Integrated waste management through symbiotic culture: A holistic approach

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Abstract. Unsegregated heterogeneous mass of solid waste is a potential threat towards the safe processing and disposal of municipal solid waste (MSW), which is cumbersome and ancillary, elevates the expenditure. The absence of any pertinent technique, to handle these bulky mass in an eco-friendly way, makes it even more hectic for the MSW processing plants. But, this substantial mass constitutes a huge potential, which can be valorized through the larval digestion of a symbiotic macro culture, to create new economic niches for small-scale entrepreneurship in developing and under-developed nations. The present study incorporates a symbiotic waste reduction system with the efficient functionalism of micro and macro conversion agents which is attributed to the synthesis of waste derived co-products from the same platform. This study is solely a novel approach, which is capable of addressing a wide fraction of solid waste, domestic sewage, and bio-leachate and converts them into value-added co-products within the magnificent period of time. Multiple experiments have been conducted under the controlled feeding environment with an established symbiosis between the BSF larvae, Wax Moth larvae (Galleria melonella), and effective microorganism culture. An initiation period of 5 days was allocated for the macro conversion agents and during the tenure, the larvae were supplied with synthetic diet to accelerate the body growth index. The entire experiments have been conducted in a newly formulated novel bioreactor namely, Integral Larval Grub Composting Reactor which is capable of performing automated pupal segregation and address solid and liquid waste under a single platform. The system enforces the zero liquid discharge concepts and also helps in an indirect suppression of house fly growth. The novel approach only required 14–16 days in order to convert the solid waste into nutrient-rich manure, having significantly high-quality component. The operation has been executed in a number of batch processes and each process valorized a quantity of approx 30 kg. The targeted larval period has been prolonged by means of maintaining higher moisture content with the help of sewage supply and once the maturation period arrives the further addition of moisture has been restricted for 3 days. Overall it’s an ultimate and wholesome biological waste management technique, which is capable of standing solely to strengthen the sustainable waste management strategy.

1. Introduction

It has been evidenced from developing and underdeveloped nations, in a disparity of inert and inorganic waste which would-become worth value for streetwalas and recyclers; the amount of the organic portion is the prime source. But it has infrequently appeared to be sent to the treatment facilities or considered as a noteworthy resource of income generation contrasting to the other fraction of MSW [1,2] nevertheless in a few instances it could get accumulated, but its concluding destiny is forever in problem and moreover it ends up in receiving landfills or on uncontrolled open dumping in outskirts of the town, is a place, materials were decomposed in the appearance of huge
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larvae flourish better in a tropical environment. In India, to achieve sustainable waste management

the utilization of BSFL for composting ought to be suggested [5].

The initiatives of using Black soldier fly larvae composting rouse in the Indian subcontinent as an

alternative requirement for formulating sustainable waste management strategy. Instead of

diminishing the waste and treating the waste, the practice of using BSFL is proficient of tackling

multidimensional problems like increasing demand for applying renewable fuel, escalating protein in

ranch and marine aquatic diet and relenting compost with huge nutrient content etc. Higher

utilization rates, Rapid rate of decomposition and bioconversion [6,7]. Using different substrate

sources on nutrition condition, tests were executed by [8] and stated that the larvae were able to

degrad an extensive variety of wastes like poultry and pig litter, garbage and sullage from kitchen,

vegetables, and fruits etc. Ultimately, poultry provided the most favourable conditions which yielded

healthier black soldier fly larvae with minimal death rates. Numerous scientists documented the

correlation between conversion efficacy and the growth of larva. On the other hand, in order to sub-

optimize the value of these two main factors of BSFL composting, tests were carried out by

providing food to larvae with four different concentrations of dairy manure to forecast its control

over the life cycle behaviour of larva, as well as adult flies, to begin a relationship between a supply

rate and BSFL growth [9]. From the results, it was observed that the feeding rate has a foremost

impact on larval development and the growth of adult flies. The nutritional profile gets illustrated

with a proportional relationship in which larvae with greater substrate availability weighed more than

those fed considerably lesser ration. Under optimal environmental condition an average pre-pupa rate

of 250g/m²/day was attained and more or less 65 to 78% bioconversion yield was achieved

depending on the amount of waste included on a regular basis and also the drainage facility available

as stated by Stefan et al (2011) [10]. Stefan et al 2009 [11] have studied about the most favourable

equilibrium between treatment efficiency and biomass population and it can be sustained by

providing appropriate dietary food and feeding rate on a daily basis impaled by a wetness of 60%

subjected to other peripheral and ecological conditions [12]. The rate of biomass production for

various kinds of substrates was investigated and it has been observed that an entity waste

stabilization constituent can create pre-pupal biomass of 145g per m² on a regular basis.

Conflictingly, Myers et al (2008) [13] have come across appreciably lesser conversion rates. The

values were less than the anticipated one because of the explicit absence of any symbiosis between

other organisms [14]. Establishment of probable symbiotism with some locally offered species might

have considerably influenced the conversion rates [15-17]. The correlation between the growth

kinetics and the feeding rate was recognized by the biokinetic study and it was noted that dry matter

weight varied inversely proportional to the loading rate of waste material. In a laboratory-scale study,

it was observed, when the larvae fed 27g of waste on regular basis being reduced by the dry fraction

approximately by 58% whereas the other experiments yield significantly lesser transfer rates (33%) when

larval feeding rate was boosted by 70 g of waste material/day. In case of life cycle studies, the

raise in larval feeding rate also found contradictory and it accelerates the death rate from 17% to 29%
among juvenile larvae. Albeit complexity the method is as well capable to degrade and convert

extremely intricate secondary wastes, for instance, bio-leachate, selective heavy metals etc.

Choudhury et al (2017) [18] stated that this treatment becomes to appear as a good choice due to the

ability of comprehensive supervision. The financial viability of the above practice was studied by

Hang et al (2013) [19] and stated that yield of raw swine manure will be up to 95 to 125 kg of larvae
population per m³ of waste supplied to the system. The observations revealed, live and fresh biomass is able to serve as an optional animal feed, with significantly high protein and fat content. In addition, it is capable of recovering the nutrients from the wastes generated and able to utilize further as agro-based crop manure and the stabilization of major pollutants took place due to bioconversion techniques. Apart from the above advantages, it also minimizes the emission of intolerable gases and odour formation by approx. 90% or more. The other exciting benefit of adapting the aforementioned technology includes huge economic profitability ranging approx. USD 33 to 46/m³/annum. In this context, the analytical figures concluded by Tschirner and Simon (2015) [20] can be considered as a baseline. Multiple factors such as the impact of different fodders, compositional characteristics etc. were investigated against the observation tenure of 15 days and reported a protein and fibre content of approx. 0.90 and 0.40 kg of wet mass, respectively.

On the other hand, wax moth larvae found to be feasible for biodegradation polyethylene, which comprises approximately 40% of the entire plastic mass and the consumption rate reported to be comparatively higher. A group of researchers from Spain and England stated that the 100 counts of larvae can efficiently degrade 92 milligrams of polyethylene within a period of 12h. It has been reported in the same study that the presence of ethylene glycol was observed during the enzymatic conversion process, which signifies the biological breakdown of the polyethylene [21]. Contradictorily, Weber et al. (2017) [22] stated that the results showcased by the previous author is uncertain and not substantiate with enough scientific evidence. Precisely this research group has questioned the interpretation of the signals obtained by infrared spectroscopy which assures the presence of ethylene glycol.

Ultimately, the whole research community pose a similar opinion to authenticate Black soldier fly larvae as the dependable revenue conversion and stabilization agent of the recent period with minimum nuisance. The scope of this experimental study was principally to explore the dominance of different external conditions on the target larval instar stage and as well as to accentuate the supremacy of symbiotic composting over the conformist, time intense and prehistoric methods. Moreover to deal with the existing lagging and negative aspects in this field and to investigate the community with the interpretation of the eventual treatment system, proficient of accounting the multidimensional features, for instance, solid waste, sewage, and leachate treatment and disposal under a single platform.

2. Methodology

2.1. Preparation of medium

Preparation of medium is a delicate issue and seeks utmost attention to germinate the mother culture. The medium should be such that, it ensures optimum body growth attributed to minimal mortality rate. Two different types of media were prepared that are delineated in details in followings.

2.1.1. Medium preparation for BSFL

In order to germinate mother culture, different mediums as shown in figure 1 were prepared and used. The body growth factor and the eating capacity for BSFL have been increased by initial feed acclimation in the form of partially degraded mixed oilcake supply enriched with Bio Nitrogen, Phosphorus, and Potassium. Four different types of cakes were used which has been prepared using different sources such as, mastered oilcake, groundnut cake, copra cake etc. They were soaked in water (i.e. 50:50 mixes) for the period of 24h under anaerobic condition and allowed the initial degradation. Then four different mediums were prepared by mixing the partially graded slurry in different ratios. The first medium incorporated all three different varieties in one third mix ratio, whereas other two consisted of mastered oilcake and groundnut cake in 1:1 mix ratio and copra cake and groundnut cake in 1:1 mix ratio. The last medium comprised solely mastered oilcake inoculated with cow dung. All the mediums were placed in an MSW processing and disposal facility namely, HiMSW, Hyderabad.

The other variety of medium was prepared using poultry litter, spiked with chicken intestines. The medium was kept in a fenced farmland nearby a stagnant algal pond under a controlled environment.
Figure 1. Medium preparation for BSFL mother culture.

2.1.2. Medium preparation for wax moth larvae
Waxmoth, basically a pest of honeybees, which feeds on the honeycomb, the raw honeycomb is expensive and thus is not a feasible option for regular usage in order to cultivate the larvae of *Galleria mellonella*. Therefore a synthetic diet was prepared with the help of the following ingredients namely, Atta (1kg), Wheat bran (1kg), Corn flour (776g), Honeycomb (200gm), Yeast (80g), Honey (1.5l), Glycerol (1.2l), Milk powder (200g). Once the entire moisture gets evaporated from the synthetic substrate then larvae were separated from the system manually and introduced to a freshly prepared medium as shown in figure 2.

Figure 2. Medium preparation for Wax moth larvae mother culture.

2.1.3. Fabrication of the bio-reactor
The ultimate objective of sustainability can be obtained only through a compact and pocket-friendly solution (Buiani 2015). Therefore, a unit with competent of successfully treating complex wastes such as solid mass and wastewater under a single umbrella named, Integral Larval Grub Composting Reactor (ILGCR) was fabricated and the schematic has been portrayed in figure 3.
Figure 3. Schematics of the Pilot Scale ILGCR.

The reactor consists of two major working elements namely, waste conversion/maturation element and liquid circulation and recirculation unit. Rest of the subordinate units is there to support the fundamental working procedure. Figure 4 shows the overview of the bioreactor. It comprises two upper-head tanks with the flow regulators, a sprayer, a grub composting area, pupal segregation and removal bucket, leachate drain with stopper, and a leachate collection tank with a recirculation system. Two peristaltic pumps are required in order to run the operation in continuous mode.

Figure 4. Indexed ILGCR schematic.

2.1.4. Working mechanism of ILGCR
Initially, the waste got introduced into the active composting zone, where larvae were working upon it and decompose the waste. Near to the top opening four hinges has been provided to captivate the entry of larvae in unwanted zones and regulates the larval movement only towards the pupal
segregation bucket. A leachate drain has been provided with a regulation system to drain the percolated bio-leachate from the system. A slope of 20° has been provided with the horizontal towards the drain opening. Pupal segregation bucket segregates the pre-pupae from the juvenile larvae and it comprises an exit hole to take out the same. A fall down slot of 1.5-inch length has to be given on both of the corners of the reactor. The upper-head tank placed in the top left corner of the reactor is meant for bio-leachate supply, which has a flow regulator in order to control the inflow volume. The other upper-head tank placed on the top right-hand side of the reactor is meant for sewage supply. The similar kind of flow regulating provision has been given to it. The moisture supplied from the upper-head tanks finally reach the sprayer and get uniformly distributed over the solid sample. A bio-leachate collection tank with influent flow regulator is placed near the bottom of the reactor. The inflow regulator only opened once in three days, once the leachate gets thickened. At the junction of the reactor and the leachate drain pipe, a fine mesh needs to be used to arrest the entry of larvae into the drain pipe. Two nos. of the peristaltic pump has been attributed to the system to convey the bio-leachate and sewage from the bottom tanks to the upper-head tanks. Altogether, the commercialization of the bioreactor may create a revolution in integrated waste management facilities and open new economic niche for small-scale entrepreneurship.

2.1.5 Segregation of the solid waste
The heterogeneous and unsegregated solid waste was initially screened with the help of trammel, which has a 70mm permeate size. The permeate was collected and manually segregated for further treatment. The lumpy and inert materials such as cardboard, glass, metals were segregated out from the system. The rest of the mass which incorporates organic fraction and the plastic waste was sent to the ILGCR.

2.1.6 Introduction of the bio-leachate and sewage
The process leachate and the brown water was collected from the HiMSW, Hyderabad and sorted in the upper head tanks. Primarily the system was boosted only with the help of sewage (i.e. 3days) and once the culture got acclimatized with the initial concentration then the process leachate was supplied for the rest of the period (i.e. 10 days). Once the maturation period reached the addition of moisture was completely restricted.

2.1.7 Drainage and recirculation
The drainage facility was attributed with a gravity flow. A chicken mesh with 1mm pore size was used to arrest the larval movement into the drainage pipe. The drain pipe consists of a control valve, which was opened once in three days to provide ample period for quantity reduction and quality concentration.

3. Results and discussion

3.1. Solid waste conversion
The major perspective of the present study was to identify the feasibility of a symbiotic culture in heterogeneous waste degradation and the minimization of the conversion period.

3.2 Biodegradable waste conversion
The biodegradable fraction of the waste mass was converted and stabilized with the help of BSF larvae and an effective microorganism culture (i.e. consists of six different organisms namely, *Pseudomonas fluorescence*, *Pseudomonas striaata*, *Bacillus substillis*, *Bacillus pumillis*, *Lactobacillus*, Bakers yeast). The study reveals that these voracious eaters initially consumes the readily biodegradable fraction of the waste and simultaneously goes for the other materials based on the stiffness and hardness index of the material. The conversion rates observed to be 280 mg/larvae/day which are slightly higher than the values reported by Diener et al. (2009) [23] (figure 5). The phenomenon of higher feeding rate was interpreted as the fusion of bio-leachate and enzyme accelerates decomposition process and converts the waste mass into easily digestible monomers which helps the conversion agents to consume the substrate at an elevated rate. In this context temperature found to play a significant role, which hugely influences the conversion rates as reported
by Stefan et al. (2011) [10]. The study indicated a sharp declination in the treatment efficiencies once the temperature dropped near to 21°C [24].

![Figure 5. Influence of temperature on the treatment efficiency.](image)

### 3.3 Plastic waste conversion
Greater wax moth caterpillar requires an initiation period of 5 days after emerging out of the hatched eggs. The polyethylene consumption rates were found to be successively increased until 30th days of the larval instar stage which rages approx 0.027g/larva/day [21] (figure 6). But, in absence of the primary food resources, the consumption rates found to get depleted simultaneously to a value of 0.009g/larva/day for 50 days old larvae (figure 7). Thereafter, a constant absence of raw substrate results in exoskeleton formation and pupal conversion.

![Figure 6. Consumption of polyethylene by wax moth larvae.](image)

![Figure 7. Variation in consumption rate with different stages of the larval period.](image)
3.4 Liquid waste consumption
Liquid waste was supplied in the form of sewage and process leachate to maintain the optimum moisture for enhanced biodegradation. The supply of liquid waste, reached the active decomposition zone was in three forms namely, solely sewage, pure leachate, and a 50:50 proportionate mixture [25-27]. The quantity of liquid waste introduced to the system found to be consumed at a rate of 69.75% at utmost between an interval of 3 days (figure 8).

![Figure 8. Leachate inflow and outflow rates.](image)

3.5 Optimization of moisture content
Maintaining a specific level of moisture in the system found to be correlated with the treatment efficiencies and body mass index of the larvae. The present research work has undertaken the influence of the moisture level on the behavioural characteristics of the larvae and as a major breakthrough prolongation of the targeted larval instar stage was recorded with an optimum moisture level of 68% (figure 9). Any further increment in the moisture level impacted negatively and accelerated the mortality rate. The maximum prolongation (i.e. 29 days) attributed to optimum moisture level found to be approx 81% higher than the normal larval period of 16 days. This prolongation of the larval period also resulted positively with the body mass index of the larvae and the larvae used in ILGCR as operational agent found to grow almost double than a normal BSF larva (figures 10 & 11) [24].

![Figure 9. Optimization of the moisture level.](image)
Figure 10. Increment in body weight content with prolongation of the larval period.

Figure 11. Variation in larval size before and after treatment with ILGCR.

4. Conclusion
The research work explicitly revealed that the symbiotic culture is utmost feasible for the treatment of unsegregated heterogeneous mass. The stipulated treatment period and minimal energy input make this treatment a pertinent option as per the societal need. Furthermore, the newly fabricated novel reactor successfully prolongs the larval instar stage of the BSF and thus maximized the body growth factor which contributed positively towards the synthesis of value-added co-products from the system. Ultimately, the research yields a wholesome treatment system with zero environmental interventions which can solely resolve the waste processing and disposal issues in lower and middle-income nations.

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