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The Addition of Black Soldier Fly (*Hermetia illucens*) Frass as Natural Fish Feed Fertilizer

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ABSTRACT

High mortality is the main challenge in fish breeding during the larval–juvenile phase. A common solution has been the use of commercial natural feed products; however, these are often too expensive to be economically feasible. Black soldier fly frass (BSF frass), produced through the bioconversion of household waste, is nutrient-rich, low-cost, and environmentally friendly. It has strong potential as a fertilizer to stimulate the growth of natural feed for aquaculture. This study aimed to analyze the abundance and diversity of natural feed (phytoplankton) following the addition of BSF frass as a fertilizer. The experiment was conducted at the Mandiangin Freshwater Aquaculture Center, Banjar Regency, using a completely randomized design with three fertilizer treatments: A (100% quail excreta), B (50% quail excreta + 50% BSF frass), and C (100% BSF frass). The results showed that BSF frass fertilizer induced phytoplankton growth. Phytoplankton from the phyla Chlorophyta and Chrysophyta were observed in treatments A and C, while treatment B supported the growth of Cyanophyta, Chlorophyta, and Chrysophyta. Phytoplankton abundance in treatment B (50% BSF frass) increased significantly on the 5th day, from 295 cells·L^{-1} to 2,020 cells·L^{-1}. The combined fertilizer of 50% quail excreta and 50% BSF frass promoted a more diverse and abundant phytoplankton community, with a greater variety of species and more even distribution. Thus, the addition of BSF frass fertilizer can enhance phytoplankton growth, providing a natural feed source that is applicable for aquaculture practices.

INTRODUCTION

The larval–juvenile phase is a critical stage in fish farming because, during this period, feeding patterns shift from endogenous to exogenous **(Mawed *et al*., 2022)**, and fish are highly susceptible to disease **(Lobanov *et al*., 2023)**, resulting in high mortality. Effective management strategies to control mortality in this phase include regulating water depth, enriching artificial feeds with antioxidants, and promoting the use of natural feed.

Natural feed (phytoplankton) plays a vital role during this transition, as its abundance is positively related to water fertility **(Raymon, 1980)**, which significantly contributes to fish growth. Enrichment of natural feed in aquaculture is commonly achieved through pond fertilization.

Traditionally, fish farmers have used poultry and ruminant manures to fertilize ponds **(Rapatsa & Moyo, 2013)**. However, the rising costs and limited availability of these manures have created a need for alternative solutions. One promising option is the black soldier fly (BSF) frass fertilizer, produced through the bioconversion of household organic waste by BSF larvae (*Hermetia illucens* L.). This fertilizer is nutrient-rich and environmentally sustainable **(Romano *et al*., 2023; Wu *et al*., 2024)**. BSF frass stands out due to its high protein content **(Weththssinghe *et al*., 2021)** and beneficial components—including amino acids, enzymes, and hormones—that are often absent in conventional organic fertilizers **(Purnamasari *et al*., 2024)**. Its nutrient profile, which includes nitrogen (N), phosphorus (P), potassium (K), and organic carbon (C), enhances soil structure, fertility, and agricultural yields **(Amandanisa & Suryadarma, 2020; Setyorini *et al*., 2020)**. Moreover, BSF frass can be effectively applied using an immersion system, making it suitable for aquaculture.

Research indicates that BSF frass not only increases soil nutrients and promotes plant growth **(Nuryana *et al*., 2019; Triwijayani *et al*., 2023)** but also serves as a potential protein source for poultry **(Purnamasari *et al*., 2024)**, thereby supporting broader agricultural needs. Given its high nutrient content, BSF frass has the potential to stimulate natural feed (phytoplankton) growth, support fish dietary needs, and reduce mortality during the larval–juvenile stage. Consequently, it offers a viable alternative to traditional manure. This innovative approach could enhance sustainability and productivity in fish farming.

MATERIALS AND METHODS

The research was carried out at the Mandiangin Freshwater Aquaculture Center, Banjar Regency, South Kalimantan Province, Indonesia (Fig. 1).

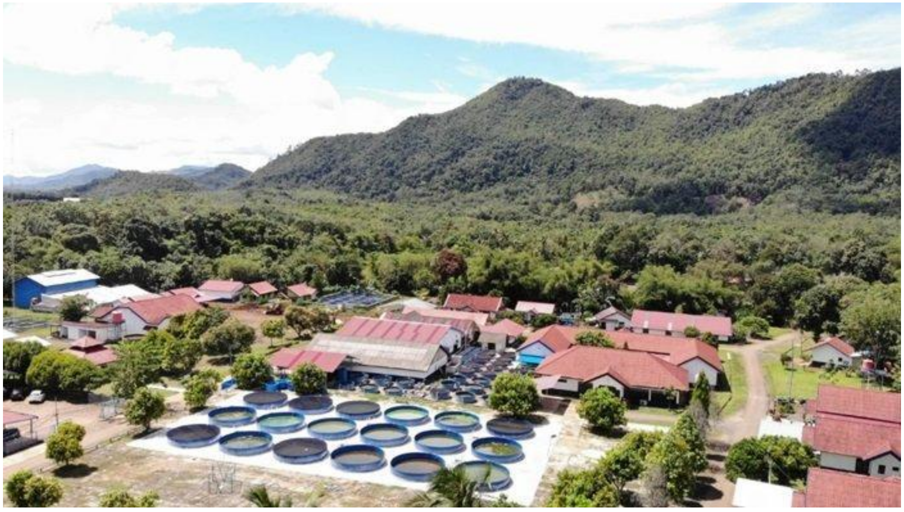

Fig. 1. Location of Mandiangin Freshwater Aquaculture Center in Banjar Regency

1. Experimental set-up

A total of three fertilizer treatments were tested in this study: A (100% quail manure), B (50% quail manure + 50% BSF frass), and C (100% BSF frass), each with three replications. The experimental units consisted of nine aquariums (60 cm × 40 cm × 60 cm) arranged randomly (Fig. 2). The primary response variables measured were the abundance and diversity of phytoplankton genera. A completely randomized design (CRD) was applied, consisting of three treatments with three replicates, to evaluate the effect of BSF frass on the growth of natural feed. The visual characteristics of BSF frass fertilizer are presented in Fig. (3).

Fig. 2. Experimental aquaria layout for fertilizer treatments

Fig. 3. Morphological features of BSF frass organic fertilizer. A. BSF larvae, B. BSF eggs, and C. BSF larvae excreta

The fertilization process was carried out by soaking and dissolving 100g of organic fertilizer in water. The prepared fertilizer was placed in a cloth bag and submerged for five days in an aquarium containing 20cm of water. This procedure, commonly practiced by local fish farmers in Indonesia, is valued for its ability to ensure gradual nutrient release, maintain stable water quality, and stimulate healthy phytoplankton growth. Observations of phytoplankton abundance and diversity were conducted at two time points: before the soaking process and on the fifth day post-soaking.

Plankton sampling was performed using a plankton net with a mesh size of 25µm, equipped with a cod end to retain collected organisms. The sampling procedure and subsequent analyses followed the *Standard Methods for Biological Examination* (SMBE) outlined by the APHA **(Baird & Bridgewater, 2017)**. Identification of plankton taxa was conducted using taxonomic keys from authoritative references, including **Belingger and Sigee (2010)**, **Sheath and Wehr (2014)** and **Komárek *et al.* (2015)**. Taxonomic synonyms and validity were verified against information provided by AlgaeBase **(Guiry, 2014)**.

Plankton community indices were analyzed using parameters such as abundance (N), species diversity index (H), evenness index (E), and dominance index (C). These indices were calculated according to established formulas **(Rahman & Herliwati, 2016)**.

$$N = 1/p \sum_{n=1}^{s} \left(n \, x \frac{a}{c} \, x \frac{1}{v}\right)$$

$$H = \sum_{n=1}^{s} (pi \, x \ln pi)$$

$$E = \frac{\mathrm{H}}{Ln.\, pi}$$

$$C = \sum (ni/N)^2$$

Where N = abundance of planktonic organisms (L); n = number of planktonic (individuals or cells) observed; a = volume of concentrated water (mL); c = volume of water sampled (L); v = volume of filtered water (mL); p = number of observation; Pi = ni/N = the ratio of the number of individuals or cells of a species to the total number of individuals or cells across all species in each sample; s = the total number of individuals or cells of all species.

2. Statistical analysis

Analysis of variance (ANOVA) was used with IBM SPSS Statistics 18 to test for significant differences in plankton abundance among the various fertilizer types. If ANOVA reveals significant differences, then post-hoc tests were conducted to identify which specific treatments differ from one another. This comprehensive approach ensures a clear understanding of how the various fertilizer compositions affect the availability of natural feed in the aquaria.

3. Water quality parameters

Water quality parameters, including amonia nitrogen, pH, temperature, and dissolved oxygen, were monitored daily (07.00 – 07.30 o'clock local time) throughout the experiment. The following instruments were used for daily water quality monitoring:

- Ammonia nitrogen (NH_3-N): Hach DR-3900 Benchtop Spectrophotometer.
- pH: pH meter Lutron PH-222.
- Temperature (∘C): Portable digital thermometer.
- Dissolved Oxygen (DO): DO meter Lutron DO-5510.

RESULTS

The phytoplankton analysis of the water source prior to fertilization identified five taxa belonging to three phyla: Cyanophyta (*Microcystis*), Chlorophyta (*Roya* sp.), and Chrysophyta (*Synedra*, *Diatom*, and *Navicula*). After five days of fertilization, both the abundance and composition of phytoplankton varied across treatments. A quantitative summary of the identified phytoplankton is presented in Table (1).

Table 1. A quantitative analysis of the abundance and diversity of phytoplankton before and after fertilization

Phylum	Genus	Water source before fertilization	Fertilizer Treatments*		
			A	B	C
Cyanophyta	*Microcystis*	60	-	250	-
Chlorophyta	*Scenedesmus*	-	120	270	35
	Roya sp.	80	-	-	70
	Staurastrum	-	45	250	-
	Microspora	-	-	-	80
	Gonatozygon	-	-	215	70
	Pediastrum	-	-	95	-
Chrysophyta	*Synedra*	70	80	-	60
	Diatom	55	-	-	-
	Melosira	-	45	-	-
	Navicula	30	-	290	-
	Nitzschia	-	75	-	80
	Stauroneis	-	-	335	-
	Surirella	-	-	315	-
Number of taxa		5	5	8	6
Abundance (cell.L^{-1})		295	365	2,020	395
Diversity index		1.5147	1.5397	2.0348	1.7611
Evenness index		0.9722	0.9567	0.9785	0.9829
Dominance index		0.2163	0.2287	0.1344	0.1758

* A = 100% quail excreta. B = 50% quail excreta and 50% BSF frass. C = 100% BSF frass.

The results of phytoplankton sample analysis showed that the addition of quail excreta and BSF frass as fertilizers increased both the abundance and diversity of phytoplankton as natural feed. In treatment A (100% quail excreta), phytoplankton were dominated by the phyla Chlorophyta (*Scenedesmus* and *Staurastrum*) and Chrysophyta (*Synedra*, *Melosira*, and *Nitzschia*). In treatment C (100% BSF frass), phytoplankton originated from Chlorophyta (*Scenedesmus*, *Roya*, *Microspora*, and *Gonatozygon*) and Chrysophyta (*Synedra* and *Nitzschia*). Treatment B (50% quail excreta + 50% BSF frass) exhibited the highest abundance and diversity, with representatives from Cyanophyta, Chlorophyta, and Chrysophyta, totaling eight genera (*Microcystis, Scenedesmus, Staurastrum, Gonatozygon, Pediastrum, Navicula, Stauroneis,* and *Surirella*).

These results highlight the positive effects of combined organic fertilizers on the phytoplankton community, underscoring their role in enhancing natural feed availability in aquaculture systems.

1. Number of genera

The number of phytoplankton genera in the mixed fertilizer treatment (B) was higher compared to the single-fertilizer treatments (A and C). Treatment B showed an increase from 5 to 8 genera, while treatments A and C remained relatively stable, with 5–6 genera. Single fertilization (A or C) likely created nutrient imbalances, favoring only certain phytoplankton species and reducing overall species richness. Such conditions may have stressed some genera, while excessive concentrations of particular nutrients could have inhibited growth and survival.

Across all treatments, *Scenedesmus* (Chlorophyta) was consistently present. The dominant genera in each treatment were as follows: *Scenedesmus* (Chlorophyta) in treatment A, *Stauroneis* (Chrysophyta) in treatment B, and *Microspora* (Chlorophyta) in treatment C. The number of phytoplankton genera across fertilizer treatments is illustrated in Figs. (4a, b).

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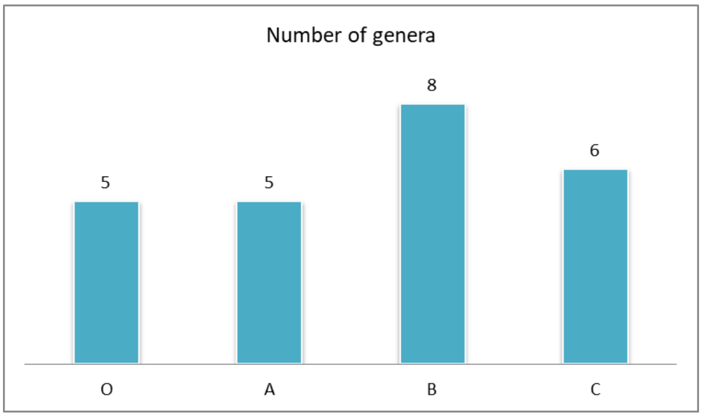

Fig. 4a. The number of phytoplankton genera in various fertilization treatments

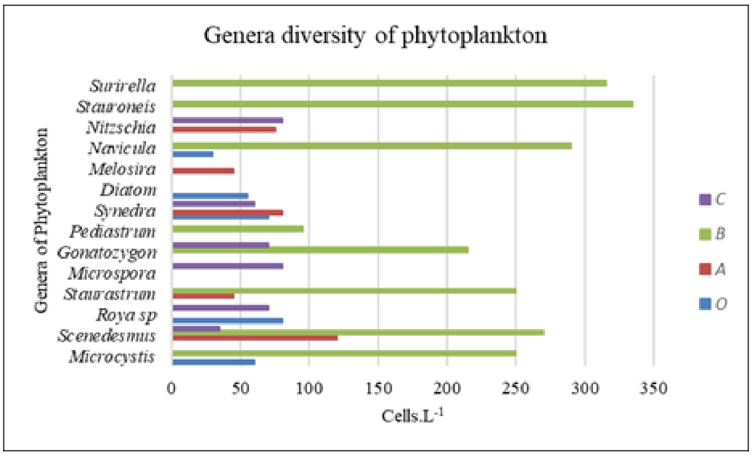

Fig. 4b. The genera of phytoplankton in various fertilization treatments

2. Total abundance

Phytoplankton abundance varied considerably across fertilization treatments. Both single-fertilizer applications (treatments A and C) and the mixed fertilizer (treatment B) increased phytoplankton abundance compared to pre-fertilization conditions. Analysis of variance revealed significant differences between treatments ($P < 0.05$).

The combination of quail excreta and BSF frass in equal proportions (treatment B) was the most effective in stimulating phytoplankton growth, reaching an abundance of 2,020 cells·L^{-1}. In contrast, 100% quail excreta (treatment A) and 100% BSF frass (treatment C) produced moderate abundances of 365 cells·L^{-1} and 395 cells·L^{-1}, respectively. Although these treatments supported phytoplankton growth, they were not as effective as the combined fertilizer. The total abundance of phytoplankton under different fertilization treatments is illustrated in Fig. (5).

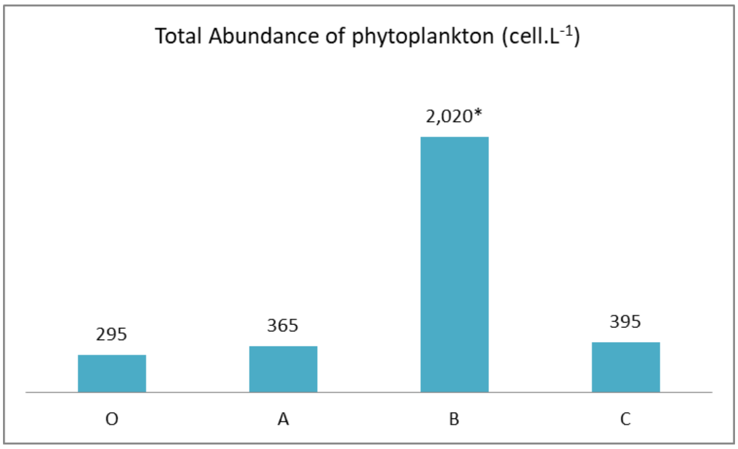

Fig. 5. The total abundance of phytoplankton in various fertilization treatments

3. Diversity index

The phytoplankton diversity index differed significantly among fertilization treatments ($P< 0.05$). The highest value was observed in treatment B, reaching 2.0348. The increase in the diversity index from 1.5147 to 2.0348 reflected a richer and more diverse phytoplankton community, highlighting the positive impact of combined fertilizers on community diversity.

The effectiveness of single fertilizers in supporting phytoplankton diversity was evident in treatment A (100% quail excreta) and treatment C (100% BSF frass). Among these, treatment C (1.7611) exhibited a higher diversity index than treatment A (1.5397). This suggests that the phytoplankton community in treatment C was more diverse, comprising a wider range of species with a more even distribution of relative abundances. In other words, the nutrient composition in treatment C may have provided a more balanced supply of resources, supporting greater species variety.

The diversity index of phytoplankton genera across the different fertilization treatments is presented in Fig. (6).

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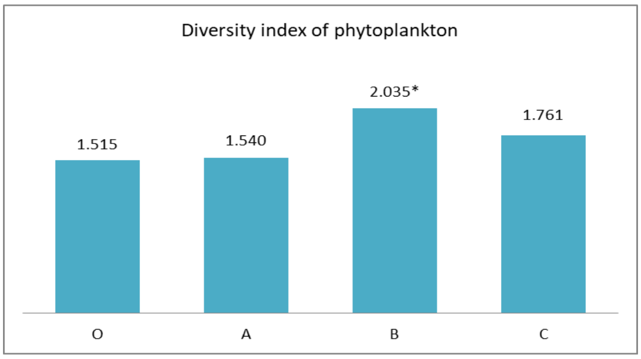

Fig. 6. The diversity index of phytoplankton genera in various fertilization treatments

4. Evenness index

The results of the evenness index calculation showed a narrow range of values (0.9567–0.9829) with no significant differences among fertilizer treatments ($P > 0.05$). The highest evenness index (0.9829) was recorded in treatment C, while the lowest (0.9567) was found in treatment A. Treatment B (0.9785) fell within this range. These results indicate that both single- and combined-fertilizer applications produced similar effects on species evenness, suggesting that nutrient input influenced diversity and abundance more strongly than species distribution.

The evenness index of phytoplankton genera across the different fertilization treatments is shown in Fig. (7).

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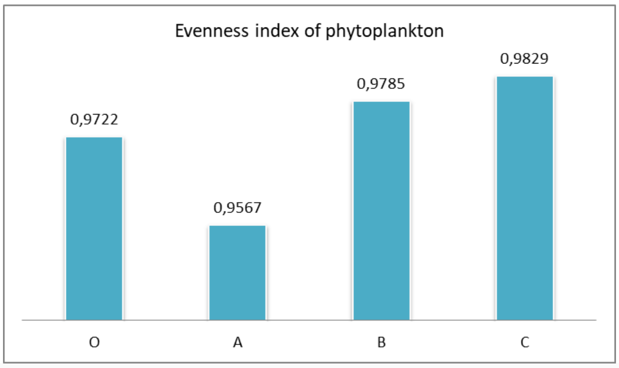

Fig. 7. The evenness index of phytoplankton genera in various fertilization treatments

5. Dominance index

The results of the dominance index calculation showed no significant differences among the fertilizer treatments (*P*> 0.05). Treatment B exhibited the lowest dominance index (0.1344), indicating a more even distribution of phytoplankton species. Treatments A and C had slightly higher dominance index values (0.2287 and 0.1758, respectively), yet both still fell within the category where no single species dominated the community.

The dominance index of phytoplankton genera across the different fertilization treatments is presented in Fig. (8).

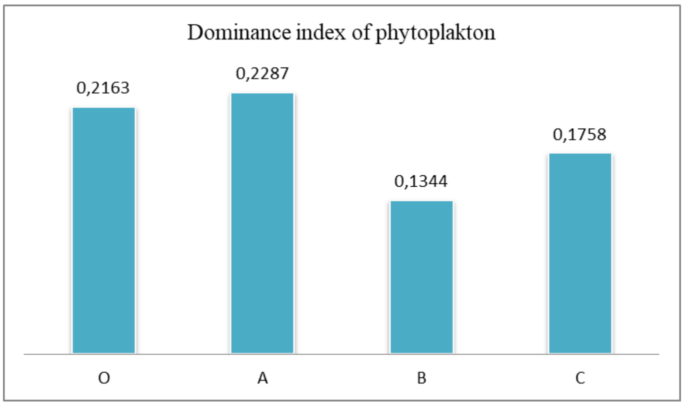

Fig. 8. The dominance index of phytoplankton genera in various fertilization treatments

DISCUSSION

The effectiveness of fertilizers is largely determined by their nutrient composition. In the case of BSF frass fertilizer, nitrogen (N) values range from 1.11% to 2.44% **(Agustin *et al*., 2023)**, indicating its potential to provide substantial nitrogen supplementation—an essential factor for promoting natural feed growth in aquaculture systems. Thus, the nutritional profile of BSF frass represents a valuable resource for enhancing fish farming productivity.

The conversion of organic waste by BSF larvae offers multiple advantages. BSF larvae efficiently transform organic waste into nutrient-rich biomass high in proteins, lipids, and vitamins, making it suitable for animal feed **(Barragan-Fonseca *et al*.,**

2017; Wang & Shelomi, 2017). Their high feed conversion efficiency reduces feed costs, a significant challenge in both agriculture and aquaculture **(Raman *et al.*, 2022)**. Approximately 90% of the total output after larval digestion consists of residual substrate and insect excreta (frass) **(Basri *et al.*, 2022)**. This frass serves as a valuable byproduct that can be used as fertilizer or soil conditioner **(Wang & Shelomi, 2017)**. When dissolved, it stimulates phytoplankton growth **(Akbarurrasyid *et al.*, 2024; Hammadi *et al.*, 2024; Zaghloul *et al.*, 2024)**, offering an eco-friendly solution for waste management while simultaneously improving soil fertility, water quality, and the availability of natural food in aquaculture systems **(Yuliana *et al.*, 2023)**.

BSF frass also provides an alternative to conventional fertilizers, supporting the transition to organic farming **(Manan *et al.*, 2024)**. It has the potential to substitute synthetic nitrogen fertilizers **(Salomone *et al.*, 2017)**, thereby reducing greenhouse gas emissions associated with conventional N fertilizer production and use **(Smetana *et al.*, 2019; Lopes *et al.*, 2024)**. Beyond nitrogen, BSF frass contains additional nutrients and beneficial microorganisms that contribute to phytoplankton health and improve water quality.

The benefits of BSF frass in aquaculture are clear. It is rich in essential nutrients that stimulate the growth of natural feed and support the dietary requirements of fish in early developmental stages. By promoting high-quality natural feed, it can reduce mortality rates in larval and juvenile fish. Its affordability compared to traditional manures enables farmers to optimize production costs while maintaining feed quality. Furthermore, it minimizes environmental impacts by recycling organic waste and reducing reliance on commercial feed inputs. Improved fish growth and survival rates ultimately enhance profitability and yield in aquaculture operations.

The application of BSF frass is therefore a cornerstone of sustainable aquaculture systems. It simultaneously addresses waste management, resource efficiency, and environmental protection. By converting household organic waste into a valuable resource, BSF frass reduces dependence on non-renewable fertilizers, lowers landfill burden, and minimizes the carbon footprint linked to fertilizer production and transport. Moreover, its ability to stimulate natural feed growth reduces reliance on commercial feeds—one of the primary sources of cost and environmental pressure in aquaculture. This contributes to both the economic viability of fish farming and the broader global goals of sustainable food production.

The even distribution of phytoplankton species, as indicated by the evenness index, further demonstrates ecosystem stability, with no species dominating the community. Such balance reflects resilience against environmental fluctuations and supports overall fish health **(Yuliana *et al.*, 2023)**.

Table (2) summarizes the water quality parameters measured throughout the experiment, all of which supported phytoplankton growth. Slightly elevated ammonia levels in treatments B and C (containing BSF frass) compared to treatment A (100% quail excreta) are linked to the higher organic matter content in BSF frass. As this organic matter decomposed, ammonia was released—a common and temporary process during the early fertilization phase. However, the rapid uptake of ammonia by phytoplankton prevented harmful accumulation, as it was efficiently utilized as a nitrogen source. This illustrates the dual role of BSF frass: supplying nutrients while supporting biological processes that maintain water quality.

All treatments maintained pH levels within the optimal range for phytoplankton growth, with treatment A showing the greatest fluctuations. Temperature remained relatively stable across treatments, ensuring favorable conditions. Treatment C exhibited the greatest variation in dissolved oxygen, suggesting more dynamic conditions that may have further supported phytoplankton development.

Table 2. Water quality parameters measured during fertilizer treatments

Parameter	Treatments			Optimal value
	A	B	C	
NH_3-N (mg.L^{-1})	0.18 - 0.20	0.24 - 0.26	0.25 - 0.28	≤ 0.5[1)]
pH	6.50 - 7.70	6.60 - 7.50	6.60 - 7.40	6.5 - 8.0[2)]
Temperature (°C)	27.0 - 28.2	26.8 - 28.3	26.7 - 28.0	24 – 32[3)]
DO (mg.L^{-1})	2.80 - 4.10	3.20 - 4.70	2.80 - 5.80	3.8–6.8[1)]

Note: A = 100% quail excreta; B = 50% quail excreta and 50% BSF frass; C= 100% BSF frass
[1)]**Bhosale and Mugale (2022)**; [2)] **SRAC (1992)** and **Lamtane *et al*. (2017)**; [3)] **Mramba and Kahindi (2023)**.

CONCLUSION

The combined fertilizer of quail excreta and BSF frass in equal proportion promotes a more diverse and abundant phytoplankton population, with a greater variety of species and a more even distribution. This can improve the overall health of aquatic ecosystems and support aquaculture.

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