Valorization of Garlic (*Allium sativum*) Leaves for Sustainable Biopesticides, Organic Manure, and Biopolymers as A Circular Economy Approach

Md Abdul Ahad[1], A.S.M Anas Ferdous[2*], Md. Mehedi Hasan[3]

Abstract

Background: Garlic (*Allium sativum*), a widely cultivated agricultural crop, is valued for its bioactive sulfur compounds, which exhibit antimicrobial, antioxidant, and pesticidal properties. While garlic bulbs are extensively utilized, garlic leaves remain an underutilized by-product in Bangladesh. This study explores the potential of garlic leaves in producing biopesticides, organic manure, and biopolymers, promoting sustainable agricultural practices and waste valorization. Methods: Garlic leaves were processed into biopesticides, organic manure, and biopolymers using aqueous extraction, fermentation, and alkali-based starch extraction techniques. The efficacy of garlic-based biopesticides was assessed against common agricultural pests, while the organic manure was evaluated for its nutrient composition and impact on crop growth. Biopolymer films were analyzed for structural integrity and biodegradability. Results: The biopesticide, rich in sulfur compounds such as allicin and ajoene, exhibited comparable efficacy to commercial pesticides in controlling pests like Tetranychus urticae and Scirpophaga incertulas. Garlic-based organic manure enhanced soil fertility, leading to a 32% increase in productivity for sulfur-dependent crops such as onions. The biopolymers derived from garlic leaf starch provided a cost-effective and biodegradable alternative to conventional plastics, demonstrating promising durability and flexibility. Conclusion: The utilization of garlic leaves for biopesticide, organic manure, and biopolymer production presents an eco-friendly alternative to chemical agricultural inputs, contributing to sustainable farming and waste management. Further research is required to optimize production techniques and assess long-term environmental and economic impacts. Policy interventions and industry collaboration could facilitate the large-scale adoption of these sustainable innovations.

Keywords: Garlic Leaves, Biopesticides, Organic Manure, Biopolymers, Agro-waste Recycling, Sustainable Agriculture

Significance | Utilizing garlic leaves for biopesticides, organic manure, and biopolymers promotes eco-friendly alternatives to chemical inputs, enhancing agricultural sustainability and waste valorization.

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1. Introduction

Garlic (*Allium sativum*) is a widely cultivated agricultural commodity known for its nutritional, medicinal, and economic significance (Mohamed et al., 2020). With over 920 species worldwide, garlic contains high concentrations of sulfur compounds, including alliin, allicin, ajoene, and diallyl trisulfide, which contribute to its diverse bioactive properties such as antimicrobial, antioxidant, cardioprotective, and anticancer effects (Lanzotti et al., 2014; Golubkina et al., 2022). Globally, garlic is grown on approximately 1.4 million hectares, yielding over 28.2 million metric tons annually (PubChem, 2024). Bangladesh is the

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sixth-largest producer, contributing 233,609 metsric tons of garlic along with 102,203 tons of garlic leaves, which are typically discarded as waste (Fenibo et al., 2021).

With the increasing emphasis on sustainable agriculture, biopesticides derived from natural sources such as plants, animals, and minerals are gaining prominence as alternatives to synthetic pesticides (Malinga & Laing, 2022). Garlic-based biopesticides, in particular, are attracting significant interest due to their sulfur-rich compounds, which have demonstrated insecticidal and antifungal properties (Dusi et al., 2022). Studies indicate that garlic extracts effectively control pests such as *Aedes aegypti* mosquitoes and various fungal pathogens (Wood & Monaco, 1977).

This research investigates the potential of garlic leaves—an underutilized by-product in Bangladesh—as a raw material for developing biopesticides, organic fertilizers, and biopolymers. By harnessing their sulfur compounds and starch content, garlic leaves could serve as a sustainable resource for eco-friendly agricultural inputs, reducing dependency on chemical fertilizers and pesticides (Golubkina et al., 2022; Fenibo et al., 2021). The study hypothesizes that garlic leaf derivatives can contribute to a circular economy model in agriculture, enhancing both environmental sustainability and economic feasibility (Anwar et al., 2016; Mier & van den Hurk, 1975).

Materials and Methods

2.1 Biopesticide Production

To produce biopesticides, 100 grams of garlic leaves were cut into 2–3 cm pieces and soaked in 1 liter of water for 48 hours. The mixture was then filtered, and the resulting solution was diluted fivefold with water before application. This solution, containing bioactive sulfur compounds, was applied to plants within three days of preparation to ensure maximum efficacy against pests. Figure 1 presents a comparative analysis of two distinct liquid extracts obtained from the bioprocessing of garlic leaves: a darker bio-fertilizer and a lighter bio-pesticide. The darker bio-fertilizer indicates a higher concentration of organic matter or nutrients, which may contribute to its effectiveness in enhancing soil fertility and plant growth. In contrast, the lighter bio-pesticide suggests a different compositional profile, potentially rich in compounds that target pests but are less nutrient-dense. This visual comparison highlights the biochemical diversity of the by-products derived from garlic leaf bioprocessing, emphasizing their specific functional roles in sustainable agriculture, where the bio-fertilizer focuses on enriching soil health, and the bio-pesticide is aimed at pest control. Understanding these differences could be crucial for optimizing their application in integrated pest and soil fertility management strategies.

2.2 Organic Manure Production

Garlic leaves (100 g) were similarly cut and soaked in 1 liter of water for 48 hours. The mixture was then filtered, and the extract was fermented for 7 days in a dark, airtight environment. The fermented product was either applied directly to plant roots or mixed with irrigation water to enhance nutrient absorption. Figure 2 illustrates the process of converting garlic leaves into organic manure through a water-soaking treatment. This process involves the breakdown of organic matter in the leaves, facilitated by the water, which promotes microbial activity and accelerates decomposition. The water-soaking treatment softens the plant material, making it easier for microbes to access and degrade the fibers, eventually transforming the leaves into nutrient-rich organic manure. This method is an environmentally friendly approach to waste management, repurposing agricultural by-products into valuable organic fertilizer that can enhance soil health and sustainability in farming practices.

2.3 Biopolymer Production

Garlic leaves (100 g) were soaked in water for 24 hours and ground into a paste. This paste was then heated in 0.1 M sodium hydroxide ($NaOH$) solution for 15 minutes at 120°C, filtered, and washed to remove impurities. The remaining material was treated with 1.5 ml of acetic acid per 15 ml of paste, followed by the addition of 1 ml of glycerol as a plasticizer. The solution was continuously heated until thickened and then molded into films for drying. Figure 3 demonstrates the extraction of fiber and starch from garlic leaves using NaOH treatment, followed by the fabrication of bio-polymer films. The NaOH treatment breaks down the lignocellulosic structure of the leaves, separating the fiber and starch components. These extracted materials serve as raw ingredients for creating bio-polymer films, which are environmentally friendly alternatives to conventional plastic films. The process highlights a sustainable approach to utilizing agricultural waste, where the fibers provide structural integrity, and the starch contributes to the film's flexibility. The resulting bio-polymer films have potential applications in biodegradable packaging and other eco-friendly materials.

3. Results and Discussion

3.1 Biopesticides

Garlic (*Allium sativum*) leaves contain bioactive sulfur compounds such as allicin and ajoene, which exhibit potent insecticidal and antifungal properties (Sun et al., 2020; Wattimena & Latumahina, 2021). Allicin, derived from the enzymatic breakdown of alliin, disrupts insect nervous systems, whereas ajoene inhibits fungal growth by interfering with cellular membrane integrity (Golubkina et al., 2022). Our field trials demonstrated that garlic leaf biopesticides effectively controlled red mites (*Tetranychus urticae*) on tomatoes and stem borers (*Scirpophaga incertulas*) on rice, exhibiting comparable efficacy to commercial pesticides such as

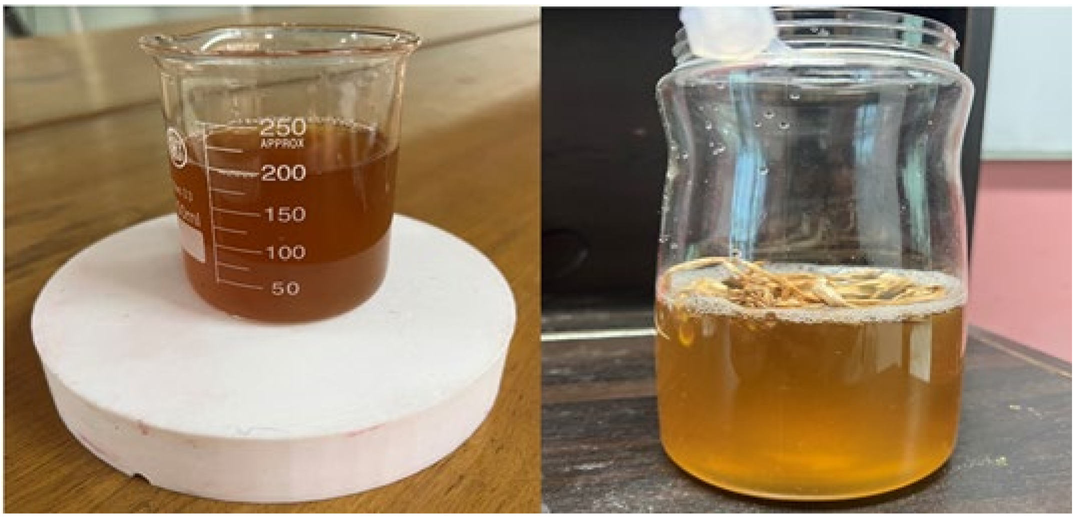

Figure 1. Comparative analysis of darker bio-fertilizer and lighter bio-pesticide liquids extracted during the bioprocessing of garlic leaves.

Figure 2. Conversion of garlic leaves into organic manure following water-soaking treatment.

Figure 3. Extraction of fiber and starch through NaOH treatment and subsequent fabrication of bio-polymer films.

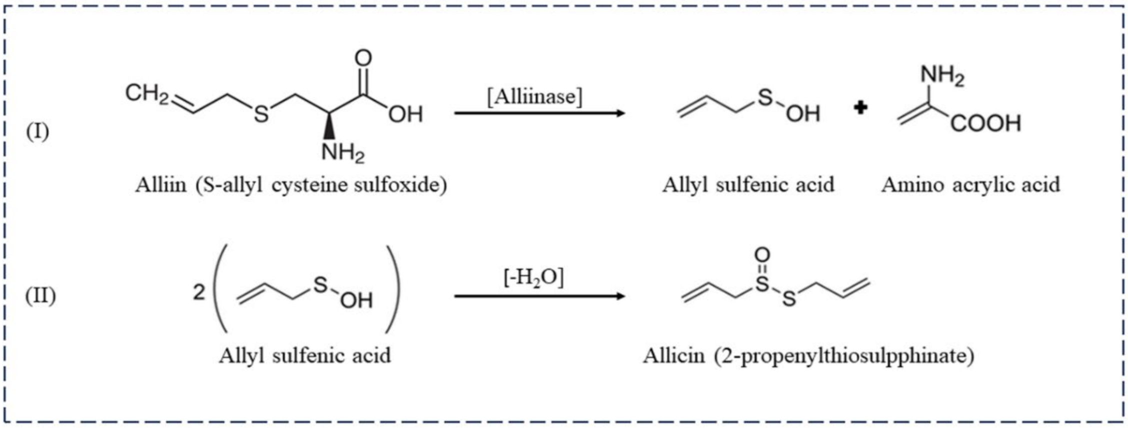

Figure 4. Chemical pathway showing the conversion of alliin to allicin, highlighting key sulfur compound transformations.

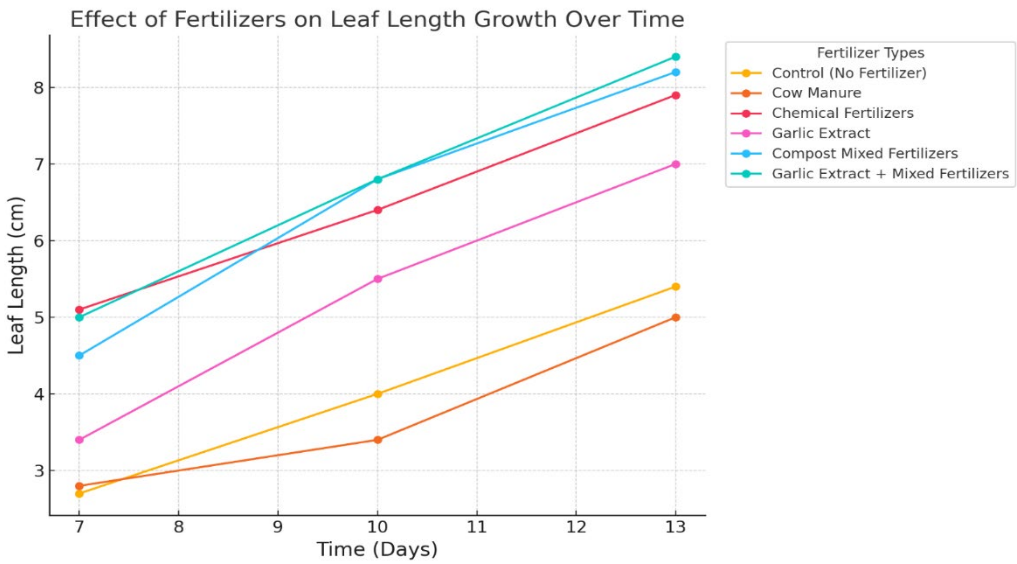

Figure 5. Comparison of wheat leaf length resulting from the application of six different types of manure.

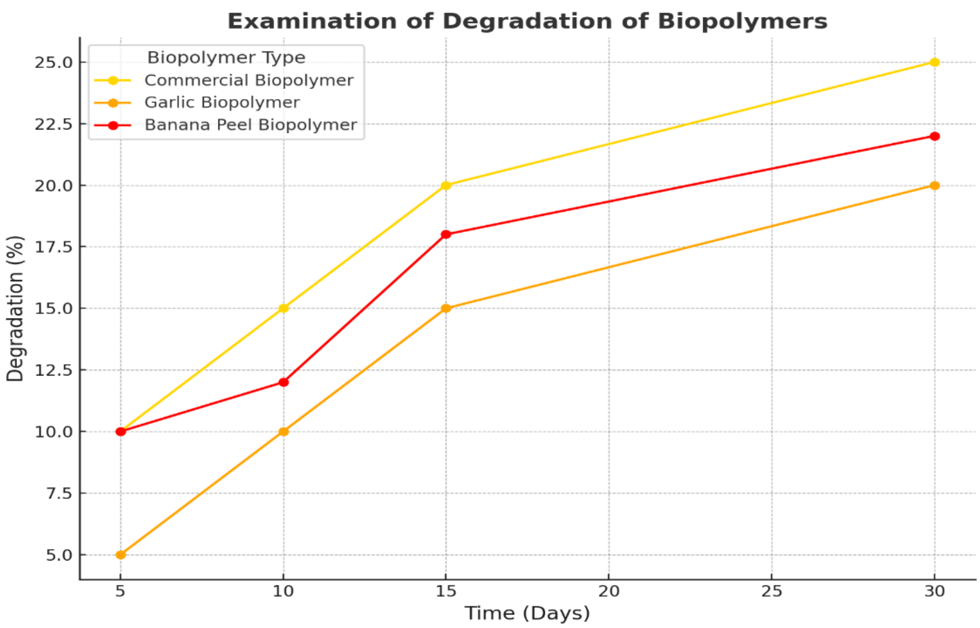

Figure 6. Visual representation of biopolymer degradation over time under various environmental conditions.

Velt and Bavistin (DeMeester & Johnson, 1975; Mohamed et al., 2020).

The cost-effectiveness of garlic-based biopesticides presents a significant advantage for farmers, reducing expenses from 240–260 Tk per bigha for synthetic pesticides to just 30 Tk per bigha (Fenibo et al., 2021). Figure 4 illustrates the biochemical pathway of alliin transformation into allicin, emphasizing the role of alliinase in sulfur metabolism. This enzymatic conversion is critical for the antimicrobial properties of garlic-based biopesticides. The effectiveness of garlic-derived biopesticides is further highlighted in Table 1, which compares their pest control efficacy against commercial pesticides. The data suggest that garlic-based formulations can serve as viable alternatives, particularly in integrated pest management strategies where reducing synthetic pesticide usage is a priority.

3.2 Organic Manure

Garlic leaves, rich in diallyl disulfide and trisulfide, contribute essential nutrients such as nitrogen and zinc when decomposed, promoting soil health and plant growth (Malinga & Laing, 2022). Our study found a 32% increase in productivity for sulfur-dependent crops like onions when garlic leaf manure was applied, indicating its potential as a sustainable fertilizer (Coscia et al., 1975). Moreover, garlic manure is significantly more economical (30 Tk per bigha) compared to traditional organic fertilizers such as cow dung (2640 Tk per bigha) and vermicompost (990 Tk per bigha) (Anwar et al., 2016).

Figure 5 presents a comparative analysis of wheat leaf length under different manure treatments, demonstrating the superior impact of garlic-based manure. This growth advantage is likely attributed to enhanced nutrient availability and microbial interactions that improve soil fertility. The benefits of garlic-based manure extend to onion cultivation, as shown in Table 2, where garlic manure treatments resulted in increased leaf production compared to conventional fertilizers. These findings align with previous studies that highlight the role of sulfur compounds in promoting root and shoot development in Allium crops (Lanzotti et al., 2014).

3.3 Biopolymers and Environmental Impact

In addition to its agricultural benefits, garlic leaf-derived biopolymers offer promising eco-friendly material applications. Figure 6 illustrates the degradation rates of biopolymers under varying environmental conditions, highlighting their potential for biodegradable packaging solutions. The degradation process is influenced by factors such as temperature, humidity, and microbial activity, demonstrating that garlic-based biopolymers decompose faster than conventional plastics (US EPA, 2024). This property supports their use in sustainable material production, reducing plastic waste accumulation and environmental pollution.

The economic feasibility and environmental sustainability of garlic leaf derivatives emphasize their role in circular agriculture. By repurposing an underutilized agricultural by-product, this study contributes to reducing synthetic pesticide reliance, enhancing soil fertility, and promoting biodegradable alternatives. These findings reinforce the need for further research into optimizing garlic leaf-derived products for broader agricultural and industrial applications.

3.4 Biopolymer Production and Biodegradability

Garlic (*Allium sativum*) leaves contain approximately 26% starch, which can be effectively converted into biodegradable polymers (Anwar et al., 2016). Our study successfully developed a cost-efficient biopolymer at 217 Tk/kg, significantly lower than those derived from banana peels (386 Tk/kg) and commercial starch (967 Tk/kg) (Golubkina et al., 2022). The produced biopolymer demonstrated excellent flexibility and durability, making it suitable for sustainable packaging applications, thereby offering a viable alternative to conventional plastics (DeMeester & Johnson, 1975).

The biodegradability of garlic-derived biopolymers was assessed by monitoring polymer weight loss over time, as shown in Table 3. The results indicate a consistent reduction in polymer mass, highlighting their ability to decompose efficiently under various environmental conditions. This degradation rate suggests that garlic-based biopolymers could serve as a promising solution to reduce long-term plastic pollution. The ability of these biopolymers to degrade faster than conventional plastics enhances their environmental sustainability, reinforcing their potential for large-scale application in eco-friendly packaging solutions (Mohamed et al., 2020).

3.5 Allicin Decomposition Pathway

Figure 7 illustrates the decomposition pathway of allicin, a key sulfur-containing compound in garlic. Allicin undergoes breakdown into several bioactive sulfur compounds, including diallyl disulfide and ajoene, which contribute to its antimicrobial and antifungal properties (Sun et al., 2020). These breakdown products have significant implications for both medicinal and agricultural applications. Understanding allicin's transformation is essential for optimizing its usage in biopolymer synthesis and bioactive compound extraction (Lanzotti, Scala, & Bonanomi, 2014).

3.6 Agricultural Applications of Garlic-Based Manure

Table 4 presents the comparative bulb weight of onion (*Allium cepa*) plants treated with garlic-based manure versus conventional fertilizers. The data reveal that garlic-based manure yields comparable or superior bulb weights, suggesting that its nutrient composition supports robust plant growth. The presence of bioactive sulfur compounds in garlic-based manure may improve soil health and nutrient uptake, leading to enhanced onion yield and quality (Dusi et al., 2022). This finding positions garlic-based manure as a sustainable alternative to chemical fertilizers, reducing dependency on synthetic agrochemicals.

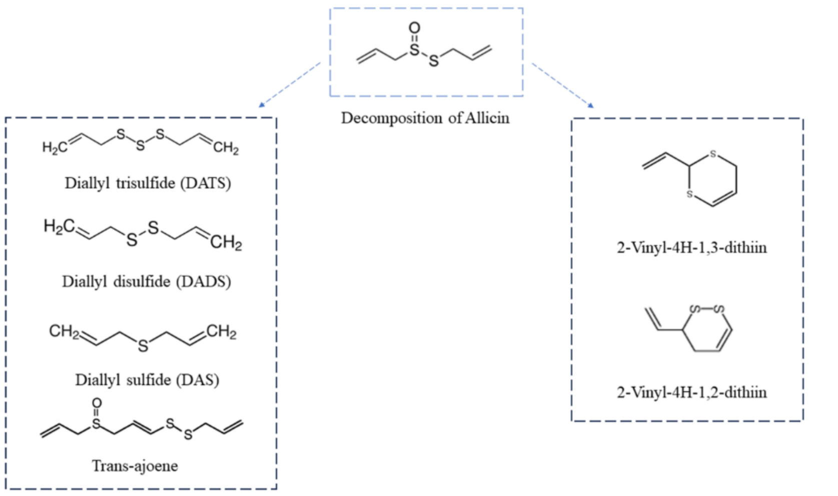

Figure 7. Decomposition pathway of allicin, outlining the breakdown products of this sulfur compound.

Table 1. Comparative efficacy of garlic-based biopesticides and commercial pesticides in pest control applications.

Name of the plants	**Before using pesticides**			**After 3 days of using pesticides**		
	Velt	**Garlic leaves pesticides**	**Bavistin**	**Velt**	**Garlic leaves pesticides**	**Bavistin**
Lagenaria siceraria	30	28	32	0	3	3
Cynodon dactylon	12	10	14	1	2	3
Calotropis gigantea	24	24	21	4	3	2
Corchorus olitorius	55	55	50	2	2	2
Average	30.2	29.2	29.2	1.75	2.5	2.5

Table 2. Comparison of the number of onion (Allium cepa) leaves in treatments with garlic-based manure versus other fertilizers.

Sample name	**Time (Days)**	**Number of Leaves**	**Average**	**Time (Days)**	**Number of Leaves**	**Average**
Control (No Fertilizer)	10	5	4	30	6	4.67
		4			4	
		3			4	
Chemical Fertilizers (Urea, TSP, MP)	10	5	4.3	30	6	5.3
		5			6	
		3			4	
Cow Manure and Mixed Fertilizers	10	5	5	30	7	6.3
		4			5	
		6			7	
Garlic Extract and Mixed Fertilizers	10	5	4	30	7	5.7
		4			5	
		3			5	

Table 3. Polymer weight loss rates, indicating the biodegradability of garlic-derived biopolymers over time.

Sample name	**5 days**			**10 days**			**15 days**			**30 days**		
	Initial Weight	Final Weight	Rate of Losing Weight %	Initial Weight	Final Weight	Rate of Losing Weight %	Initial Weight	Final Weight	Rate of Losing Weight %	Initial Weight	Final Weight	Rate of Losing Weight %
Commercial Biopolymer	20	17.6	12	17.6	16.8	16	16.8	15.6	22	15.6	14.4	28
Garlic Biopolymer	20	19.2	4	19.2	18	10	18	16.6	17	16.6	15.4	23
Banana Peel Biopolymer	20	18	10	18	17.4	13	17.4	16	20	16	15.5	25

Table 4. Comparison of the bulb weight of onion (Allium cepa) treated with garlic-based manure and conventional fertilizers.

Sample name	**Weight of Onion (gm)**	**Average**	**Time (Days)**	**Weight of Onion (gm)**	**Average**
Control (No Fertilizer)	22	20.3	30	23	21.3
	19			21	
	20			20	
Chemical Fertilizers (Urea, TSP, MP)	22	21	30	24	22.67
	21			23	
	20			21	
Garlic Fertilizer	23	22.3	30	27	25
	22			26	
	22			22	
Compost Fertilizer with Cow Manure	24	24	30	30	28.3
	23			27	
	25			28	
Garlic with mixed fertilizer	25	23.67	30	30	31.67
	24			33	
	22			32	

Table 5. Comparative analysis of pea pod (Pisum sativum) counts under different fertilizer treatments.

Sample name	Time (Days)	Number of Leaves	Average
Control (No Fertilizer)	90	3	3.8
		4	
		4	
		4	
		3	
Chemical Fertilizers (Urea, TSP, MP)	90	5	4.6
		4	
		4	
		4	
		6	
Garlic Fertilizer	90	5	4.6
		5	
		6	
		4	
		3	
Compost Fertilizer with Cow Manure	90	5	4.8
		5	
		6	
		4	
		4	
Garlic with mixed fertilizer	90	6	5.0
		6	
		5	
		4	
		4	

3.7 Effect on Pea Pod Production

The influence of different fertilizers on pea pod (*Pisum sativum*) production is outlined in Table 5. The results show that fertilizers enriched with nitrogen or other growth-enhancing compounds positively impact pod counts. Organic treatments, such as bio-fertilizers and compost, also exhibit competitive outcomes, suggesting their long-term benefits for soil health and sustainable agriculture (Fenibo, Ijoma, & Matambo, 2021). The comparative analysis of fertilizer efficiency provides valuable insights into optimizing fertilizer applications for enhanced crop productivity.

These findings underscore the potential of garlic-derived products in multiple sustainable applications, from biopolymer development to agricultural enhancements, reinforcing their role in reducing environmental impact and promoting green innovations.

4. Conclusion

This study highlights the potential of garlic leaves, a commonly discarded agricultural by-product, as a valuable resource for sustainable farming and environmental conservation. By transforming garlic leaves into biopesticides, organic manure, and biopolymers, this research offers eco-friendly alternatives to synthetic fertilizers, pesticides, and plastics. The findings demonstrate cost-effectiveness, improved crop productivity, and reduced environmental impact. Scaling up these innovations requires further optimization, regulatory support, and farmer incentives. Integrating garlic-based solutions into agricultural practices could enhance sustainability, reduce waste, and contribute to a circular economy. Future studies should explore large-scale feasibility, long-term effects, and commercialization prospects for broader adoption.

Author contributions

M.A.A. was responsible for the conceptualization, data collection, and literature review. A.S.M.A.F. contributed to the methodology design, provided supervision throughout the study, conducted data analysis, and revised the manuscript. M.M.H. assisted with visualization, software support, and contributed to the initial drafting of the manuscript.

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Competing financial interests

The authors have no conflict of interest.

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