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# Physical, Chemical and Biological Changes of Enriched Insect Biomass Compost at Different Stages of Decomposition

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

Changes in physical, chemical and biological changes during different stages of insect enriched compost were determined with compost enriched with insect biomass such as silkworm pupae, silkworm moth, uzi fly and fruit fly. There were higher in moisture and temperature during initial weeks of composting and thereafter it decreased with time. The pH of the decomposing materials decreased with the time of decomposition of silkworm pupae, moth, uzi fly and fruit fly residue except farm yard manure. There were losses of N in FYM+ silkworm pupae and FYM + silkworm pupae with the effect an initial increase in C:N ratio was observed which decreased later on due to

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decomposition. Per cent major, secondary and micronutrients content increased during composting of silkworm pupae and moth residues as compare to all composts. The microbial population and enzymatic activities were higher between 30 and 60 days of composting during various compost which was enriched with selected insect biomass. Whereas, higher were observed in pupa and moth composts compared to fruit fly an uzi fly compost.

*Keywords: Insect biomass; enriched compost; silkworm pupae and moth; nutrient content.*

## 1. INTRODUCTION

The application of chemical fertilizers can increase the crop yields quickly, but they also could cause soil hardening and decrease soil organic matter and pH after a long period of application, resulting in loss of soil productivity [1]. However, most proportion of the chemical fertilizers will be run off or leached due to rain and heavy irrigation, consequently leading to environmental pollution and lower fertilizer effect. Compost is produced from organic waste, which not only contains organic matter but also is rich in micro and macronutrients. The utilization of compost as a soil fertilizer or amendment could restore the soil quality and improve soil structure and fertility, which not only serves an important role in agricultural production but also is of great significance for improving the ecological environment [2]. Nowadays, using compost as a substitute to chemical fertilizer has become a global consensus. The application of compost could promote soil productivity and improve the crop quantity and quality, as well as increase the income of the farmers. Composting is effective in reducing the volume and weight of the organic waste as well as in producing a stable and nutrient-rich final product (compost). The utilization of composting technology to dispose of and recycle organic waste has been widely recognized [3]. Composting is a natural organic decomposition process controlled by a number of environmental conditions including pH, moisture content, porosity for air passage, soil microorganisms, carbon-to-nitrogen ratio, *etc.,* which determine the success of a composting process [4]. By effectively controlling these composting conditions, high-quality mature compost can be obtained. However, the compost has low nutrient content and they have to apply in bulk quantity. So, because of the bulky nature of compost, enrichment of the compost is necessary to maintain soil and plant health. Compost enrichment is done by using various materials like rock phosphate.

Insects are crucial components of many ecosystems, where they perform many important functions. They aerate the soil, pollinate blossoms, and control insect and plant pests. Many insects, especially beetles, are scavengers, feeding on dead animals and fallen trees, thereby recycling nutrients back into the soil. As decomposers, insects help create top soil, the nutrient-rich layer of soil that helps plants grow. Burrowing bugs, such as ants and beetles, dig tunnels that provide channels for water, benefiting plants. The major components of insect body are water, proteins and amino acids, because of their high nutritional value insects are used as food by humans. So, an attempt was conducted to study the changes in physical, chemical and biological parameters with insect population and nutritional value can be used in enrichment of compost at different stages of decomposition.

## 2. MATERIALS AND METHODS

The composting of enriched insect biomass were prepared in the following treatments

| | |
|---|---|
| C1 | Control (FYM) + Cow dung slurry |
| *C2 | Silkworm pupae+ FYM + Cow dung slurry |
| *C3 | Silkworm moth+ FYM + Cow dung slurry |
| *C4 | Uzi fly + FYM + Cow dung slurry |
| *C5 | Fruit fly+ FYM + Cow dung slurry |

** Insect biomass and FYM mixed in the ratio of 1:4 N equivalent ratios*

Since farm yard manure is a waste of high C:N ratio, it was mixed with selected insect biomass and cow dung slurry to narrow down the C:N ratio. Silkworm pupae and silkworm moth was obtained from sericulture based industries silk reeling and grainage unit Chintamani, Chickkaballapur district. Uzifly was collected from cocoon market and fruit flies was collected from mass trapping method by using *cue-lure* traps which attract male fruit fly in cabbage, tomato and mango orchards. Slurry was prepared by adding 100 g of cow dung/ 1 liter of water Aerobic compost was prepared**.** The organic additives used were farm yard manure and cow dung slurry. Compost was prepared in compost

**Table 1. Methods followed for physical, chemical and biological properties**

| Parameter | Method | Reference |
|---|---|---|
| **Physical parameters** | | |
| Maximum water holding capacity (%) | Gravimetric analysis | Piper [5] |
| Temperature ($^oC$) | Thermometer probe | Piper [5] |
| **Chemical parameters** | | |
| pH | Potentiometry | Jackson [6] |
| EC (dS $m^{-1}$) | Conductometry | Jackson [6] |
| Organic carbon (%) | Dry combustion | Jackson [6] |
| Total nitrogen (%) | Micro kjeldahl digestion and distillation | Piper [5] |
| Total phosphorus (%) | Vanadomolybdic yellow colour spectrophotometry | Piper [5] |
| Total potassium (%) | Flame photometry | Piper [5] |
| Total calcium (%) | Versenate titrimetry | Piper [5] |
| Total magnesium (%) | Versenate titrimetry | Piper [5] |
| Total sulphur (%) | Turbidimetry | Bradsley and Lancester [7] |
| Total Fe, Mn, Zn and Cu (ppm) | Atomic absorption spectrophotometry | Lindsay and Norvell [8] |
| Total B (ppm) | Colorimetry using Azomethane-H | Page et al., [9] |
| **Biological properties** | | |
| **A. Enzymatic activities** | | |
| Dehydrogenase activities | Spectrophotometery | Casida et al., [10] and Chhonkar et al.,[11] |
| Acid and alkaline phosphatase activities | Colorimetrically | Tabatabai and Bremner [12] |
| Urease activities | $NH_4$ released during assay | Tabatabai and Bremmer [13] |
| **B. Microbial population** | | |
| Bacteria, Fungi and Actinomycetes population | Serial dilution pour plate technique | Halvorsun and Zeiglar [14] with little modification by Chhonkar et al., [6] |

pits of size 7 m X 4 m X 3 m (length X breadth X height). The quantity of various raw materials (Raw insect species waste: 05 kg, Farm Yard Manure: 20 kg and Cow dung slurry @ 10% w/w used for composting. Five treatments replicated four times with RCBD design followed for conducting enriched insect biomass compost. Composting process was carried out for 3 months. The decomposing materials were turned once in 30 days. The compost was ready by 90$^{th}$ day. As monthly turning was given, samples were collected from each compost pits using spiked augers and were pooled and composite samples were prepared and subjected for analysis. The samples were dried in shade and were analyzed for physical, chemical and biological properties by following standard procedures described in Table 1.

All determinations were carried out in four times and level of significance used in 'F' and 't' test was 5 % probability and wherever 'F' test was found significant, the 't' test was performed to estimate critical differences among various treatments.

## 3. RESULTS AND DISCUSSION

Silkworm pupae contained 7.32 % N, 1.13 % P, 2.28 % K, 2.72 % Ca and 1.98 % Mg (Table 1). It is quite rich in micro nutrients mainly Zn, Fe, Mn, Cu and B (180.50, 956.40, 828.20, 14.40 and 6.00 mg $kg^{-1}$). The pupae of silkworms are rich in nutrients, which can be used to make nutrient-rich compost. According to Tomotake et al,[15] Bombyx mori has a high protein content of 55.6% dry weight and is the most abundant dry matter in silkworm pupae The amino acid composition of the proteins is essentially the same in the different species of silkworm pupae, all consisting of 18 amino acids.

**Table 2. Chemical composition of selected insect species and raw materials used for composting**

| Characteristics | Silkworm pupae | Silkworm moth | Uzi fly | Fruit fly | Farm yard manure |
|---|---|---|---|---|---|
| pH | 9.51 | 6.88 | 6.73 | 6.82 | 6.80 |
| EC (dS $m^{-1}$) | 3.10 | 2.18 | 2.04 | 1.95 | 0.92 |
| Organic carbon (%) | 30.32 | 30.21 | 25.56 | 28.95 | 36.58 |
| C:N | 4.14 | 4.37 | 5.95 | 4.56 | 65.32 |
| Nitrogen (%) | 7.32 | 6.91 | 4.29 | 5.68 | 0.56 |
| Phosphorus (%) | 1.13 | 0.57 | 0.80 | 0.72 | 0.41 |
| Potassium (%) | 2.28 | 1.45 | 1.59 | 1.50 | 0.48 |
| Calcium (%) | 2.72 | 1.92 | 2.00 | 2.56 | 2.90 |
| Magnesium (%) | 1.98 | 1.50 | 1.33 | 1.78 | 1.18 |
| Sulphur (%) | 0.28 | 0.24 | 0.22 | 0.23 | 0.32 |
| Zn (mg $kg^{-1}$) | 180.50 | 148.64 | 117.42 | 154.68 | 87.70 |
| Cu (mg $kg^{-1}$) | 14.40 | 11.80 | 9.92 | 12.74 | 8.70 |
| Fe (mg $kg^{-1}$) | 956.40 | 762.80 | 669.06 | 596.00 | 808.80 |
| Mn (mg $kg^{-1}$) | 828.20 | 500.40 | 461.60 | 395.70 | 65.94 |
| B (mg $kg^{-1}$) | 6.00 | 7.40 | 5.50 | 9.60 | 13.60 |
| Pb (mg $kg^{-1}$) | BDL | BDL | BDL | BDL | BDL |
| Cr (mg $kg^{-1}$) | BDL | BDL | BDL | BDL | BDL |
| Cd (mg $kg^{-1}$) | BDL | BDL | BDL | BDL | BDL |
| Ni (mg $kg^{-1}$) | BDL | BDL | BDL | BDL | BDL |

Silkworm moth contained 6.91% N, 0.57% P, 1.45% K, 1.92% Ca, 1.50 % Mg and it was fairly rich in micro nutrients. It also contained 148.64 mg $kg^{-1}$ Zn and 762.80 mg $kg^{-1}$ Fe. In the process of egg production of parental lines, the grainages (egg-producing centers) yield substantial quantities of moths as a by-product. Uzi fly contained 4.29% N, 0.80% P, 1.59% K, 2.00% Ca and 1.33% Mg. It also contains micro nutrients mainly Zn, Fe, Mn, Cu and B (117.42, 669.06, 461.60, 9.92 and 5.50 mg $kg^{-1}$). The results of the experiments were similar with house fly by Gadzama and Ndudim, [16]. Farm yard manure contained 0.56% N, 0.41% P, 0.48% K, 2.90% Ca and 1.18% Mg. In most countries, it is the most commonly and widely used organic manure. A decomposed mixture of cattle dung, stable bedding and any leftover straw and plant stalks fed to cattle makes up manure.

### 3.1 Physical Changes during Insect Biomass Composting

Moisture content of the compost treatments ranged from 63.38% in farm yard manure (C1) to 69.01% in farmyard manure + uzi fly (C4) in 2nd week of composting (Fig. 1). In spite of this, the measured moisture content dropped from an initial maximum of 66.55% (C1) to 71.72% (C4). A major pathway for moisture loss was leaching. By 12th week (90 days) the moisture content varied from 27.74% in farm yard manure + Silkworm moth (C3) to 31.30% in farm yard manure + fruit fly (C5). During the curing process, further reduction of moisture occurred to stabilize between 22-26%. As insect biomass compost went through different stages of composting, the moisture content changed significantly. The moisture content of the compost was highest during the first two weeks of composting, since the principal component of insect biomass, except for biochemical compounds was water, which ranged from 62–70 % on average. The moisture content began to decline after the second week of decomposition, and by the end of the 12th week, it had decreased substantially. One of the main reasons for moisture reduction is thermo-genesis, a result of microbial activity, in addition to manual turning, which causes moisture to evaporate. The excess moisture is released as leachates. Compost curing results in a further reduction of moisture in the compost. Similar findings were observed by Heenkende, [17].

Changes in temperature at various stages of decomposition of compost enriched with selected insect biomass are shown in Fig. 2. Initial temperature were ranged from 29 to 31 ºC recorded farm yard manure + silkworm moth compost (C3) and farm yard manure + uzi fly compost (C4). The microbial action on insect biomass matter causes the temperature to rise

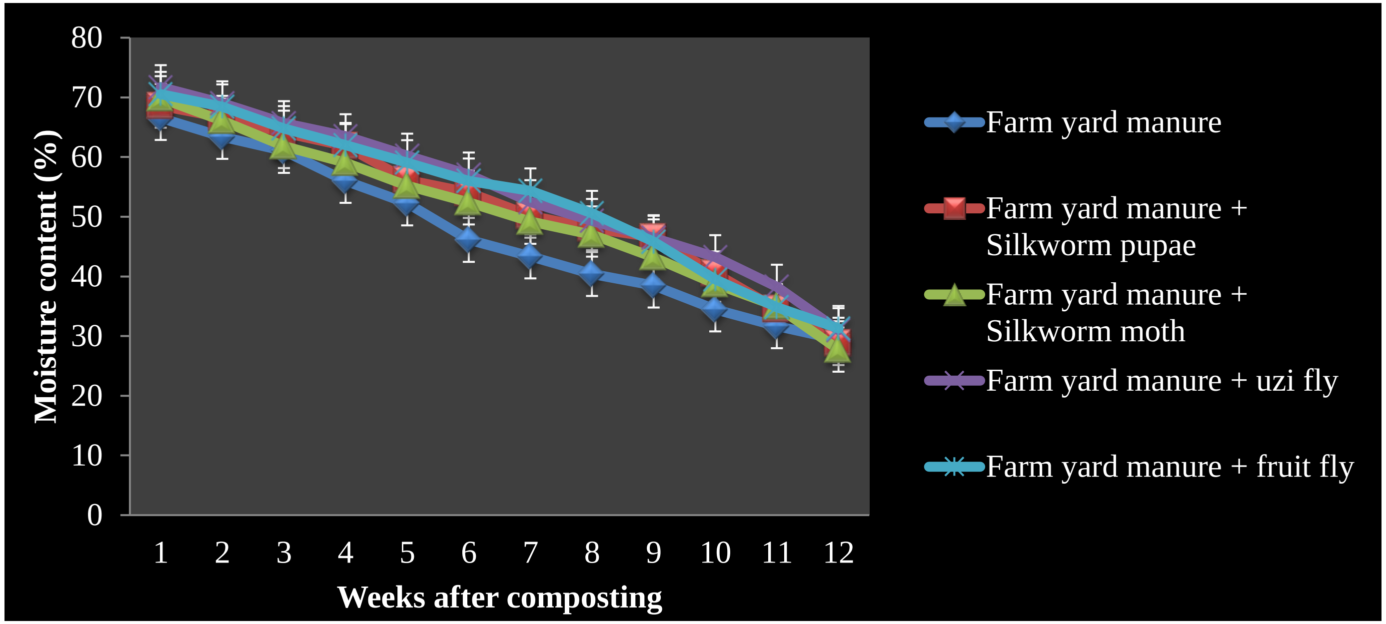


**Fig. 1. Changes in the moisture (%) during different stages of insect biomass compost**

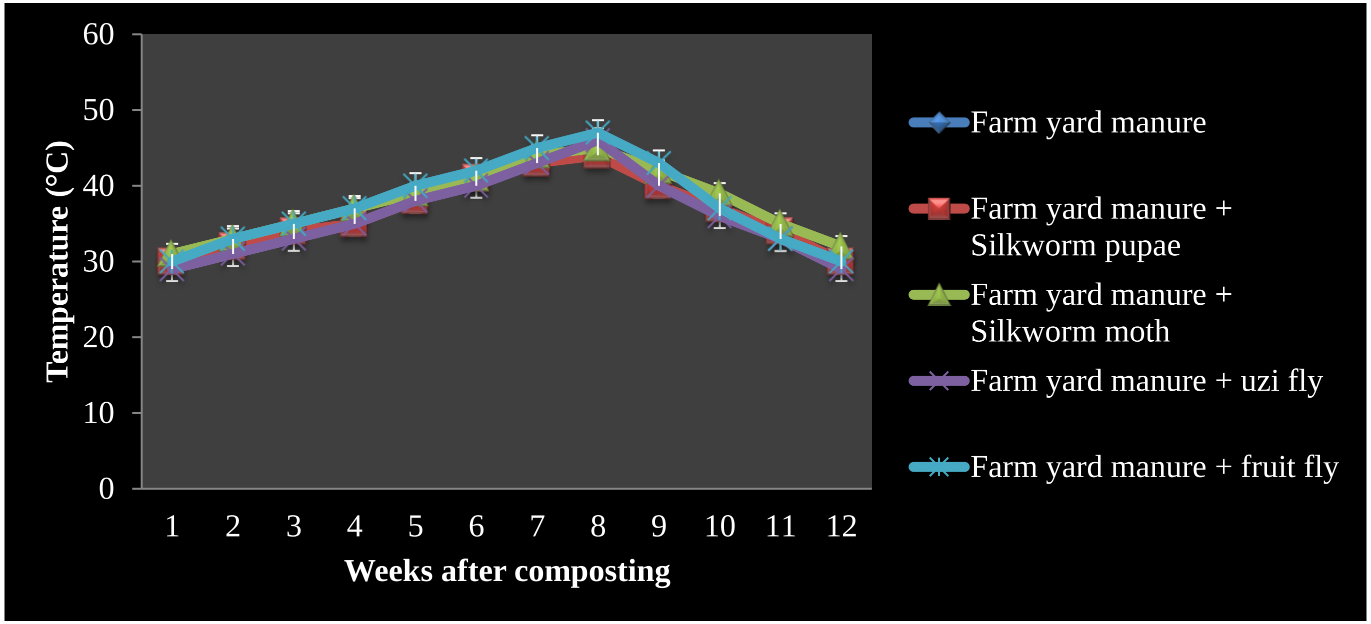


**Fig. 2. Changes in the temperature (°C) during different stages of insect biomass compost**

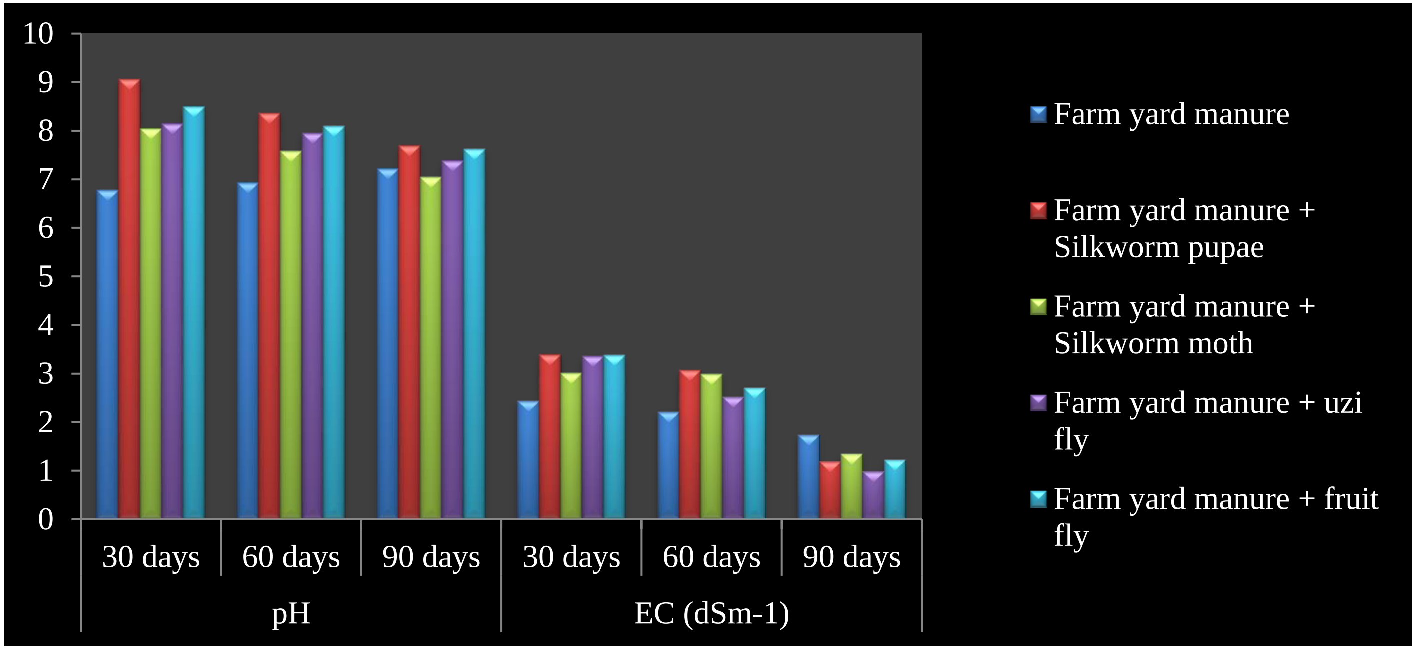


**Fig. 3. Changes in the pH and EC (dS/m) during different stages of insect biomass compost**

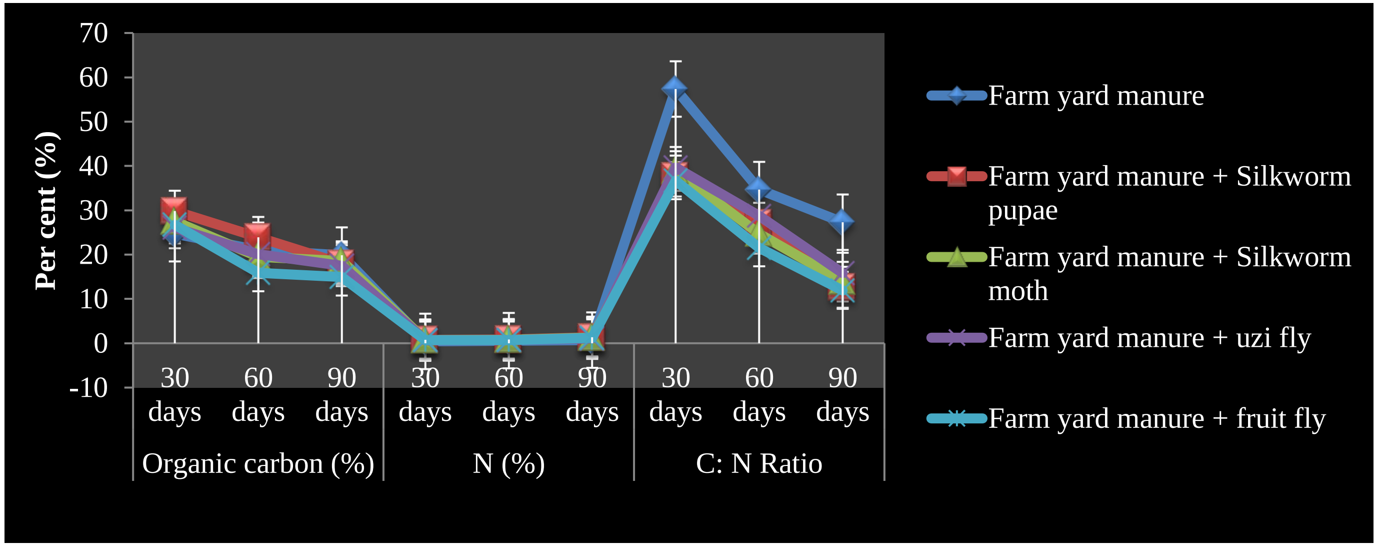


**Fig. 4. Changes in the Organic carbon (%), Nitrogen (%) and C: N ratio during different stages of insect biomass compost**

as the composting process advances. During the eighth week composting of insects biomass, maximum temperatures were recorded for the all the treatments. The temperature ranged from 47ºC (C5) to 44ºC (C2) follows a gradual decrease, till it reaches ambient temperatures by 12th week. Temperature fluctuations can be seen during the decomposition process. From the first day to 8th week, the temperature progressively increased in all treatments. As the decomposition is microbially mediated, the microbial action on insect biomass composting matrix results in raising temperatures with progress in microbial decomposition. First, thermophyllic microorganisms and then thermophyllic microorganisms that increases the temperature, making the compost hygienic and eco-friendly. Compared to the initial values, the temperatures in all of the treatments drastically dropped during the final stages of composting. Similar findings were observed with Heenkende, [17].

### 3.2 Chemical Changes during Insect Biomass Composting

At the beginning of the compost pH of the decomposing material was maximum in farm yard manure + silkworm pupae treatment (C2) 9.06 and minimum of 6.78 in farm yard manure (C1) (Fig. 3). The observations indicate that pH in all treatments decreased except for C1, which increased. Higher reduction in pH was noticed in FYM + silkworm pupae treatment (C2) 9.06 to 7.69 and lower reduction was noticed in farmyard manure + silkworm moth (C3) 8.04 to 7.04 of insect biomass composting. pH value of decomposing materials of silkworm pupae waste on 60 days was low when compared to 30 days and later decreases 90 days after that pH decreased up to neutral values. On 30th day of compost, decomposing of silkworm moth, uzi fly, and fruit fly had a high pH when compared to 90 days. The mature compost had low pH may be due to production of organic acids, phenolic substances and ammonia formation during decomposition. Varying pH levels can be observed in different waste substrates, such as low pH in FW as compared to animal manure. Activities of acid producing bacterial communities have been considerably affected by pH of the system. Thus, pH is an important parameter affecting the decomposition rate and quality of compost [18]. This increase of pH can be attributed to the decomposition of organic components like proteins, amino acids or peptides and the release of ammonium ions or volatile ammonia [19]. The electrical conductivity (EC) was used as an indicator of salinity, in order to evaluate any potential problems on using the compost as soil amendment. The EC should remain below 4 mS/cm to be tolerated by plants [20]. Fig. 3 showed that maximum EC of decomposing material was recorded in farm yard manure + silkworm pupae treatment (C2) 3.39 $dSm^{-1}$ and minimum of 2.44 $dSm^{-1}$ was found in control treatment (C1- farm yard manure only). However, the data reveals that from 30 to 90 days of composting, EC of decomposing materials decreased over time. Highest reduction in EC was found in farm yard manure + silkworm pupae treatment (C2) 3.39 to 1.19 $dSm^{-1}$ and lower reduction was noticed in farm yard manure treatment (C1) 2.44 to 1.74 $dSm^{-1}$.

### 3.3 Organic Carbon (%), Nitrogen (%) and C: N Ratio

The organic carbon in all composting treatments decreased during the composting process (Fig. 4). The organic carbon values of the enriched compost treatments ranged from 24.71 % in farmyard manure (C1) to 29.80 % in farm yard manure + silkworm pupae (C2) However, there was a reduction in organic carbon during all the stages of decomposition. The maximum decomposition of organic matter was noticed in (C1) 19.89 and the minimum decomposition were noticed in (C5) 14.94. As a result of all the treatments, the percentage of organic carbon decreased in enriched insect biomass compost. Organic carbon content was lowest in C5 treatment (farm yard manure + fruit fly). The loss of organic carbon may be faster during different composting intervals. Similarly, treatment (C1) recorded highest organic carbon content could be due to lesser organic carbon loss or may be due to presence of resistant materials. These results are similar to those reported in the present study Haynes and zhou [21]. Greater organic matter decomposition occurred during the process of composting than vermicomposting since the organic C content of products was measurably lower for composts. During the thermophilic phase of composting, intense microbial activity results in a substantial loss of C as $CO_2$. Similar results were obtained with Goyal et al. [22] who reported there were losses of N in poultry waste and water hyacinth with the effect an initial increase in C:N ratio was observed which decreased later on due to decomposition.

The per cent nitrogen increased with decomposition in all treatments during enriched insect biomass composting (Fig. 4). Highest N percentage of 1.39 was noticed in farmyard manure + silkworm pupae (C2) treatment and lowest of 0.71 % was noticed in farmyard manure (C1) treatment on maturity. Nitrogen content increased during composting of insect biomass at all stages. During composting, the increase in nitrogen levels found in compost was caused by mass loss. Higher nitrogen content was found in C2 (farmyard manure + silkworm pupae). The high levels of nitrogen may be caused by the combination of silkworm pupae waste and farmyard manure and organic nitrogen which adds up to form high nitrogen content. Similarly, Kadalli [23] reported an increase in N content in composts prepared from different organic sources. However, the data reveals that there was a decreasing trend in C:N ratio at all stages of enriched compost insect biomass. The drop in the C:N ratio during 60 days was much more than during later (90 days) period. Higher C:N ratio was observed in (C1) treatment at 30, 60 and 90 days after decomposition and it recorded C:N ratio of 57.36, 34.67 and 27.31 and lowest C:N ratio was noticed in C5 of 36.67, 21.54 and 11.94 at 30, 60 and 90 days after decomposition. In all treatments, the C:N ratio of compost materials decreased with progress in decomposition. Depending on the type of raw material used, Chanayasak and Kubota [24] showed that the C:N ratios in sufficiently well decomposed materials range from 5 to 20.

### 3.4 Major, Secondary and Micronutrient Content of Insect Biomass Compost at Maturity

The results showed farm yard manure + silkworm pupae enriched compost in general having relatively higher Major, Secondary and micronutrient nutrient contents (N, P, K, Ca, S, Zn, Cu, Fe, Mn and B) at maturity stage of compost (Table 3). High nutrient contents in insect biomass enriched compost may be due to better decomposition because of higher microbial activity observed in this study. Compost enriched with additives exhibited a higher rate of decomposition, possibly because there were more nutrients available for greater biological activity. Based on the results of this study, it can be concluded that enrichment of insect biomass with silkworm pupae, moth, uzi fly and fruit fly waste with cow dung, farm yard manure. By enriching composts with nutrients such as phosphate increased the value of composts due to a higher level of decomposition. Because of the lack of mineral surfaces to adsorb phosphate and the concentration of nutrients during composting, large quantities of ex tractable P can accumulate in green waste composts [25] and similar findings were observed by Gowda et al, [26].

### 3.5 Changes in Microbial Dynamics during Composting

The results revealed that bacteria were the predominant microorganisms found throughout the study followed by actinomycetes and the fungi the least (Fig. 5). Bacterial population was found to be significantly higher in silkworm pupae enriched compost (30.00, 35.00 and 55.75 X $10^6$ CFU $g^{-1}$ at 30, 60 and 90 days after composting) as compared to all other treatments. This was followed by enrichment of FYM with silkworm moth (26.75, 34.00 and 49.00 X $10^6$ CFU $g^{-1}$ at 30, 60 and 90 days after composting). The least bacterial population (19.75, 22.25 and 43.25 X $10^6$CFU $g^{-1}$ at 30, 60 and 90 days after composting) was noticed in FYM alone. According to Mujiyati and Supriyadi [27], organic manures can increase the population of bacteria by as much as 0.02 % (Azotobacter) and 0.46 % (Aspergillus) when compared to NPK fertilizer. The fungal population at 30 days after composting is ranged from 2.75 to 11.25 X $10^4$ cfu $g^{-1}$ compost and at maturity it ranged from 9.25 to 28.50 X $10^4$ cfu $g^{-1}$ compost. Significantly the higher fungal population (28.50 X $10^4$ cfu $g^{-1}$ compost) was observed in farm yard manure + silkworm pupae followed by farm yard manure + silkworm moth. The lowest fungal population (9.25 X $10^4$ cfu $g^{-1}$ compost) was observed in farm yard manure alone. Fungal populations were affected by an increase in pH and total soluble salts content in soil Mujiyati and Supriyadi [27]. Similarly, the reduction in organic carbon was reflected in a consistent reduction in fungal population. Like bacterial and fungal populations, there was a significant difference in actinomycetes population due to compost enriched with insect biomass as compared to FYM alone compost. Similar trend of results was noticed for actinomycetes population in present after composting and at 90 days it was ranged from 16.25 X $10^2$ cfu $g^{-1}$ compost in farm yard manure 32.25 X $10^2$ cfu $g^{-1}$ compost in farm yard manure + silkworm pupae. These data compare well with the results study was ranged between 10.75 – 17.00 X $10^2$ cfu $g^{-1}$ compost at 30 days obtained by Mujiyati and Supriyadi [27] when the pH of the material was changed, a significant effect was observed on the actinomycetes population. Microbial population *viz.,* bacteria, fungi and actinomycetes were significantly increased when organic nitrogen sources were applied compared to the control Krishnakumar et al, [28].

**Table 3. Major, Secondary and micronutrient content of insect biomass compost at maturity**

| Insect biomass compost | N (%) | P (%) | K (%) | Ca (%) | Mg (%) | S (%) | Zn (mg kg$^{-1}$) | Cu (mg kg$^{-1}$) | Fe (mg kg$^{-1}$) | Mn (mg kg$^{-1}$) | B (mg kg$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Farm yard manure | 0.71 | 0.62 | 1.05 | 1.85 | 0.92 | 0.99 | 141.78 | 51.76 | 1087.10 | 795.76 | 18.33 |
| Farm yard manure + Silkworm pupae | 1.39 | 0.86 | 5.21 | 4.10 | 2.37 | 1.33 | 163.88 | 73.06 | 2213.60 | 804.70 | 29.06 |
| Farm yard manure + Silkworm moth | 1.30 | 0.72 | 4.14 | 3.61 | 1.94 | 1.24 | 142.66 | 59.62 | 1985.36 | 790.36 | 25.35 |
| Farm yard manure + uzi fly | 1.08 | 0.66 | 3.43 | 2.89 | 1.56 | 1.05 | 123.58 | 68.86 | 1118.80 | 629.04 | 25.16 |
| Farm yard manure + fruit fly | 1.22 | 0.70 | 3.98 | 3.45 | 2.19 | 1.08 | 156.58 | 69.25 | 1325.20 | 710.90 | 27.69 |

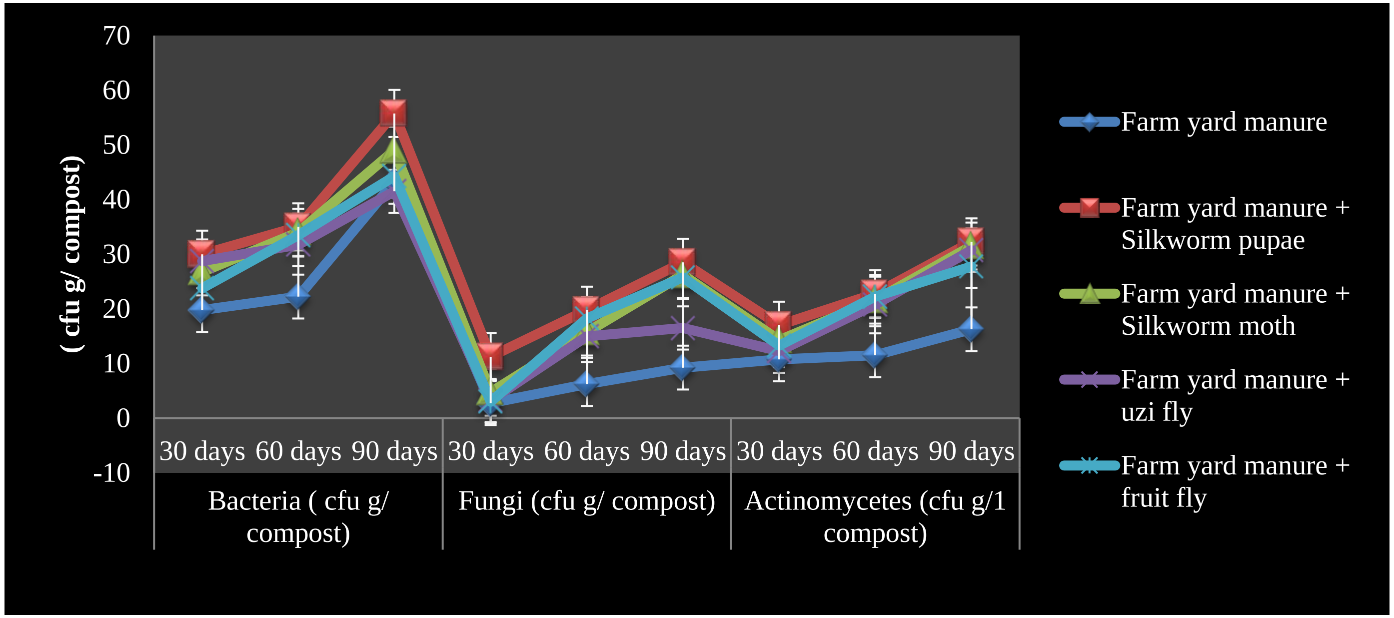


**Fig. 5. Changes in microbial dynamics during composting**

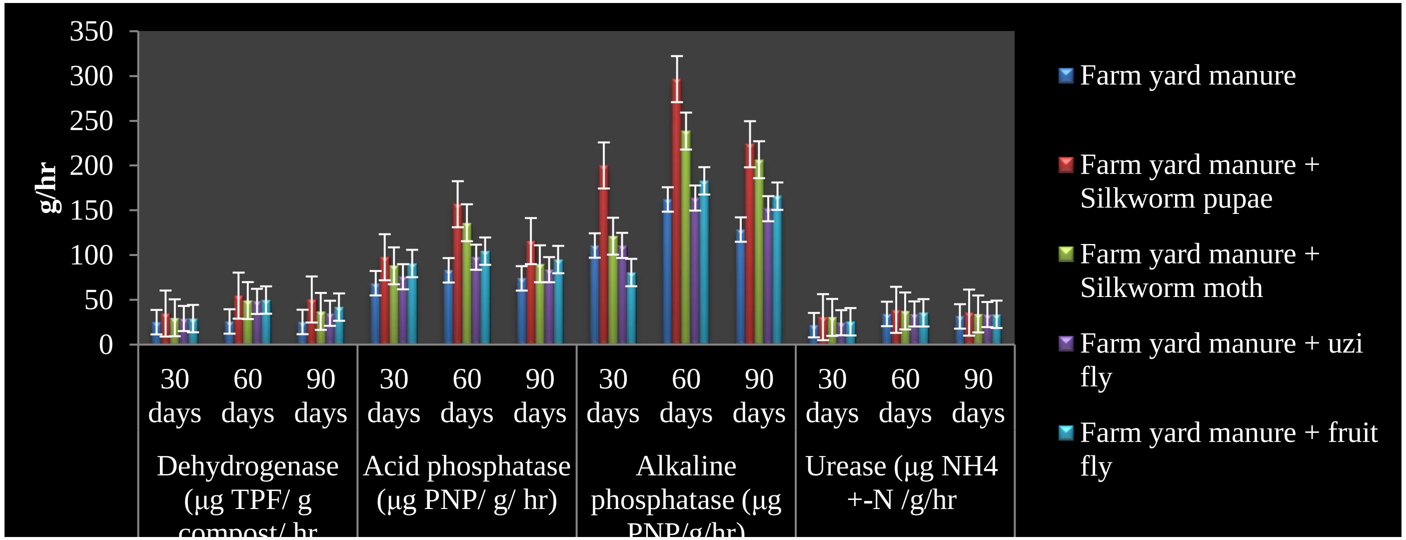


**Fig. 6. Changes in enzyme activities during enriched insect biomass composting**

### 3.6 Changes in Enzyme Activities during Enriched Insect Biomass Composting

The activity of all the enzymes increased up to two months and decreased after maturity during enriched composting of insect biomass in all the treatments (Fig. 6). The dehydrogenase activity significantly varied between 25.31 to 50.40 µg TPF $g^{-1}$ compost $hr^{-1}$ at maturity. Significantly the highest (50.40 µg TPF $g^{-1}$ compost $hr^{-1}$) activity of dehydrogenase was recorded in the C2 (farm yard manure + silkworm pupae) treatment followed by C5 treatment (farm yard manure + fruit fly). The lowest DHA (25.317 µg TPF $g^{-1}$ compost $hr^{-1}$) was found in C1 containing only FYM. There is a positive correlation between DHA and microbial population this is confirmed by observations on microbial populations and DHA. Dehydrogenase is an intracellular enzyme having an important role to play in organic compound bio-oxidation and as a measure of the total microbial population [29] responsible for the decomposition of organic materials. In soil microbial activity studies, dehydrogenase activity is commonly used as a measure of catabolic activity of microorganisms under anaerobic conditions.

The acid phosphatase activity ranged from 74.00 µg PNP $g^{-1}$ $hr^{-1}$ (C1) to 115.6 µg PNP $g^{-1}$ $hr^{-1}$ (C2) at maturity. There was increase in acid phosphatase activity during 60 days after decomposition of enriched insect biomass composting in all the treatments. The activity of all the enzymes increased up to two months and decreased after maturity during composting of enriched insect biomass compost. The higher acid phosphatase activity was noticed in C2 treatment (115.60 µg PNP $g^{-1}$ $hr^{-1}$) and lower was noticed C1 treatment (74.00 µg PNP $g^{-1}$ $hr^{-1}$). Biological processes such as biomass and metabolic activity, as well as short metabolic lifespans, enable microbes to produce and excrete large amounts of extracellular phosphatase.

The alkaline phosphatase activity increased up to 60 days after composting and then decreased at maturity. The alkaline phosphatase activity ranged from 80.50 µg PNP $g^{-1}$ $hr^{-1}$ (C5) to 200.10 µg PNP $g^{-1}$ $hr^{-1}$ (C2) on 30 days and on 90$^{th}$ day it ranged from 128.50 µg PNP $g^{-1}$ $hr^{-1}$ (C1) to 223.80 µg PNP $g^{-1}$ $hr^{-1}$ (C2). The changes in acid phosphatase and alkaline phosphatase activity were monitored for 30, 60 and 90 days after composting (only during turning). The activity of alkaline phosphatase increased during 60 days after decomposition of enriched insect biomass composting in all the treatments. Subsequently the activity reduced in all the treatments. The rapid increase in microbial activity may be due to easily degradable substances available at the early stages, while the decrease in alkaline phosphatase activity by the later stages may be due to the lack of suitable compounds for microbial activity. All treatments showed a reduction in alkaline activity after the eighth week. Also, easier degradation of substances may have resulted in a spurt in microbial activity, in contrast to a decrease in alkaline phosphatase activity due to the lack of suitable compounds for microbial activity during later stages. Alkaline phosphatase activity was increased continuously in all other treatments. Plants utilise the organic P part of the soil because the soil root interface is enriched with phosphatase activity [30]. According to the results of the present investigation, phosphatase activity increased in the FYM treatment that had been enriched by the application of insect biomass, leading to a greater level of soil accessible P. According to the results of the present investigation, phosphatase activity increased in the FYM treatment that had been enriched by the application of insect biomass, leading to a greater level of soil accessible P.

Similar findings were observed with urease activity ranged from 21.79 µg $NH_4^+$- N $g^{-1}$ $hr^{-1}$ (C1) to 30.67 µg $NH_4^+$-N $g^{-1}$ $hr^{-1}$ (C2) at 30 days after composting and at maturity it ranged from 31.51 µg $NH_4^+$-N $g^{-1}$ $hr^{-1}$ (C1) to 35.76 µg $NH_4^+$-N $g^{-1}$ $hr^{-1}$ (C2). There was a decreasing trend was observed in urease activity after 60 days after composting of enriched insect biomass. The urease activity recorded highest values on 60$^{th}$ day in all the treatments. The highest urease activity in C2 treatments was recorded at 60 days after composting. After 90 days in all the treatments, the urease activity reduced till maturity. There may be an increase in microbial activity due to the availability of easily degradable substances. It is possible that the production of metabolic intermediates including radicals changed the biology of the system. A secondary stage of synthesis occurs during composting after an initial stage of active decomposition. During this phase, there will be a change in the spectrum of enzyme activities. During the later stages, enzyme activity may be decreased due to the lack of suitable carbon compounds for microorganisms, leading to a decline in microbial biomass. According to Smith and Powlson [31], the presence of readily available organic N (manure) induced urease enzyme activity. These outcomes support the study's findings. In addition, urease activity was lowest when inorganic fertilisers were used. According to Mohammadi et al. [32], soils with and without NPK application have less urease activity. It may be due to high availability of easily degradable substances, relatively high nitrogen, and a narrow C:N ratio that urease was more active in treatment (C2) [33].

## 4. CONCLUSION

Sericulture waste (silkworm pupae and moth waste), uzi fly and fruit fly upon enrichment can be converted to high value manures and can effectively be used as useful organic manure in an integrated system for sustaining soil organic status. Physical, chemical and biological changes of enriched insect biomass compost at different stages of decomposition indicated that there is a succession of physical, elemental, microbial population and enzymatic activates depending on the temperature reached during composting. Maximum changes in physical, chemical and biological properties manifested between 30 and 60 days, which is active phase of decomposition. Farm yard manure + silkworm pupae showed optimum physical condition, higher nutritive and biological population. By utilizing these waste products farmers can get additional income and it can be sold as a high quality enriched compost the future.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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