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SHORT COMMUNICATION

Evaluating black soldier fly frass as a biofertilizer for soybean cultivation in Mwanza, Tanzania

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ABSTRACT

The adoption of sustainable, locally available biofertilizers presents a promising strategy to address soil fertility constraints in Sub-Saharan Africa, particularly for resource-limited smallholder farmers. This study assessed the effectiveness of Black Soldier Fly Frass (BSFF) as a biofertilizer in enhancing the growth and yield of soybean (*Glycine max*) under controlled screen house conditions at MATI-Ukiriguru, Mwanza, Tanzania. A Completely Randomized Design (CRD) was employed with seven treatments, five BSFF application rates (0.2–1.0 kg/pot), a chitosan treatment and a control, each replicated six times. Growth and yield parameters, including germination rate, leaf number, flowering time, pod number, and pod weight, were recorded. While germination and early vegetative growth showed no significant response, BSFF application significantly increased pod number and pod weight. The results demonstrate the potential of BSFF as an environmentally sustainable biofertilizer that enhances soybean productivity and contributes to soil health, thereby supporting long-term agricultural sustainability in low-input systems.

Keywords: black soldier fly frass (BSFF), biofertilizer, *Glycine max*, pod number, pod weight, soil fertility, sustainable agriculture

INTRODUCTION

Soybean (*Glycine max*) plays a vital role in global agriculture due to its high protein content and its capacity to improve soil fertility through nitrogen fixation (Salvagiotti et al., 2008). In Tanzania, the demand for soybeans has increased due to their nutritional benefits and industrial applications, but their production is constrained by declining soil fertility, particularly in sandy and slightly acidic soils with low organic matter (Msita et al., 2020). The overreliance on chemical fertilizers to boost yields has resulted in adverse environmental effects and increased production costs, prompting the need for sustainable and affordable alternatives. Black Soldier Fly Frass (BSFF), a by-product of insect farming, has emerged as a promising biofertilizer due to its rich nutrient composition and microbial content. Studies have shown that BSFF contains essential macro- and micronutrients such as nitrogen (N), phosphorus (P), potassium (K), and beneficial microorganisms that improve soil structure, water retention, and nutrient availability (Lalander et al., 2015; Beesigamukama et al., 2020). Furthermore, BSFF is increasingly being recognized for its potential to replace synthetic fertilizers in organic and low-input agricultural systems (Zhang et al., 2022).

Despite the growing body of literature supporting BSFF as a viable soil amendment, empirical evidence on its application in Sub-Saharan Africa remains scarce. Moreover, its effectiveness in legume crops such as soybean, which have unique nitrogen-fixing properties, is not well documented (Chepkorir, 2024). This study aimed to evaluate the effect of BSFF on soybean growth and yield under controlled screen house conditions in Mwanza, Tanzania. By assessing a range of BSFF application rates and comparing their effects to a chitosan treatment and a control, this research provides insights into the agronomic potential of BSFF and its role in promoting sustainable agriculture for smallholder farmers.

MATERIAL AND METHODS

The study was conducted at MATI-Ukiriguru, an agricultural training institution in Mwanza, Tanzania, situated at 1,236 meters above sea level. The location experiences an average monthly rainfall of 299.16 mm over about 14 rainy days, with daytime temperatures around 25°C and nighttime temperatures near 19°C, and relative humidity of approximately 74%. The soils are mainly sandy to sandy loam, slightly acidic (pH 5.0–6.0), low in fertility and organic matter (TMA, 2022). MATI-Ukiriguru also collaborates with TARI-Ukiriguru on crop research and agricultural extension activities. The laboratory analyses for the study were performed at Sokoine University of Agriculture in Morogoro.

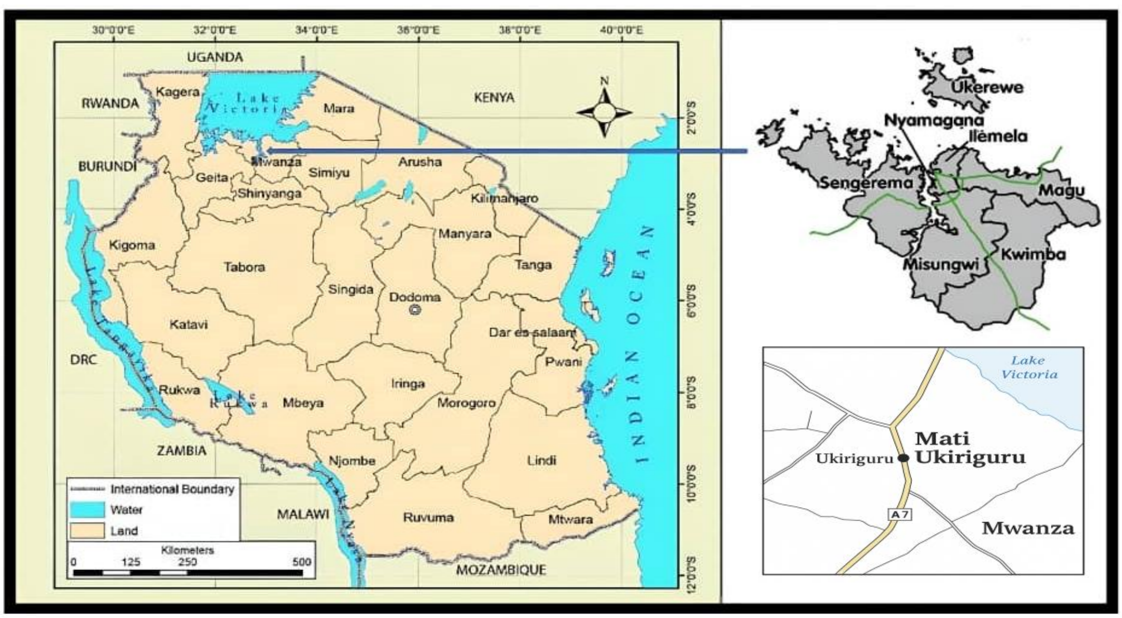

Figure 1. The map shows the experimental site.

The materials used in this study included soybean (*Glycine max*) seeds, Black Soldier Fly Frass (BSFF), a growth medium composed of a 3:1 ratio of forest soil to rice husks, 78 planting containers, irrigation water, 78 collection plates, an irrigation sprayer, two pairs of scissors, two buckets, an electronic weighing balance, a ruler, and basic recording tools such as a notebook and pen. The BSFF was sourced from a BSF production farm located in Kibamba, Dar es Salaam. The experiment was conducted in a screen house environment to minimize external variables such as rainfall, pests, and pathogens, ensuring consistent growth conditions throughout the trial. The Black Soldier Fly Frass (BSFF) was oven-dried at 60 °C overnight to ensure hygienization prior to use.

Forest soil was collected and combined with rice husks in a 3:1 ratio to prepare the growth medium. This mixture was then sterilized using a locally designed heat vessel to eliminate soil-borne pathogens and weed seeds, ensuring experimental integrity. Following sterilization, both the BSFF and the growth medium were measured and incorporated in varying quantities to establish seven treatment groups: Treatment 1 (T1) through Treatment 7 (T7). Each treatment contained a different level of BSFF and was replicated six times. Forty-two sterilized pots filled with a forest soil and rice husk mixture (3:1) were used, with each of the seven treatments replicated six times. Two healthy soybean seeds were sown per pot, and after germination, the more vigorous seedling was retained to maintain consistency. Treatment 7 involved applying a diluted chitosan solution (50 mL in 250 mL water) to the base of the seedlings 14 days after emergence, coinciding with the early vegetative stage for optimal effectiveness. All pots were regularly irrigated, manually weeded, and kept free of synthetic fertilizers or pesticides to prevent confounding effects. Throughout the growth cycle, data were collected on germination rate, shoot and root length, pod development, and final yield parameters such as pod number and weight. The experiment conducted by following Completely Randomized Design (CRD) under controlled screen-house conditions to ensure uniformity and minimize external interference. A total of 42 pots were used to assess the effect of Black Soldier Fly Frass (BSFF) on soybean growth and productivity across seven treatment levels, each replicated six times. The treatments included a control (no treatment), five BSFF application rates ranging from 0.2 kg to 1.0 kg per pot (200 g, 400 g, 600 g, 800 g, and 1000 g), and a chitosan treatment of 50 mL.

Data collection was conducted systematically throughout the soybean growth cycle to evaluate the effects of different treatments on plant performance. During the experiment, key agronomic parameters were recorded at various growth stages. These included seed germination rate, vegetative growth characteristics such as shoot height, number of leaves, and plant biomass, as well as developmental indicators like the number of flowers and the timing of flowering. Yield-related traits, including the number of pods per plant and total pod weight, were also assessed at maturity. This comprehensive data collection allowed for the evaluation of treatment effects on both growth dynamics and productivity of soybean plants.To evaluate the impact of Black Soldier Fly Frass on soybean productivity, the normality of the data was verified using the Shapiro-Wilk test, and the homogeneity of variance was confirmed through Levene's test. One-Way ANOVA and two-sample t-tests were applied to assess differences between treatments. For each parameter, the mean and standard error were calculated, and mean separations between treatments were performed at $P \leq 0.05$ using post-hoc Tukey HSD. All statistical analyses were performed using R statistical software version 4.2.1 (R Core Team, 2022).

RESULTS AND DISCUSSION

The application of Black Soldier Fly Frass (BSFF) significantly enhanced ($P \leq 0.05$) the growth and reproductive performance of soybean plants in a dose-dependent manner, highlighting its potential as a sustainable biofertilizer. Although germination rates did not differ statistically across treatments, the highest values were observed in the 0.6 kg and 1.0 kg BSFF treatments as well as the chitosan treatment, suggesting that moderate to high BSFF levels may promote early seedling vigour. This is consistent with prior findings where organic amendments improved germination through enhanced nutrient availability and soil condition optimization (Parsaeyan et al., 2020; El Hadrami et al., 2010).

Vegetative growth parameters, including leaf number, shoot length, and above-ground biomass, showed significant improvements ($P \leq 0.05$) with increasing BSFF application rates. The 1.0 kg BSFF treatment produced the highest trifoliate leaf count (22.67 leaves), longest shoots (51.02 cm), and greatest biomass accumulation (171.83 g). These enhancements are likely driven by the rich nutrient composition of BSFF, particularly its nitrogen and phosphorus content, which are essential for vegetative development (Lalander et al., 2019). Additionally, BSFF's organic matter and microbial populations may stimulate soil microbial activity, thereby improving nutrient mineralization and uptake (Azeez et al., 2023). The improved shoot elongation and leaf development imply increased photosynthetic capacity, which is crucial for biomass production and subsequent reproductive success.

Root length also increased significantly with BSFF application, with the longest roots recorded at 0.8 kg and 1.0 kg treatments (28.85 cm and 28.68 cm, respectively). Enhanced root growth improves the plant's ability to explore the soil profile for nutrients and water, which is especially beneficial under nutrient-poor or drought-prone conditions (Thakur & Tewari, 2022). The positive influence on root architecture aligns with previous research showing that insect-derived organic fertilizers promote root system development through improved soil structure and beneficial microbial interactions (Lalander et al., 2019).

Reproductive traits, including flowering, pod number, and pod weight, were similarly enhanced by BSFF. Flowering was observed exclusively in the 1.0 kg BSFF treatment, suggesting that higher nutrient availability or possible bioactive compounds within BSFF may accelerate the transition to reproductive growth. This finding aligns with studies reporting that organic fertilizers can influence phenological stages and improve flowering (Singh & Kumar, 2020). Pod number per plant increased significantly with BSFF dose, reaching 73.17 pods at 1.0 kg, compared to only 36.00 pods in the chitosan treatment and 37.50 in the control. This clear dose-response relationship underscores BSFF's role in supporting reproductive development, likely through the provision of phosphorus and potassium nutrients critical for flower and pod formation (Zhao et al., 2019).

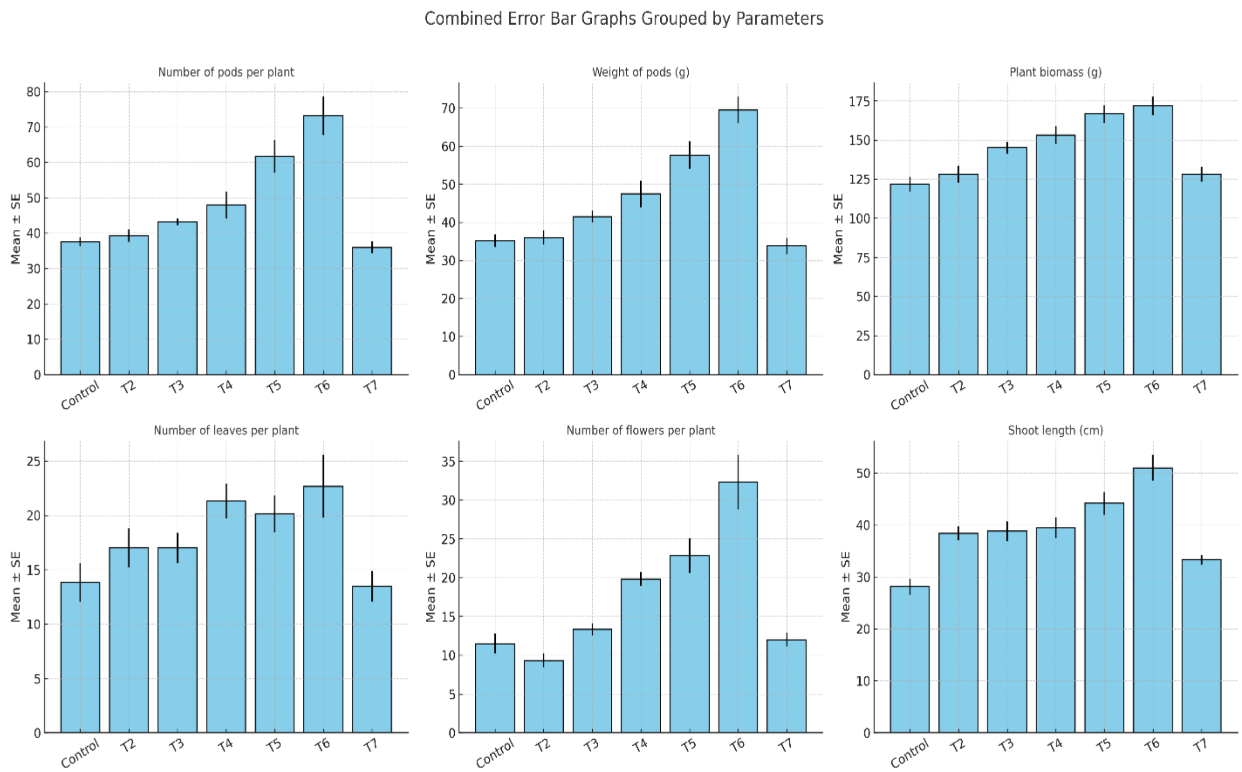

Figure 2. Effect of BSFF and Chitosan on Soybean Development

Similarly, pod weight per plant increased significantly with BSFF treatment, peaking at 69.5 g in the highest application rate. This suggests that BSFF not only promotes a greater number of pods but also improves seed filling and quality, consistent with enhanced nutrient uptake and assimilation (Elghandour et al., 2020). The combination of increased pod number and weight translates into a higher yield potential, demonstrating BSFF's efficacy as a biofertilizer in legume production systems (Kigeso et al., 2024). Overall, the results demonstrate that BSFF enhances both vegetative growth and reproductive output in soybean, with consistent improvements observed at the 1.0 kg application rate. The nutrient-rich profile of BSFF, including essential macronutrients (N, P, K) and micronutrients, combined with its organic matter content and microbial communities, likely contributes to these beneficial effects. The observed stimulation of root and shoot growth, alongside enhanced flowering and pod development, underscores BSFF's multifaceted role in improving plant health and productivity. These findings align with growing evidence that insect frass fertilizers can serve as effective alternatives to synthetic fertilizers, particularly in resource-limited and sustainable agricultural contexts (Lalander et al., 2019; Parsaeyan et al., 2020). The improvement in soybean growth and yield attributes confirms BSFF's potential to improve nutrient cycling and soil fertility while supporting higher crop productivity in low-input systems.

Table 1. Summary of different means and their standard errors

Parameters	Treatment							p-value
	Treatment 1 (Control)	Treatment 2 (0.2kg BSFF)	Treatment 3 (0.4kg BSFF)	Treatment 4 (0.6kg BSFF)	Treatment 5 (0.8kg BSFF)	Treatment 6 (1.0kg BSFF)	Treatment (Chitosan)	
Germination rate	1.83±0.2^{a}	1.67±0.2^{a}	1.83±0.2^{a}	2.00±0.0^{a}	1.67±0.2^{a}	2.00±0.0^{a}	2.00±0.0^{a}	0.388
Number of leaves (20 days)	3.00±0.3^{b}	3.50±0.2^{a}	3.50±0.2^{ab}	3.67±0.4^{ab}	3.67±0.3^{ab}	4.33±0.3^{ab}	3.33±0.2^{ab}	0.11
Number flowers (Flowering)	0.00±0.0^{a}	0.00±0.0^{a}	0.00±0.0^{a}	0.00±0.0^{a}	0.00±0.0^{a}	0.67±0.7^{a}	0.00±0.0^{a}	0.441
Number of leaves per plant	13.83±1.8^{b}	17.00±1.8^{a}	17.00±1.4^{a}	21.33±1.6^{ab}	20.17±1.7^{ab}	22.67±2.9^{ab}	13.50±1.4^{b}	0.006
Number of flowers per plant	11.50±1.3^{c}	9.33±0.9^{c}	13.33±0.8^{ab}	19.83±0.9^{bc}	22.83±2.2^{bc}	32.33±6.5^{e}	12.00±0.9^{c}	0.001
Number of pods per plant	37.50±1.2^{a}	39.33±1.8^{a}	43.17±0.9^{b}	48.00±3.8^{b}	61.67±4.6^{d}	73.17±5.4^{d}	36.00±1.7^{c}	0.001
Weight of pods (g)	35.17±1.6^{a}	36.00±1.9^{a}	41.50±1.5^{ab}	47.50±3.5^{bc}	57.67±3.6^{cd}	69.50±3.5^{d}	33.83±2.1^{e}	0.001
Plant biomass (g)	121.83±4.9^{a}	128.00±5.5^{a}	145.17±3.8^{ab}	153.17±5.8^{ab}	166.83±5.7^{bc}	171.83±5.9^{cd}	128.00±4.6^{d}	0.001
Shoot length (cm)	28.13±1.5^{d}	38.42±1.3^{a}	38.80±1.9^{ab}	39.47±2.0^{ab}	44.17±2.2^{c}	51.01±2.5^{bc}	33.28±0.9c^{d}	0.001
Root length (cm)	23.63±1.4^{a}	23.70±1.6^{a}	24.75±1.7^{a}	25.00±1.7^{a}	28.85±0.9^{c}	28.68±0.9^{c}	22.95±0.8^{a}	0.013

Mean (± SE) percentage values with different superscript letters in the same rows are significantly different at P≤0.05

CONCLUSION

This study demonstrates that Black Soldier Fly Frass (BSFF) can significantly enhance soybean yield performance, particularly by increasing pod number and pod weight. Although early growth parameters such as germination rate, leaf number, and flowering initiation showed no significant differences, the positive trend in yield attributes indicates BSFF's potential as an effective organic fertilizer. Its nutrient-rich composition, including nitrogen, phosphorus, and potassium, supports plant growth beyond the nitrogen fixed by legumes (Pagano & Miransari, 2016). The use of BSFF aligns with sustainable agricultural practices by improving soil fertility and crop productivity while reducing dependence on synthetic inputs. Moreover, its availability as a low-cost, locally produced resource makes it highly suitable for smallholder farmers in Tanzania and similar regions across Sub-Saharan Africa. This research adds to the growing body of evidence promoting insect-based fertilizers as a viable and environmentally responsible alternative in crop production systems.

Recommendation: Furthermore, Future studies should validate the performance of BSFF under field conditions across different agroecological zones in Tanzania to determine its practical scalability. Research should also aim to identify optimal application rates that maximize yield without causing nutrient imbalances or economic inefficiencies. Investigating the co-application of BSFF with nitrogen-fixing inoculants such as *Rhizobium* could offer synergistic effects, enhancing both soil fertility and crop performance (Islam *et al*., 2021). Additionally, comprehensive cost-benefit analyses are needed to assess the long-term economic viability of BSFF compared to conventional fertilizers. Finally, farmer training and extension services will be crucial for ensuring effective and widespread adoption of BSFF.

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Not applicable

AUTHORS CONTRIBUTIONS

I hereby verify that all authors mentioned on the title page have made substantial contributions to the conception and design of the study, have thoroughly reviewed the manuscript, confirm the accuracy and authenticity of the data and its interpretation, and consent to its submission. All the authors equally contributed to this work.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

ETHICAL APPROVAL

Ethical approval for this research, conducted from June 2023 to April 2024, was obtained from the Ethics Review Committee of Jaramogi Oginga Odinga University of Science and Technology (JOOUST). Additional authorization was granted by the Department of Pest Management and Technology Development, Pest Management Centre of Sokoine University of Agriculture; Reference No: DPRTC/R/186 VOL IV.

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AVAILABILITY OF DATA AND MATERIALS

All datasets analyzed and described during the present study are available from the corresponding author upon reasonable request.

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