nature of the waste. So it was identified to subject this waste to vermicomposting using an endemic variety of earthworm *E. eugeniae*.

Materials and methods

Sludge from gum arabic refining was collected from a unit manufacturing spray-dried products. This sludge depicts dark brown to black colour with total solid content of 60 % and percent volatile solids of total solids of 89.46 %. This sludge was subjected to routine physicochemical parameters and also heavy metal analysis as per the standard methods (Clesceri et al. 2012). Characteristics of raw gum arabic sludge and of the mixture of raw gum, soil and cattle dung are shown in Tables 1 and 2, respectively. Cattle dung needed was procured from a local cow shed, and it was allowed to dry in a shade for a week before it is used in vermicomposting. The analysis of cattle dung is shown in Table 3. The reason for drying cattle dung is to prevent any harm to earthworms due to the heat generation in the fresh cattle dung. Moreover, the fresh cattle dung invites termites, worms and insects.

Endemic species of *E. eugeniae* was obtained from a vermiculture centre of a NGO—Centre of Science for Villages at Wardha, Maharashtra, India.

Vermicomposting was carried out in earthenware pots. During the experimental work, gum arabic refining sludge, soil and dried cattle dung were mixed in 1:1:1 ratio and left for pre-decomposing for a period of 10 days. Figure 1 shows the mixture of gum arabic sludge, soil and cattle dung. After pre-decomposing the mixture of soil, gum arabic refining sludge and dry cattle dung, it was transferred to earthenware vermibeds. A total of 15 healthy earthworm species of *E. eugeniae* were introduced into the experimental pots having an average weight of 3–5 g. The surface of the pots was covered uniformly with mulch, and daily, water was sprinkled over them to keep the environment suitable for the earthworms to carry out their activity. After a time interval of 30 days, it was completely vermicomposted into uniform granular black coloured manure (Fig. 2). This vermicompost was subjected to routine physico-chemical and metal analysis as per the standard procedure (Table 4). Physical parameters like bulk density, porosity and water holding capacity were also analysed (Arey 2010). Results of the same are indicated in Table 5.

Table 1 Characteristics of raw gum arabic sludge

Parameters	Raw gum arabic sludge
pH	9.9
Conductivity (μs/cm^2)	225
Alkalinity as $CaCO_3$	80
Chloride as Cl (mg/l)	197.04
Sodium as Na (mg/l)	7.3
Potassium as K (mg/l)	9.1
Sulphate as SO_4 (mg/l)	34.38
% Nitrogen as N	0.85
% Phosphate as PO_4	0.19
% Total solids	60.18
% Total volatile solids	53.84
% Ash content	10.53
% Volatile solids of total solids	89.46
% Moisture	39.82
C/N ratio	36.73
Heavy metals (in mg/kg)	
Cadmium	0.015
Cobalt	0.55
Chromium	1.2
Copper	1.275
Iron	1125
Manganese	40
Nickel	0.05
Lead	7.5
Zinc	8.625

Scanning electron microscopy (SEM) studies of vermicompost were carried out to see the maturity and granulation pattern of the vermicompost. SEM [model, JEOL, JSM 6380A, USA] was used. About 2–3 mg sample of particle size 300 mm was spread uniformly over the stub with the help of a double-sided adhesive tape, and subsequently, the samples were ultrasound de-agglomerated in etalon for 10 min gold splattered and then subjected to SEM analysis.

An aqueous suspension using a vermicompost was prepared as per the method quoted in the literature (Pandey and Kalra 2010) to evaluate the microbial quality of the vermicompost. This aqueous suspension was filtered and was subjected to microbial test. Results are indicated in Table 6.

Table 2 Characteristics of raw substrate mixture

Parameters	Raw substrate mixture
pH	8.2
Conductivity (μs/cm^2)	720
Alkalinity as $CaCO_3$	2732
Chloride as Cl (mg/l)	152
Sodium as Na (mg/l)	3.4
Potassium as K (mg/l)	1.10
Sulphate as SO_4 (mg/l)	20.12
% Nitrogen as N	0.72
% Phosphate as PO_4	0.52
% Total solids	83.40
% Total volatile solids	48.18
% Ash content	42.23
% Volatile solids of total solids	57.76
% Moisture	16.60
C/N ratio	38.1
Heavy metals (in mg/kg)	
Cadmium	0.97
Cobalt	12.66
Chromium	9.01
Copper	62.74
Iron	1411
Manganese	321.26
Nickel	0.041
Lead	1.73
Zinc	62.32

Table 3 Characteristics of shade-dried cattle dung

Parameters	Shade Dried Cattle Dung
pH	7.5
Conductivity (μs/cm^2)	2200
Alkalinity as $CaCO_3$	4382
Chloride as Cl (mg/l)	236
Sodium as Na (mg/l)	5.2
Potassium as K (mg/l)	0.29
Sulphate as SO_4 (mg/l)	16.20
% Nitrogen as N	0.92
% Phosphate as PO_4	0.63
% Total solids	93.0
% Total volatile solids	67.85
% Ash content	27.04
% Volatile solids of total solids	72.96
% Moisture	7.0
C/N ratio	42.77
Heavy metals (in mg/Kg)	
Cadmium	1.28
Cobalt	0.032
Chromium	18.00
Copper	35.35
Iron	1284.00
Manganese	116.00
Nickel	0.005
Lead	2.2
Zinc	141.6

Results and discussion

Gum arabic refining sludge is an unconventional solid waste, which is generated during the refining of gum arabic. Gum arabic is used for its properties as an emulsifier, thickener, binder, stabilizer and adhesive. It is reported that soft drinks and confectionery represent 70 % of the demand for gum arabic. Its demand is increasing day by day, resulting in solid waste generation. Managing solid waste has become a major problem in the industries in India. If these wastes are disposed off as such on land, it will require large area of land and may result in severe environmental problems leading to ground and surface water pollution, pathogens and odour nuisance, etc. Unscientific disposal of large quantity of gum arabic refining sludge may cause energy, economical and environmental nuisances. As this waste is rich in organic matter to the tune of 53.84 % and also

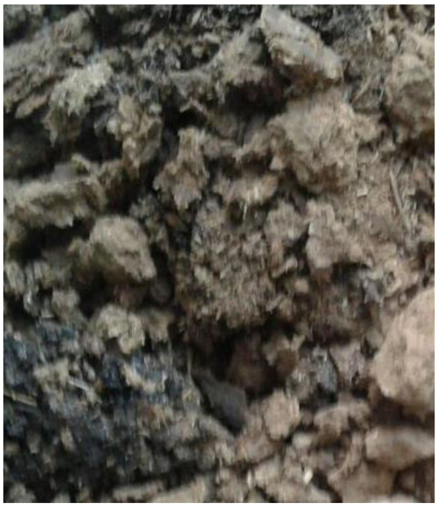

Fig. 1 Mixture of gum arabic sludge, soil and cattle dung

Fig. 2 Uniform granular-size vermicompost prepared from sludge produced during gum arabic refining, cattle dung and soil mixture

mineral elements, it can potentially be utilized in restoring soil fertility. Recycling of gum arabic sludge by vermicomposting can mitigate environmental hazards resulting from simple disposal on land, and also, value added by-product rich in plant nutrients can be harvested. This solid waste needs an eco-friendly disposal method. On analysis of this solid waste as indicated in Table 1, the presence of very efficient quantity of volatile solids of total solids, i.e. around 89.46 %, indicates that this sludge is highly biodegradable in nature and suitable for both biogas production and vermicomposting.

Table 4 Characteristics of vermicompost

Parameters	Values
pH	7.5
Conductivity (μs/cm^2)	1083
Alkalinity as $CaCO_3$	900
Chloride as Cl (mg/l)	198.52
Sodium as Na (mg/l)	1.7
Potassium as K (mg/l)	14.3
Sulphate as SO_4 (mg/l)	7.26
% Nitrogen as N	1.2
% Phosphate as PO_4	0.73
% Total solids	84.5
% Total volatile solids	33.76
% Ash content	64.72
% Volatile solids of total solids	39.95
% Moisture	15.5
C/N ratio	16.31
Heavy metals (in mg/kg)	
Cadmium	7.5
Cobalt	16.375
Chromium	10.425
Copper	85.55
Iron	6271.8
Manganese	472.5
Nickel	0.065
Lead	2.2475
Zinc	72.075

Table 5 Physical parameters of vermicompost and soil

Parameters	Name of sample	
	Soil	Compost[a]
Bulk density (in g/cm^3)	1.6966	1.0057
Porosity (in %)	46.8815	67.7401
Water holding capacity (in %)	38.7447	65.7545

[a] Vermicompost prepared using sludge generated during gum arabic refining process

Electrical conductivity of raw sludge is around 225 μs/cm^2, which increased to 1083 μs/cm^2. Literature also indicates increase in electrical conductivity during vermicomposting. Increase in electrical conductivity is due to the soluble salt levels resulting from mineralization action of earthworms and micro-organisms present in the gut of earthworms and also because of those micro-organisms, which are already present in the organic substrate. Gradual decrease in the organic carbon content in the raw feed material also seems to be responsible for the electrical conductivity increase.

Increase in total Kjeldhal nitrogen was also observed. Percent total nitrogen in the feed mixture was around 0.72 % which increased to 1.2 % in the final vermicompost. Likewise, total phosphate also increased from the original of 0.52 to 0.73 % in the final product. Increase in phosphorus content in vermicompost clearly indicated earthworm-mediated phosphorus mineralization, and further, it was observed that an increase in rise of phosphate content of vermicompost may be due to

Table 6 Microbial quality of the vermicompost

Microbes	c.f.u/ml
Total count of bacteria	0.01×10^7
Total count of fungi	Nil
Total actinomycetes	0.01×10^6

*No Pathogenic bacteria found

**Beneficial thermophilic bacteria were found the presence of alkaline phosphates in the worm cast (Suthar 2009; Bayon and Binet 2006).

Earthworm enriches the nitrogen content of the final vermicompost by the decaying action of dead tissues of earthworms, if any, and microbial mediated nitrogen transformation in vermicomposting process results in further increase of nitrogen (Suthar 2007).

It has been reported that for efficient vermicomposting, the optimum C/N ratio is 26–40 (Joshi 2004). Gum arabic sludge depicts a C/N ratio of 36.73 which further confirms its suitability for vermicomposting. Considering this point, it was envisaged to study the feasibility of subjecting this gum arabic refinery sludge to vermicomposting. Already, this sludge has been successfully used for biogas production. Initial pH of this sludge was around 9.96 indicating alkaline nature which reduced to 7.5 in the final vermicompost; this is also an indicator of efficient activity. There was no repellant odour instead good earthy smell was observed in the final product. Total solid content in the raw sludge was around 60.18 % and a moisture content of 39.82 %, projecting it as the most suitable substrate for vermicomposting.

On the final vermicomposting, the original C/N ratio of 38.81 reduced to 16.31 in a time period of 30 days, apart from 10 days of pre-decomposing.

This C/N ratio of 38.81 is well within the optimal range required for good vermicomposting. The process of conversion of organic material into manure is chiefly microbiological activity and influenced by the amount of carbonaceous and nitrogenous substrates that are present in the organic biomass. In this process, initially micro-organisms need carbon for their multiplication and nitrogen for protein synthesis. When the organic substrates are deficient in nitrogen, i.e. C/N ratio is on a higher side as in case of agricultural residues, microbial activity reduces considerably as nitrogen content is very less. When C/N ratio is optimal, then the microbial activity is faster and inassimilable nitrogen is lost in the form of ammonia gas.

The final compost showed a C/N ratio of 16.31 which categorizes it as grade 'A' quality compost (Phirke et al. 2004).

Very efficient volatile solid reduction has been achieved which is around 51.34 %. Percent volatile solid reduction was calculated as per the literature (Anaerobic Sludge Digestion 1991). This volatile solid reduction is more than two times of what is achieved during the biogas production of cattle dung by the anaerobic fermentation technique. It is hence preferable to subject digested biogas slurry to vermicomposting to stabilize it further. This high reduction indicates that vermicomposting is more efficient in consuming/converting all the biodegradables present in gum arabic refining sludge. Important heavy metals, viz., copper, iron, manganese and zinc, showed an increased trend.

It can be inferred from the physical parameters (Table 5) that bulk density is very optimum of 1.0057 g/cm^3, which is very suitable for root growth of plants (Mckenizie et al. 2004). The final vermicompost depicted uniform granular structure with good dark brown colour. On spreading the vermicompost on a plate, it did not show compaction but depicted good loose fluffy quality. Water holding capacity was around 65.75 % with porosity of 67.74 %. Moreover, the worms showed very healthy growth as indicated in Fig. 3. The healthy growths of worms indicate that this biomass (gum arabic refining sludge) is a very suitable substrate, and earthworms have grazed very heartily on this waste. The colour of the earthworm was very bright and dark pink indicating their good healthy condition. No death of earthworm was noticed during the vermicomposting period.

As per the standard, in a finished vermicompost, the organic matter should be greater than 20–25 % (but probably less than 50 %). In the present studies, the organic matter content in the final vermicompost was around 33.76 %, indicating efficient vermicomposting.

Moisture content in the raw waste was approximately around 16.6 % and was marginally less than the required range for vermicomposting as quoted in the literature. Vermicomposting of different organic matters have been reported in the literature. But less attention has been paid on waste solid management of gum arabic refining sludge with vermicomposting process.

Fig. 3 Healthy earthworm

Scanning electron microscopy

SEM was applied to the vermicompost prepared out of gum arabic refining waste sludge to observe the morphological changes occurring during vermicomposting process and evaluate the maturity of the compost (Senthil Kumar et al. 2014). Along with the vermicompost, raw gum arabic waste sludge was also subjected to the SEM analysis for a simple comparison with the final product.

Figure 4 shows the SEM of raw substrate while Fig. 5 shows the final vermicompost quality. In Fig. 4, raw substrate clearly shows haphazardly arranged aggregates spread over the fine fibres of the bark of the tree. Fine dust particles are also seen interlocked with the fine fibres. In some places, the soil/dust particles are condensed in one place while the fibres are lying separately. It is more defined in Fig. 5. The final vermicompost shows the fibres more uniformly digested by the earthworms. Earthworms with the help of micro-organisms present in the gut gradually degrade the raw material. Post vermicomposted mixture confirms the increase in surface area of the compost. Hence, final vermicompost depicts uniform matrix with fluffy nature indicating that the raw substrate has been efficiently vermicomposted and resulted in manure having good porosity and water holding capacity.

Results of microbial analysis indicated presence of few beneficial thermophilic bacteria. No fungal cells and no pathogenic bacteria were observed indicating good stabilization of the final vermicompost (Table 6).

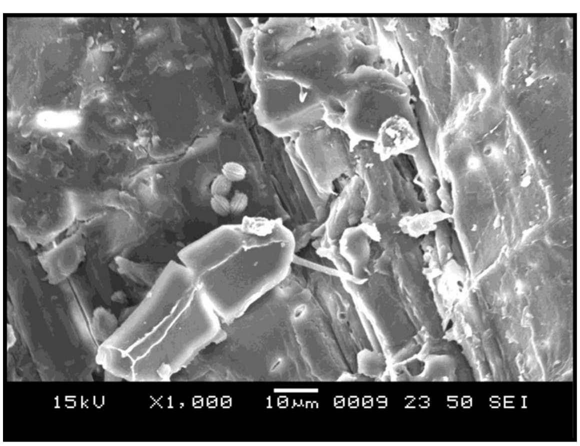

Fig. 4 Scanning electron micrograph of the raw sludge generated during gum arabic refining process

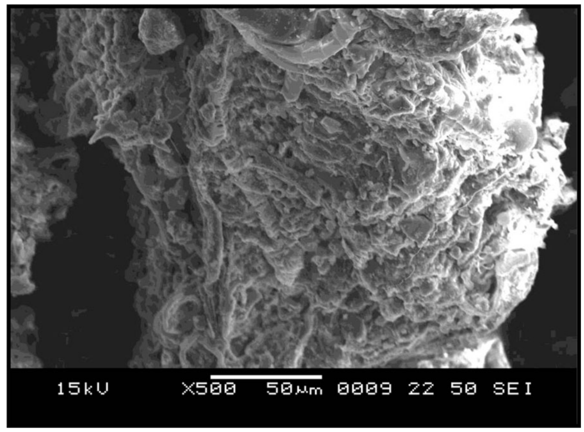

Fig. 5 Scanning electron micrograph of the final vermicompost

Conclusion

One of the most eco-friendly cost-effective and sustainable technology is vermicomposting. The main advantage of vermicomposting technique is that the final product is pathogen free and rich in plant nutrients. The use of vermicompost in agriculture will help in recycling the plant nutrients and prevent degradation of soil quality. Burden on inorganic chemical fertilizers will reduce considerably.

The final vermicompost was pathogen free and also fungal cells free indicating efficient stabilization.

From the detailed studies carried out, it can be inferred that gum arabic refining sludge is the most suitable substrate for vermicomposting using the earthworm species of *E. eugeniae*. Earthworms exhibited very healthy nature and dark pink colour.

Vermicompost is a well-stabilized and mineralized product having greater contents of important nutrients in the form that is readily absorbed by the plants. The maturity of the vermicompost is confirmed by the high total nitrogen, total phosphorous and potassium values of 1.2, 0.73 and 14.3 %, respectively. Hence, vermicomposting of degradable organic substrate should be advocated. Vermicompost improves the soil structure and fertility and also improves the moisture holding capacity and porosity. Vermicompost application enhances proper aeration in the soil.

The quality of the vermicompost with respect to bulk density, porosity and water holding capacity is very efficient.

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