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To Cite:
Shrathchandra K, Devika CH, Sharma BB, Sridhar KR. Assessment of black soldier fly (*Hermetia illucens*) larval compost liquor fed on food waste in cowpeas (*Vigna unguiculata*). *Discovery* 2025; 61: e16d3109
doi: https://doi.org/10.54905/dissi.v61i337.e16d3109

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Peer-Review History
Received: 09 December 2024
Reviewed & Revised: 17/December/2024 to 17/April/2025
Accepted: 25 April 2025
Published: 29 April 2025

Peer-Review Model
External peer-review was done through double-blind method.

Discovery
pISSN 2278–5469; eISSN 2278–5450

Assessment of black soldier fly (*Hermetia illucens*) larval compost liquor fed on food waste in cowpeas (*Vigna unguiculata*)

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ABSTRACT

This study evaluated the impact of Black Soldier Fly Larvae (BSFL) (*Hermetia illucens*) compost liquor on the growth of cowpea (*Vigna unguiculata*) using hydroponic culture. Pure water has been mixed with different amounts of compost liquor (5–30%), along with pure water as a control, to assess the growth parameters of cowpea seedlings. The growth parameters were the best at 15%, followed by 20% combinations. A 15% combination at 24 days showed significantly enhanced plant weight, root biomass, root length, number of root nodules, early flowering, and pod setting. The results of BSFL compost liquor resemble those of vermiwash of earthworms. However, the production of BSFL compost liquor is easier than vermiwash, as the composting ability of BSFL is very rapid. The present study supports the possibility of vertically forming desired herbs by hydroponics using the compost liquor of BSFL. This compost liquor also serves as a foliar spray because it contains several plant growth-promoting nutrients. In view of plant conservation, this hydroponic technique could be employed to grow medicinal plants, especially those that have active principles in their roots.

Keywords: Biostimulant, compost liquor, hydroponics, legumes, plant biomass, plant growth

1. INTRODUCTION

Drastic improvement of cereal production was achieved with the use of fertilizers for food crop production (Morari et al., 2011). Excessive use of inorganic fertilizers, although it increases food production, was detrimental to soil, the environment, and human health (Rockström et al., 2009). Recycling of food industry waste is one of the lucrative approaches to improving micronutrients and macronutrients in soil to enhance food supply without interrupting soil quality, environmental security, and human health (Ravi et al. 2020). Nowadays, the most valuable natural means of food

waste mineralization by larvae of black soldier fly (*Hermetia illucens* Linn.) is gaining popularity owing to its broad range of food waste processing capabilities (Poveda, 2021). The major life cycle of the black soldier fly is in the larval and pupa stages (Sheppard et al. 2002). Hence, Black Soldier Fly Larvae (BSFL) is efficient in processing food waste.

The BSFL, besides being used in food waste mineralization, is also useful in industries such as food, cosmetics, and biodiesel (St-Hilaire et al., 2007; Hem et al., 2008; Sealey et al., 2011; Singh and Kumari, 2019; Ravi et al., 2020; Jalil et al., 2021; Basri et al., 2022; Lopes et al., 2022). Food waste conversion efficiency is attractive as it converts one ton of vegetable and fruit waste into 250 kg of frass and 125 kg of BSFL in a 2–3 week duration (Ravi et al. 2020). In fact, the BSFL has a high waste bioconversion efficiency (65–80%), and it could be achieved faster than conventional composting methods (5 vs. 8–24 weeks) (Diener et al., 2011; Beesigamukama et al., 2021; David et al., 2024). The production of BSFL frass depends on the nature of biowaste and became attractive to optimally rear the larvae for various conventional and industrial applications (Singh and Kumari, 2019; Gärttling et al., 2020). The BSFL compost has been used as organic fertilizer for various crops (e.g., vegetable crops and non-vegetable crops) (Beesigamukama et al., 2020a, 2020b; Agustiyani et al., 2020; Anyega et al., 2021; Menino et al., 2021). In addition, the BSFL is rich in proteins, lipids, polysaccharides, and calcium (Li et al., 2011; Sheppard et al., 2002).

Similar to earthworm-generated vermicompost (Agustiyani et al., 2020; Anyega et al., 2021; Goodwin, 2022), vermiwash obtained from earthworm culture units will be a potent biofertilizer that helps in seed germination as well as seedling survival in crop plants growing in different soils (Fathima and Sekar, 2014; Varghese and Prabha, 2014; Kaur et al., 2015; Jaikishun et al., 2018; Awadhpersad et al., 2021; Chandrakishore et al., 2023). It could be utilized effectively for sustainable green farming on a low-input basis (Edwards et al. 2004; Verma et al., 2018). Sobha et al. (2003) have recorded significant growth and productivity in the black gram (*Vigna mungo* (L.) Hepper). Similar to vermiwash, BSFL compost liquor could be used for sustainable agriculture through hydroponics.

Hydroponics, or aquaponics, or hydroculture (cultivation of plants in liquid medium) has been considered a beneficial horticultural practice to grow several plant species, including medicinal plants, by mineral nutrients without using soil under laboratory or greenhouse conditions (Gericke, 1937, 1945; Davtyan and Mairapetyan, 1976; Mairapetyan, 1989; Malabadi et al., 2024). Hydroponic techniques were commercially applied during the 1930s; since then, based on the evident quality and quantity of the products, the application of hydroponic techniques has improved greatly (Heyden, 2009). For certain imported crops, such as temperate lettuce, herbs, and some other popular food crops, farmers prefer hydroponic techniques against conventional methods (Wattanapreechanon and Sukprasert, 2016).

The BSFL compost liquor, or leachate, passes through the different layers of maggot compost units. It can serve as a potential liquid manure owing to the presence of minerals, enzymes, and nutritional components that support the production of economically viable test plant systems in a laboratory or greenhouse setup. Such studies could be conducted either by incorporating BSFL compost liquor into the desired soil or liquid media. There seems to be meager information on the efficiency of BSFL compost liquor in plant production (Green and Popa, 2012). Therefore, the current study envisages assessing the BSFL compost liquor in hydroponics on the growth and development of a model vegetable crop, cowpea (*Vigna unguiculata* (L.) Walp.). The study involves an assessment of the different compositions of compost liquor, impact on plant biomass, plant length, number of leaves, number of flowers, pod-setting, and number of root nodules.

2. METHODS

Compost Liquor

Vegetarian food waste composted by BSFL in the production unit in Ramakrishna Matt and Ramakrishna Mission, Mangalore, India, was the source to obtain BSFL compost liquor (Figures 1and 2). A schematic presentation of the experimental design to study compost liquor by hydroponics is presented in Figure 3.

Figure 1. Production unit of BSFL compost in Ramakrishna Math and Ramakrishna Mission, Mangalore, India (a, overall compost unit; b, close-up view of compost unit; c, liquor collected from the outlet of compost unit; d, 10-day-old *Vigna unguiculata* grown in sandy loam soil).

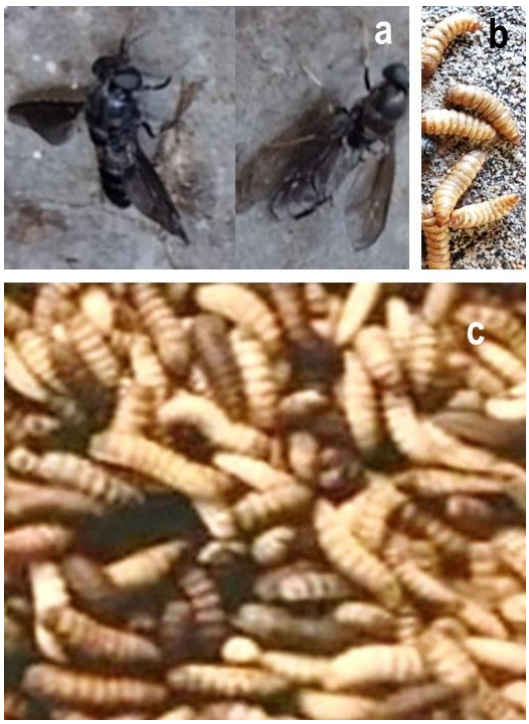

Figure 2. Black soldier flies and larvae: flies (a); larvae (b); larval biomass fed on food waste (c).

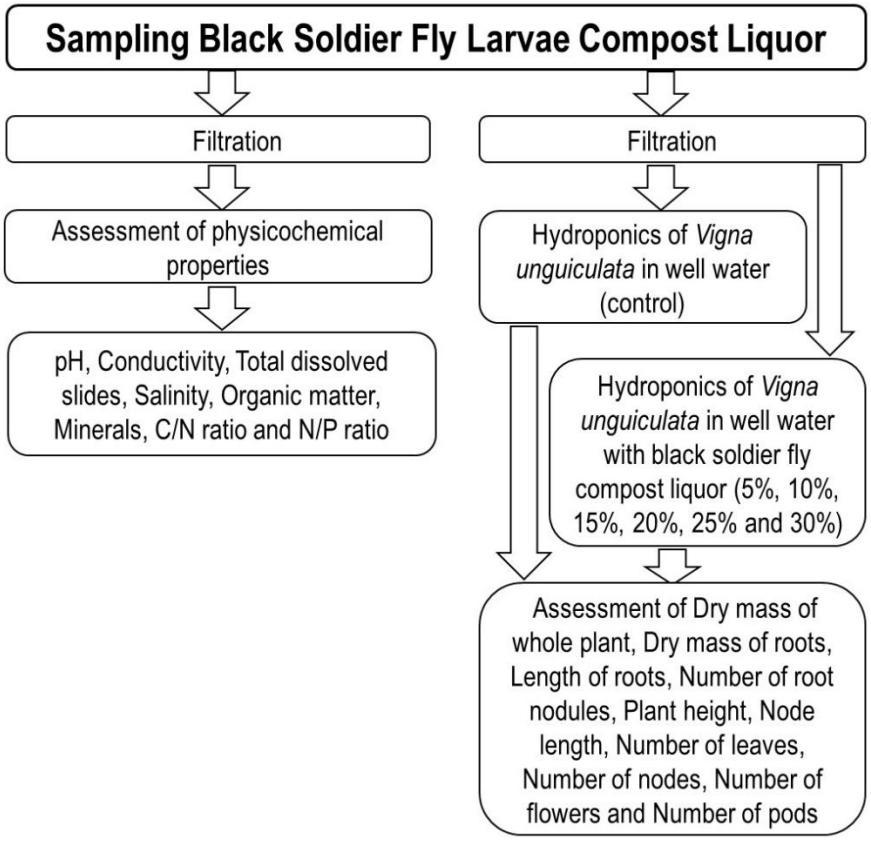

Figure 3. Schematic presentation of steps followed to assess BSFL compost liquor.

Liquor Analysis

Liquor samples were assessed for pH (dilution, 1:5 liquor/distilled water), conductivity, salinity, and total dissolved solids (TDS) using a water analyzer (Water Analyzer #371, Systronics India Ltd., Ahmedabad, Gujarat, India). Organic matter of liquor was calculated by the titrimetric method (Sestu and Bekele, 2000), while organic carbon was assessed by Walkley and Black's titration method (Jackson, 1973).

The filtered liquor was dried at 55±2°C until the formation of crystals to analyze minerals (total carbon, total nitrogen, phosphorus, sulfur, calcium, sodium, potassium, magnesium, manganese, iron, copper, zinc, aluminum, chromium, selenium, and silicon) by the field-emission scanning electron microscope-energy dispersive spectrometer (SEM-EDS) (FESEM Carl Zeiss, Oxford Instruments, USA) at 15 kV (Ramamurthy and Kannan 2009). The SEM images and the corresponding EDS spectrum of liquor crystal samples depend on the specific properties, like shape, shell, and size, to evaluate the mineral contents. The C/N ratio and N/P ratio of liquor samples were calculated based on total carbon, total nitrogen, and phosphorus.

Test Plants

One hundred seeds of *Vigna unguiculata* (L.) Walp. (obtained from agricultural fields in suburban Mangalore, Karnataka, India) were soaked in water for up to 6 hr and sown onto the moistened bed of red sandy loam soil in rectangular trays (30 × 20 × 15 cm). Water was sprinkled daily, and seed germination was seen within two days. After 10 days, plant seedlings were uprooted without damaging the root system, rinsed in running water to remove adhered soil and dirt, and used for hydroponic experiments.

Bioassay

Two cleaned ten-day-old seedlings grown in red sandy loam soil were transferred into 30 sets of brown plastic bottles with 200 ml of pure water as a control and different concentrations of liquor in pure water (5%–30% at a 5% range). A few gravels were added to

bottles for anchorage of roots. They were kept in sunlight (12/12 hr, light/dark) for up to 32 days in an open place (10-day trial; Figure 4a). Water level was maintained by adding distilled water every two days. On every four days, up to 32 days (at a 4-day interval), the dry mass of the whole plant, the dry mass of the root, the length of the roots, and the number of root nodules were assessed in triplicate. In addition, plant height, internodal length, number of leaves, number of nodes, number of flowers, and number of pods were documented.

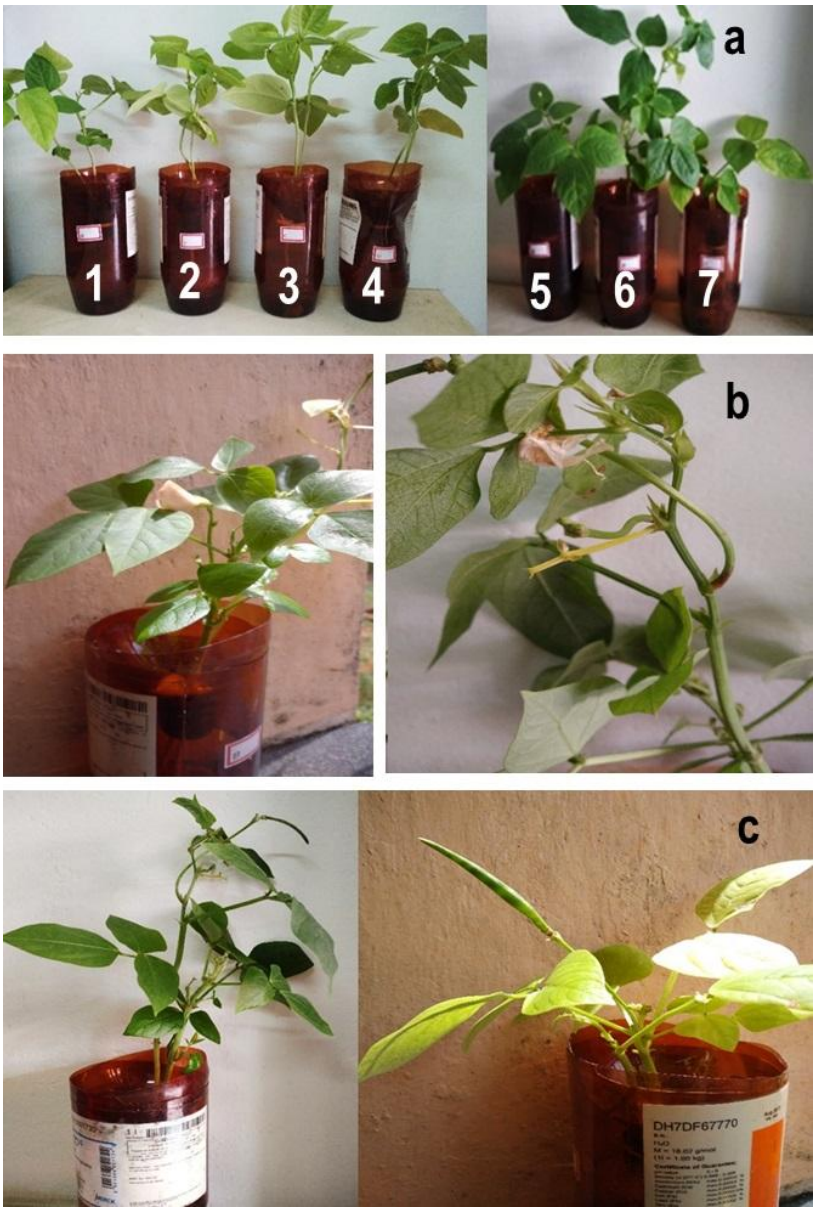

Figure 4. *Vigna unguiculata* grown in hydroponics: growth in different concentrations of BSFL compost liquor (1–6: 5%, 10%, 15%, 20%, 25%, and 30% during a 10-day trial; 7, control in pure water during a 10-day trial) (a); flowering and pod setting in a 24-day trial (b and c).

Data Analysis

Differences in various parameters between control and experimental plants were evaluated by a *t*-test by Statistica, Version # 8 (StatSoft Inc., 2008).

3. RESULTS

Liquor Quality

The pH of liquor was acidic (6.1), conductivity was high (4133 mg/l), salinity was 1.2 ppt, organic carbon was 9.2%, and organic matter was 16% (Table 1). Among the minerals, manganese, aluminum, chromium, and selenium were below detectable limits. Total carbon was highest (25.4%), followed by total nitrogen (4.1%), potassium (3.9%), and sodium (2.8%). The rest of the minerals were <1%. The C/N ratio was 6.2, while the N/P ratio was 12.4.

Table 1. Physicochemical properties of black soldier fly larvae (BSFL) compost liquor (n=3, mean±SD).

Parameter	Quantity
pH	6.10±0.19
Conductivity (µS/cm)	4133.3±35.1
Total dissolved solids (mg/l)	1222.3±17.5
Salinity (ppt)	1.17±0.01
Organic carbon (%)	9.24±0.76
Organic matter (%)	15.96±1.34
Total carbon (%)	25.35±0.86
Total nitrogen (%)	4.10±0.26
Phosphorus (%)	0.33±0.05
Sulphur (%)	0.11±0.02
Calcium (%)	0.90±0.02
Sodium (%)	2.78±0.38
Potassium (%)	3.87±0.37
Magnesium (%)	0.31±0.04
Manganese	BDL
Iron (%)	0.29±0.04
Copper (%)	0.013±0.005
Zinc (%)	0.035±0.015
Aluminum	BDL
Chromium	BDL
Selenium (%)	BDL
Silicon (%)	0.07±0.007
C/N ratio	6.18
N/P ratio	12.42

Bioassay

The impact of pure water and various concentrations of liquor on seedlings of *V. unguiculata* on four parameters, like whole plant dry biomass, root dry biomass, root length, and number of nodules on day 24, was presented in Table 2. All parameters in liquor concentrations were significantly different on day 24 between control and test plants ($p<0.05$) (Figure 5). All parameters measured were the highest in 15% liquor, followed by 20%. On day 24, blossom and pod formation were observed (Figure 4, b, c). Further details between control and 15% and 20% liquor trials from days 1–32 are presented in Figure 6. Plant height, internode length, number of leaves, and number of nodes were significantly higher in almost all durations with 15% liquor; it was followed by 20% liquor. In control trials, until 32 days, no flowering and pod formation were seen, while they were initiated during days 24 and 28 in 15% and 20% liquor, respectively. However, like 20% liquor, 10% liquor also showed flowering at 28 days. The number of flowers and pods reached the highest on day 32 in 15% as well as 20% liquor trials. Hydroponics used to grow *Vigna unguiculata* did not show any deficiency symptoms of minerals or infestation by microbes and insects.

Table 2. Impact of black soldier fly larvae (BSFL) compost liquor in hydroponics of *Vigna unguiculata* on day 24 (n=3, mean±SD; *, $p<0.05$; **, p<0.01; ***, $p<0.001$).

BSFL compost liquor (%)	Dry mass of whole plant (g)	Dry mass of roots (g)	Length of the roots (cm)	Number of nodules in roots
0 (control)	2.535±0.45	1.055±0.65	5.8±0.06	6.0±0.01
5	5.728±0.22**	1.418±0.28**	10.5±0.15**	16.0±0.20***
10	6.272±0.28**	1.517±0.33**	12.8±0.28***	20.5±0.05***
15	8.754±0.12***	1.922±0.08*	16.2±0.32***	26.25±0.15***
20	7.561±0.10***	1.630±0.55*	15.4±0.62***	22.0±0.02***
25	7.128±0.08***	1.345±0.80*	12.2±0.12***	18.5±0.45***
30	5.722±0.05**	1.222±0.42*	8.0±0.05**	12.0±0.05***

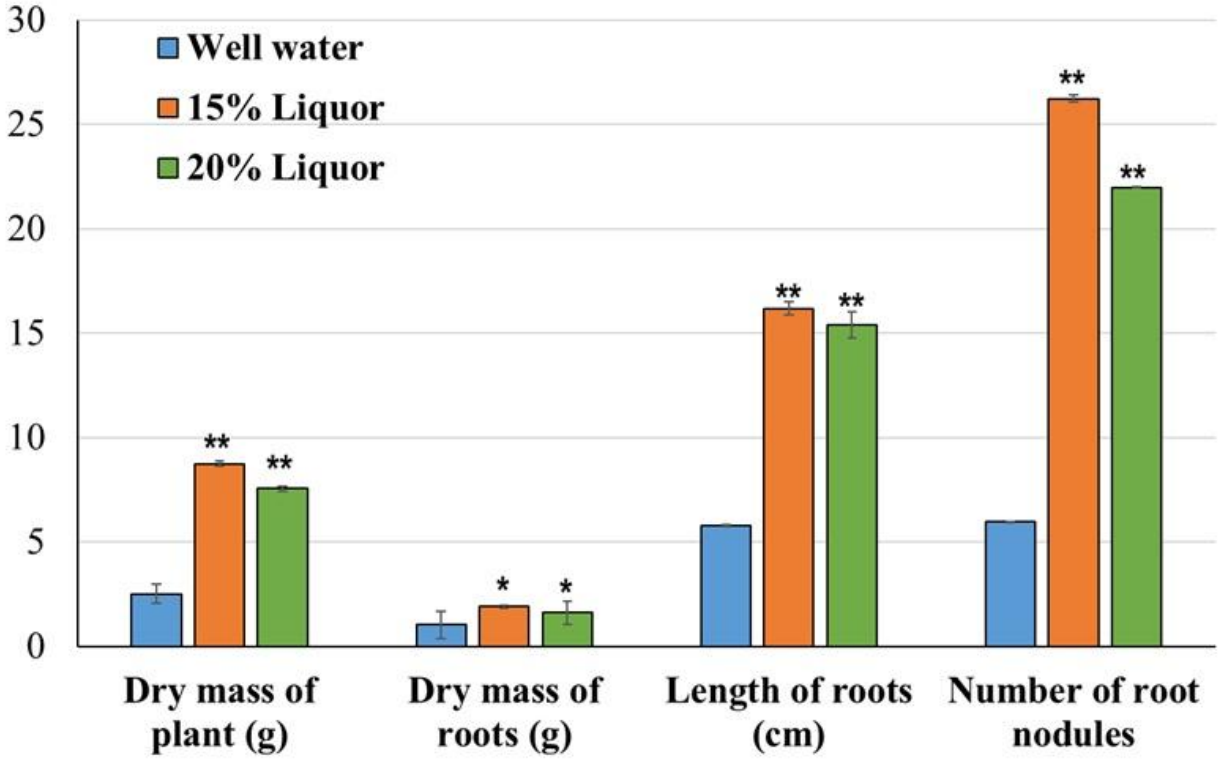

Figure 5. Growth parameters of *Vigna unguiculata* in hydroponics with pure water (control), 15% and 20% BSFL compost liquor on a 24-day trial (mean±SD; *t*-test: *, $p<0.01$; **, $p<0.001$).

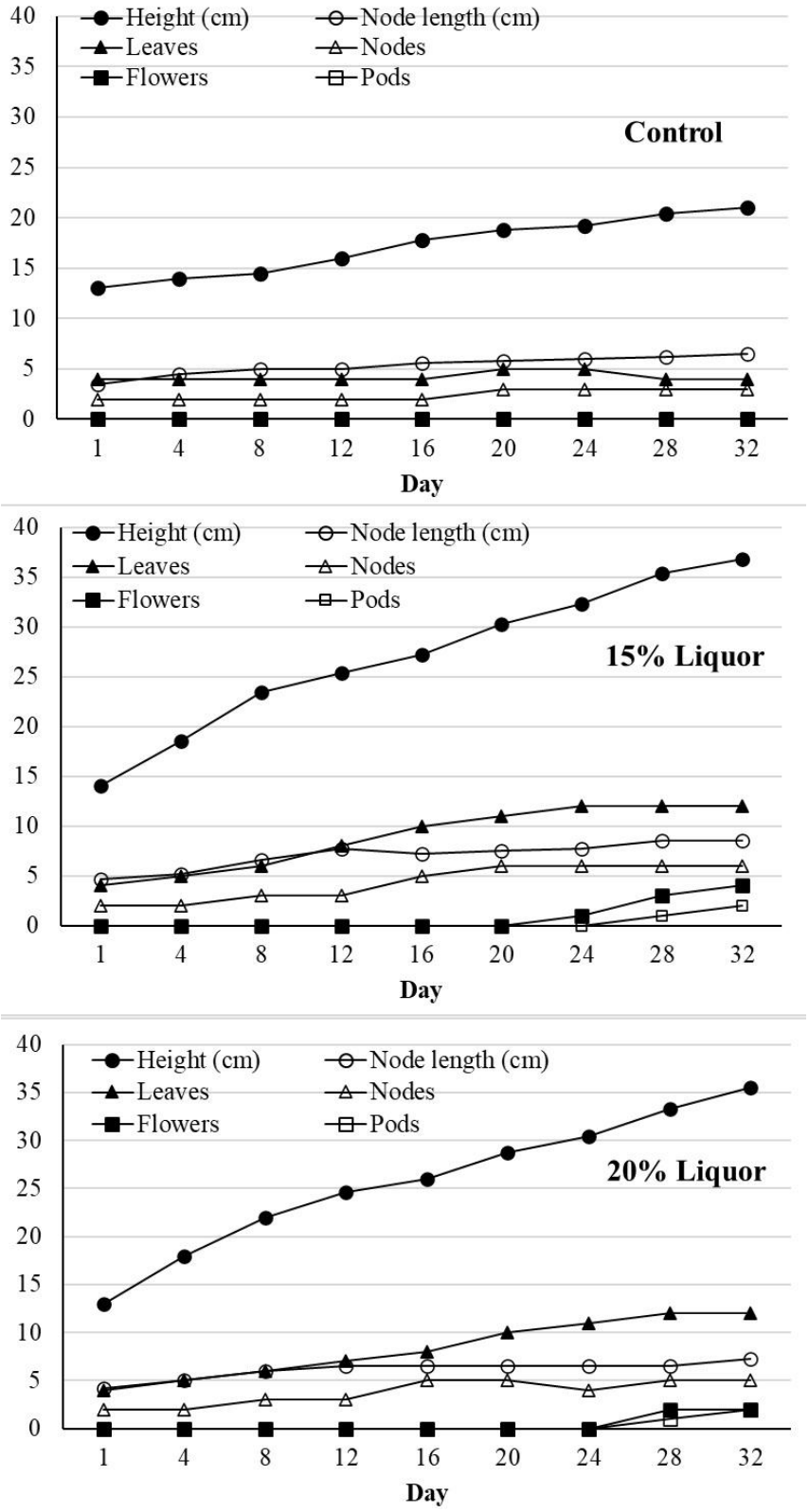

Figure 6. Pattern of growth of *Vigna unguiculata* in hydroponics with pure water (control), 15%, and 20% BSFL compost liquor from days 1–32 (mean of 3 trials).

4. DISCUSSION

Production of BSFL compost is easy compared to other organic composts like vermicompost. Production of BSFL compost is advantageous for transforming food waste into organic manure in a short time. Unlike earthworms, there is no need to culture black soldier flies to produce compost, as such flies are prevalent everywhere, especially in warm climates. As the compost process is very fast, the waste foodstuffs will not generate pathogenic bacteria and fungi. Similar to vermiwash, BSFL compost also provides leachate or liquor as a byproduct for utilization as a biostimulant for desired plant species. The BSFL compost liquor is the product of food waste liquid passing through layers of maggots and waste foodstuff in compost units. Such liquor serves as an inoculum to soil used in pots or in the field. It is possible to use liquor as a foliar spray for plant improvement and to control pathogens. According to Sulaiman and Mohamad (2020), the liquid extract of vermicompost from the compost unit is suitable to be used as a foliar spray, which serves dual purposes as a biofertilizer and a biocontrol agent.

In hydroponic systems, nutrient solution is a water-based solution containing inorganic ions from soluble salts of essential elements necessary for higher plants. Establishing hydroponics with BSFL compost liquor is an innovative approach to utilizing the byproduct of compost, as it is affordable, economically viable, and eco-friendly. It is a new method to grow plants using nutrients leached from compost to economically enhance productivity (Kotzen et al., 2019). Besides, it is a new method of organic waste management that helps to conserve the space in the vertical farming systems to ensure food production and water conservation. Nutrients present in liquor serve as biostimulants for plant productivity, resulting in the production of organic plant produce.

Liquor Quality

The pH of the liquor was acidic (6.1), whereas the conductivity was very high (4133 μS/cm) owing to the presence of several minerals. Total dissolved solids were also high (1222 mg/l) due to the activity of maggots. The salinity of 1.2 ppt is not hindering the activity of maggots, and it is not too high to use in hydroponics. The organic carbon (9.2%) and organic matter (15%) were high, which depends on the food waste offered for composting. Total nitrogen content is quite high (4.1%), which is advantageous to hydroponics. Sodium, calcium, and other mineral contents are also in desirable quantities. The C/N ratio (6.2) and N/P ratio (12.4) indicate rapid availability of nitrogen as well as phosphorus to test plants in hydroponics. Potassium content is also in the desired quantity (3.9%) to support plants in hydronics. The BSFL compost liquor is also rich in proteins, lipids, polysaccharides, and calcium (Sheppard et al., 2002; Li et al., 2011). Besides these nutrients, liquor also possesses enzymes necessary for promoting the growth of plants.

Bioassay

Hydroponic production of crops improves the quality as well as productivity. The current consumer demand is to consume food products grown organically to avoid pollutants and other nutritionally dangerous substances. For example, growing tomatoes through soilless culture systems has similar qualities to that of soil cultivation (Gruda, 2009). Up to 95% of greenhouse tomatoes were grown under soilless culture systems (Peet and Welles, 2005). However, the sugar/acid ratio raised significantly in soilless culture systems, but no difference in sensory values was found between conventional and soilless cultivation (Gruda, 2009). Hydroponics with BSFL compost liquor may bring desired changes in quality and quantity in the test plant system.

The test plant system used in our study, *Vigna unguiculata*, is an annual herbaceous legume adapted as an intercrop that serves as an important food and forage crop across the African and Asian continents. Other than Africa, Asia, Central America, and South America are the major producers of cowpea. Brazil is the second-largest producer of cowpea (Gómez, 2003). The pH of BSFL compost liquor was acidic (6.1), and the conductivity was very high (4133 mg/l) due to the presence of various minerals. The onset of flowering at 15% liquor (day 24) and pod-setting (day 28) indicates the desired dilution of liquor. This positive result was further improved on day 32. At 20% dilution, no flowering and pod-setting were seen on day 24, but flowering as well as pod-setting was seen on day 28, and it was further improved on day 32. However, flowering was seen on day 24 in 10% liquor; it has flowering as well as pod-setting on day 32 with less plant height. An almost similar result was seen in 25% and 30% liquor trials.

Regarding plant height, it has reached the highest on day 32 at 15% (36.8 cm), followed by 20% (35.5 cm) against the control (21 cm). It was found that lower than 15% liquor seems to be insufficient, while higher than 20% liquor may be an excess for optimum production. Similar to the above parameters, the dry mass of the whole plant, dry mass of roots, length of roots, and number of root nodules on day 24 were the highest at 15% liquor; it was followed by 20%. However, 5%, 10%, and 25% liquor concentrations also

showed considerable root nodule numbers, but at 30%, their number declined. Due to increased nodule numbers, it seems, cowpea plants fixed the atmospheric nitrogen by nitrogen-fixing bacteria from compost or the initial soil culture. Interestingly, the experimental setup up to 32 days did not show any symptoms of leaf yellowing (by deficiency of minerals) or attack by microbes or insects, indicating the vigor of BSFL compost liquor.

Other Benefits

The hydroponic method is highly suitable due to overcoming the impacts of soil pollution, deficiency of soil, mineral deficiency, and other harmful effects in farming (Verdonck and Demeyer, 2014). There are several benefits of BSFL compost and its liquor in plant production, plant protection, nutrient management, agricultural innovations, and industrial applications. The effect of BSFL compost liquor appears to be similar to the use of vermiwash. As BSFL compost liquor showed positive results in plant production, it will be suitable to use in desired concentrations in soils deficient of minerals and growth factors. Similar to vermiwash spray used to control thrips (Kaur et al., 2015), BSFL compost liquor could be used as a foliar spray to provide nutrients and to control insect and microbial pests. The presence of bioactive macromolecules in mucus and the secretion of maggots in BSFL compost liquor boost plant production. The liquor also possesses growth factors like enzymes, hormones, amino acids, humic acids, and vitamins to cater to the needs of plants. Similar to the present experiment, BSFL compost liquor may control pests and avoid pathogenic symptoms. The BSFL are also useful in aquaculture, cosmetics, and energy industries (St-Hilaire et al., 2007; Singh and Kumari, 2019; Ravi et al., 2020).

5. CONCLUSION

The present experiments demonstrated the use of BSFL compost liquor as a substitute for vermiwash for plant production as a novel approach. Production of BSFL compost and its liquor by food waste processing is a rapid, affordable, and eco-friendly approach. The BSFL compost liquor substitutes the commercial chemical biostimulants for plant production. This compost liquor at 15% and 20% composition helps to improve the growth and production of cowpea in hydroponics. Possibly, for the foliar spray, a lower concentration is required to supply nutrients and control pathogens. In urban environments, the production of BSFL compost and liquor will be advantageous to transform food waste into valuable BSFL maggots in mini compost units to supply larval frass and dried larvae for various industrial purposes. The BSFL compost liquor obtained by the compost unit will serve as suitable nutrients to grow vegetable crops, flowering plants, indoor decorative plants, and medicinal plants by hydroponics. Such hydroponics could be achieved in limited space by vertical hydroponic systems. Dependence of medicinal plants possessing medicinal principles in root systems is highly valuable through hydroponics and has conservation value as the pressure to uproot naturally grown medicinal plants. If affordable, a mini-production unit could be established in urban areas to utilize food waste tangibly. Besides, establishing a continuous flow system could be followed by the addition and removal of BSFL compost liquor to the hydroponics system, which will further enhance our knowledge of hydroponics. The knowledge gained in household urban and mini production units will pave the way for large-scale hydroponic cultures. Hydroponics will be one of the novel approaches to developing urban agriculture in the future.

Acknowledgements

The authors acknowledge the support of Mangalore University and the Department of Biosciences for laboratory facilities. We are indebted for providing necessary samples by Ramakrishna Math and Ramakrishna Mission, Mangalore, India. The authors are thankful for constrictive suggestions by Dr. S. Mahadevakumar, Scientist, Botanical Survey of India, Port Blair, Andamans, India.

Author contribution

Kodandoor Shrathchandra: Conceptualized the study and carried out partial experiments;
Chavarkad H. Devika: Carried out experiments; Bhagya B. Sharma: Maintained the compost units; Kandikere R. Sridhar: Conceptualized, reviewed, and drafted the manuscript.

Informed consent

Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

Ethical approval & declaration

In this article, the animal regulations followed as per the ethical committee guidelines of Department of Biosciences, Mangalore University, India; the authors assessed of black soldier fly (*Hermetia illucens*) larval compost liquor fed on food waste in cowpeas (*Vigna unguiculata*). The Animal ethical guidelines are followed in the study for species observation, identification & experimentation. Also, the ethical guidelines for plants & plant materials are followed in the study for species collection & experimentation.

Funding

The study has not received any external funding.

Data and materials availability

All data associated with this study are present in the paper.

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