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Corresponding Author
M. Anil Kumar
e-mail: anilmethuku70320@gmail.com

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Insect Frass: A Promising Fertilizer for Sustainable Agriculture

M. Anil Kumar[1*], M. Rajashekhar[2], A. Vaishnavi[3], K. Sahithi[4], K. Bharghavi[2], S. Leela Praveen[1] and Ch. Asritha[2]

Abstract

With the increasing global human population rapidly, there is demand for alternative animal protein sources. Mass breeding of insects for feed and food has emerged as a notable alternative. Byproduct of this process is insect frass (excreta), produced up to 40 times more than the actual insect biomass. Utilizing frass as an organic fertilizer, a viable alternative to chemical fertilizers in sustainable agriculture. The article highlights the merits of insect frass in sustainable agriculture. (1) Frass serves as source of nutrients for the soil, particularly nitrogen, offering easily absorbable elements for plants. (2) The composition of frass includes biomolecules and microorganisms that actively promote plant growth, enhances plants resilience to environmental stresses, bolstering their resistance to diseases and pests.

1. Introduction

Frass is a composition of insect excreta, shed exoskeleton-exuviae and undigested feed material. The name "frass" is derived from a German word meaning "Devour". It is probably a reference to the voracious appetites of problematic insects like grasshoppers and caterpillars.

Insect frass is beneficial for plant growth because it contains important nutrients such as nitrogen, phosphorus and potassium. It also provides micronutrients that can improve soil fertility and act as a soil amendment. Additionally, frass promotes the health of plants by facilitating nutrient absorption through positive microbiological activity. It is a cost-effective option with high nutritional value. Frass contains components like insect exoskeletons, chitin and other biomolecules that enhance plant productivity. When applied to crops, frass can significantly increase resistance to pests and withstand abiotic stresses. Furthermore, the application of frass has positive effects on soil fertility, structure and water retention.

Author's Address

[1]National Institute of Plant Health Management, Rajendranagar, Ministry of Agriculture and Farmers Welfare, Government of India, Hyderabad, Telangana (500 030), India
[2]Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad, Telangana (500 030), India
[3]Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu, Jammu and Kashmir (180 009), India
[4]Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chattisgarh (492 006), India

Chitin and its derivatives may enhance plant growth by increasing the density of beneficial microorganisms in the soil to the detriment of plant pathogens and also involves in synthesis of phytohormones, associative in N fixation, improved mineral uptake and enhance enzyme activity. Plants are engaged in interactions with insects and microbes above and belowground. Aboveground interactions include mutualistic interactions with pollinators and antagonistic interactions with insect herbivores; belowground interactions involve, among others, microorganisms such as fungi and bacteria that can be detrimental or beneficial to the plant (Figure1). Amending soil with mealworm frass resulted in higher densities of beneficial bacteria, such as plant-growth-promoting rhizobacteria (PGPR), can promote plant performance by increasing plant defense against aboveground attackers through the induction of systemic resistance (ISR), which proved to be effective against a wide range of pathogens and insect pests. PGPR can also increase plant tolerance against attackers by improving nutrient and water uptake, enabling faster regrowth of plant biomass after herbivory. PGPR can furthermore stimulate flower abundance and consequently influence plant reproduction.

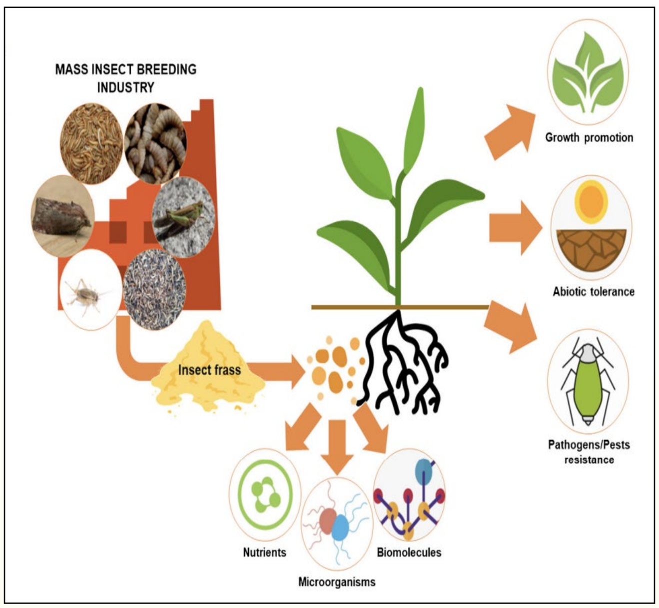

Figure 1: Benefits from insect frass

2. Mass Insect Breeding Industry

In recent years, there has been a growing interest in the utilization of insects for both food and feed, leading to an increase in scientific publications and the establishment of numerous private enterprises dedicated to producing insect-based products. As of April 2019, the global count of companies engaged in the insect food and feed sector, excluding industry organizations and advocacy groups, exceeded to 250 (Van Huis, 2020). An integral aspect of the mass rearing process in these ventures is the generation of frass, the excreta produced by insects, which serves as a significant end product within the system. Consequently, within industrial setups, frass has been recognized not only as an organic fertilizer but also as potential food for other livestock farms (Ortiz et al., 2016). The daily accumulation of frass in such industries, it has been observed that the yellow mealworm (*Tenebrio molitor*), for instance, can consume 220 g of corn and carrots, resulting in an insect biomass production of 4 g and the generation of 180 g of frass and residues, respectively (Wang et al., 2017).

3. Insect Frass as a Source of Nutrients and Compounds of Interest for Plant Growth

The abundance of nutrients found in insect frass has prompted consideration for its potential incorporation into fish feed. For instance, frass derived from the Black Soldier Fly, *Hermetia illucens*, is being explored as a component in the diets of channel catfish (*Ictalurus punctatus*) or hybrid tilapia (*Oreochromis niloticus*×*O. mozambique*) (Yildirim-Aksoy et al., 2020).

As far as plants are concerned, nitrogen often emerges as a limiting factor due to low soil nitrogen levels. Insects play a pivotal role as a crucial nitrogen source for plants, serving as a reservoir integral to the nitrogen cycle in soil. In practical applications, defoliating insects, such as the grasshoppers *Chorthippus curtipennis* and *Melanoplus borealis* that feed on grass, contribute nitrogen-rich droppings, enhancing the nitrogen content available to the plants they consume (Fielding et al., 2013). In a two-year study involving the eucalyptus defoliating beetle *Paropsis atomaria* and the lepidopteran *Doratifera quadriguttata*, frass production ranged between 160 to 270 kg ha^{-1}, depositing 2 to 4 kg ha^{-1} of nitrogen. This increased nitrogen contribution in field settings promotes plant growth and supplements the nitrogen content within plant tissues. However, in certain instances, such as the defoliation caused by the moth *Lymantria monacha* on *Pinus sylvestris*, despite an enhanced availability of soil nitrogen through frass input, trees did not show an increase in nitrogen acquisition. Instead, they allocated resources to defense mechanisms by accumulating amino acids and proteins as a survival strategy (Gherlenda et al., 2016).

Furthermore, nitrogen contributions to the roots can appear in various forms, such as amides. Exploring the circular economy for the conversion of plastics used in agriculture, the *Zophobas morio* beetle was fed with polystyrene, resulting in frass rich in amides. This amide-rich frass proved to be a promoter of plant growth in dragon fruit cacti (*Hylocereus undatus*) plants, enhancing both shoot height and root development. In addition to nitrogen, insect frass returns other essential nutrients to the soil in field conditions. For instance, frass from the defoliation moth *M. americanum* on red oak contributes carbon to the soil, increasing total carbon, total nitrogen and ammonium levels while nurturing microbial activity (Frost and Hunter, 2004). Defoliating insects like the mopane worm (*Imbrasia belina*), when feeding on *Colophospermum mopane* trees, contribute nitrogen, phosphorus and potassium to the savanna ecosystems through their frass. Frass obtained from mealworms, exhibiting an NPK balance of 3-2-2 (g 100 g^{-1}) and an iron content of 140 mg kg^{-1}, demonstrated its capability to promote the growth of chards in pots, increased chlorophyll content, stem length, stem width and fresh weight of the aerial part (Poveda et al., 2019). Moreover, frass from saproxylic-cerambycid larvae of *Chlorophorus annularis*, obtained by feeding on the wood of dead twigs of *Acacia stenophylla*, enriches the soil with sugars, alkaloids and phenols, partly due to the presence of beneficial microorganisms such as the fungus *Trichoderma hamatum*.

4. Insect Frass as a Generator of Tolerance to Abiotic Stress Resistance to Biotic Stresses

The capacity of insect frass to enhance plant tolerance to various abiotic stresses has been described. In the case of bean plants, the application of frass from mealworms resulted in increased seedling tolerance to drought, flooding and salinity. The sterilization of the frass did not diminish its efficacy, pointing to the role of microorganisms within the frass. Numerous bacterial and fungal isolates were identified, showcasing their ability to fix atmospheric nitrogen, solubilize phosphates and potassium and produce siderophores, auxins and 1-amino cyclopropane-1-carboxylic acid

Table 1: Uses of frass from different insects as fertilizer in field

Order	Species	Crop	Benefits	Mechanisms
Diptera	*Hermetia illucens*	Cowpea	Decreased Fusarium wilt disease	Activation of plant defensive responses by chitin presence
Lepidoptera	*Agrotis ipsilon*	Potato	Reduction of oviposition of the insect pest Phthorimaea operculella	Presence of phenols and flavonoids
	Mamestra brassicae	Cabbage	Increased nitrogen content in plant tissues	Plant growth promotion Nitrogen supply to soil
	Ostrinia nubilalis	Maize	Activation of plant defences against pathogens and pests	Presence of eliciting molecules
	Spodoptera frugiperda	Maize	Activation of plant defences against pathogens	
	Paropsis atomaria	Eucalyptus	Plant growth promotion	Nitrogen supply to soil
	Trirhabda virgata	Goldenrod	Plant growth promotion	Nitrogen supply to soil
	Chlorophorus annularis	Lettuce	Increased germination and plant growth	Sugars, alkaloids and phenols supply
	Tenebrio molitor	Chard	Plant growth promotion	Nutrients supply
	Zophobas morio	Dragon fruit cacti	Plant growth promotion	Amides supply to soil
Orthoptera	*Chorthippus curtipennis*	Beans	Plant growth promotion	Nitrogen supply to soil
	Melanoplus borealis	Maize	Plant growth promotion	Nitrogen supply to soil

(ACC) deaminase (Poveda et al., 2019).

In terms of defense against pests and pathogens, the roots' recognition of microorganisms and biomolecules within insect frass may play a role in activating plant systemic resistance through the salicylic acid (SA) and/or jasmonic acid/ethylene (JA/ET) pathways. This defensive mechanism relies on cellular receptors recognizing molecular patterns associated with microorganisms and herbivores, such as chitin (Poveda, 2020).

Insect frass can directly influence pest behavior. Research on potato plants has demonstrated that frass produced by the black cutworm (*Agrotis ipsilon*) contains phenols and flavonoids, leading to a reduction in oviposition by the potato tuber moth (*Phthorimaea operculella*) (Ahmed et al., 2013).

5. Conclusion

Incorporating insect frass as a fertilizer presents an opportunity to reduce dependence on agrochemicals and advance sustainable agriculture. With its abundant nutrients, essential compounds, and beneficial microorganisms, insect frass emerges as a promising alternative to traditional fertilizers and insecticides. Recognizing its potential in large-scale insect rearing, utilizing frass contributes to establishing a circular economy with minimal residues, fostering environmentally friendly crop systems and promoting plant nutrition and health.

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