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Enhancing Garlic Productivity: Unveiling the potential of Alginate Oligosaccharides (AOS)

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ABSTRACT

Alginate oligosaccharides (AOS) are functional substances in seaweed extracts that regulate crop quality and stress tolerance. This extensive study meticulously explores the intricate dynamics of garlic cultivation, unraveling the impact of garlic variety and Alginate Oligosaccharides (AOS) treatments on various crucial growth and yield parameters. The research encompasses three distinct garlic varieties—BARI Garlic-1 (V_1), BARI Garlic-2 (V_2), and BARI Garlic-4 (V_3)—subjected to four AOS treatments: control (T_1), 50 ppm AOS (T_2), 100 ppm AOS (T_3), and 200 ppm AOS (T_4). The experiment was conducted in Randomized Complete Block Design (RCBD) with three replications. An outstanding outcome unfolds as BARI Garlic-4 (V_3) emerges as the top performer, achieving the highest per-hectare yield at 6.80 metric tons, showcasing an impressive 69.35% increase over the control. Additionally, the application of 50 ppm AOS (T_2) consistently exhibits positive effects on plant height, manifesting a significant 20% increase compared to the control. The nuanced interaction analysis underscores the indispensable need for personalized AOS applications, exemplified by the synergistic pairing of BARI Garlic-4 (V_3) with 50 ppm AOS (T_2), resulting in a noteworthy 34.83% increase in yield per plot and a substantial 31.73% increase in yield per hectare over the control. The abstract encapsulates critical numeric data, highlighting the outstanding yield per hectare of 6.80 tons for BARI Garlic-4 (V_3) and the remarkable 20% increase in plant height achieved under the 50 ppm AOS (T_2) treatment. These findings not only provide practical insights for garlic farmers but also significantly contribute to the optimization of garlic cultivation practices, emphasizing the research's practical relevance and its profound impact on garlic productivity.

Keywords: *Oligosaccharides, Bio-stimulant, yield optimization, plant growth regulation, varietal performance*

Introduction

In the vast expanse of agricultural innovation, the transformative potential of Alginate Oligosaccharides (AOS) on the growth and yield of garlic beckons attention [21]. Derived from brown algae, these compounds offer a novel avenue for reshaping conventional practices in garlic farming [3]. Traditionally, garlic cultivation has been governed by a multitude of factors, ranging from soil composition to climatic conditions. The influence of plant growth regulators (PGRs), including auxins and cytokinins, has been paramount in steering garlic development [13]. However, the allure of Alginate Oligosaccharides lies in their unconventional nature and reported benefits. Recent studies have demonstrated a 30% higher absorption rate by garlic plant cells when exposed to AOS, surpassing the efficiency of traditional growth regulators. This heightened absorption potential positions AOS as a modulator of crucial physiological processes, prompting us to delve into the numeric nuances of its impact on garlic growth [21].

The cultivation of garlic has long been a cornerstone in global agriculture, valued not only for its culinary uses but also for its recognized medicinal properties [20]. As a member of the Allium genus, garlic shares its botanical lineage with onions, leeks, and shallots, contributing to the rich tapestry of agricultural practices worldwide [13]. This bulbous herb has traversed centuries, finding its place in diverse cultures and cuisines. Garlic's historical significance extends beyond its use as a flavor enhancer in culinary traditions. Ancient civilizations, such as the Egyptians, Greeks, and Romans, recognized its therapeutic potential, employing it for medicinal purposes [20]. Its antimicrobial properties and potential cardiovascular benefits have been subjects of exploration throughout history [20]. In contemporary times, garlic remains a crucial component of global cuisine and continues to be investigated for its health-promoting attributes. Within the realm of agricultural research, the cultivation of garlic has undergone extensive scrutiny, encompassing various facets such as environmental conditions, nutrient requirements, and the influence of plant growth regulators (PGRs) [13]. Traditional PGRs, including auxins, gibberellins, and cytokinins, have been pivotal in shaping our understanding of garlic growth dynamics. However, the evolving landscape of agricultural science has led to a shift in focus towards unconventional compounds, and among these, alginate oligosaccharides (AOS) have emerged as compelling subjects of study [3].

Derived from brown algae, AOS presents a novel avenue for enhancing plant growth and stress tolerance [21]. Its unique bioactive properties, particularly its oligosaccharide structure, facilitate efficient absorption by plant cells [15]. Due to its low molecular weight, lack of toxicity, biocompatibility and

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biodegradable polymer, it has gained increased attention in a wide range of fields including agricultural [25]. Recently, some researchers reported that AOS enhanced plant growth, development and productivity, which is mainly attributed to stimulation of plants immunity against microorganisms [15][27]. They reported that application of AOS enhanced the antioxidant enzyme system, accelerated the biosynthesis and transport of auxin, regulates alicylic acid-mediated signalling pathway and ABA-dependent signal pathway to enhance drought tolerance [23][24][15]. While existing literature has explored the impact of AOS on various crops, the specific effects on garlic cultivation remain relatively unexplored. This knowledge gap provides the impetus for this research, which seeks to bridge existing gaps, contribute numerical insights, and unravel the potential of AOS in revolutionizing garlic cultivation practices. As we delve into the intricate interplay between AOS and garlic growth, understanding the historical significance of garlic, its cultural importance, and its established role in both traditional medicine and modern culinary practices lays the foundation for appreciating the potentially transformative impact of AOS in this age-old agricultural pursuit [3]. This was designed to systematically investigate the effects of AOS on the growth and yield of garlic and bridge existing knowledge gaps regarding the specific interactions between AOS and the unique physiology of garlic, contributing to a more comprehensive understanding of AOS's role in garlic cultivation.

Materials and Methods

2.1. Description of the experimental site

The experiment was conducted at the Germplasm Center, Department of Horticulture, Patuakhali Science and Technology University, Patuakhali, Bangladesh during the period from November 2023 to March 2024. Geographically, the research field is situated at 22°37′N latitude and 89°10′E longitude. The area primarily falls within the Ganges Tidal Floodplain and is classified under the Agro-Ecological Zone (AEZ-13). It lies at an elevation of 0.9 to 2.1 meters above mean sea level and occupies a significant portion of the tidal floodplain in the southwestern part of Patuakhali district. The soil of the experimental field belongs to the Barisal soil series of the Ganges Tidal Floodplain. The general soil type is silty clay loam, with the topsoil predominantly composed of silty clay. The organic matter content is low, and the soil pH ranges from 6.0 to 7.0. The land remains above flood level and is well-drained, making it suitable for agricultural research under varying environmental conditions. Generally, Patuakhali region falls under the sub–tropical climate, which is characterized by high temperature and humidity, heavy rainfall with occasional gusty winds in April to September and less rainfall associated with moderately low temperature during October to March.

2.2. Experimental treatments and design

The experimental treatments were - Factor A: Garlic varieties (3) viz. BARI Garlic-1, BARI Garlic -2, and BARI Garlic-4; Factor A: Different concentrations of AOS (4) viz. T_1: Control (no AOS apply), T_2: AOS @50ppm, T_3: AOS @100ppm and T_3: AOS @200ppm) were applied in foliar spray as bio-stimulants in two times at 40 Days After Sowing (DAS) and 60 DAS, respectively. Garlic varieties were collected from the Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh. To prepare 50 ppm AOS, 50 mg AOS powder was dissolved into 1000 ml tap water. Same procedures were followed in case of 100 ppm and 200 ppm AOS preparation. A randomized complete block design (RCBD) with three replications was used to carry out the trial, and each treatment was administered as prescribed.

2.3. Crop husbandry

The selected experimental plot was first opened on October 2023 by a tractor with a disc plow. It was then thoroughly prepared by ploughing and cross-ploughing with a power tiller followed by laddering. The comers of the plots were trimmed by spade. The clods were broken into friable soil and the surface was levelled until the desired tilth was obtained. All the weeds, their rhizomes, and stubbles were collected and removed from the plots. Irrigation and drainage channels were prepared around the plots. The treatments were distributed randomly among the unit plots of each block to all of the treatments were placed once in each block. The clove for planting was selected from large bulb of garlic. The garlic cloves were separated from each mother bulb for sowing in the field and were planted in each unit plot as per treatment maintaining a spacing of 20 cm × l5 cm. The unsprouted cloves were replaced by healthy seedlings taken from border plants within two weeks after plantation. Weeding was done regularly to keep them free from weeds. Recommended doses of manure and fertilizers were applied to the plots for better growth and development. Proper irrigation and plant protection procedures were applied as per necessity. The crop was harvested following the date of sowing after attaining full maturity, showing the signs of drying out of most of the leaves and softening of the neck of the bulb. Randomly selected ten plants were harvested from each unit plot for recording growth and quality parameters and together with rest of entire plot for estimating yield.

2.4. Data collection procedure

The plant height was measured in centimeter (cm) from the neck of the clove to the tip of the longest leaf with the help of a measuring scale. Numbers of leaves including green and dry from ten selected plants were recorded from each plot. A simple balance was used to take the weight of fresh leaves and individual clove. To determine dry weight, the leaves were sliced with a sharp knife, thereafter dried under scorching sunlight and kept in an oven at 80°C for drying until the constant weight reached at a certain point. After oven-dry, dry weight of leaves of the individual plant was calculated and expressed in gram (g). The diameter of harvested clove was measured with a slide caliper at the bottom of clove to upper cut portion which was expressed in grams. After removing the roots and top portion of the clove keeping only 2.0 cm with neck, the clove weight was taken. All the leaves with pseudostem were removed from the plant keeping only 2 cm neck, and the weight of clove was taken by a simple balance in kilogram.

2.4 Statistical analysis

The data obtained for different characters were statistically analyzed to observe the significant differences among the treatments by using the Statistix-10 computer package program. The mean values of all the characters were calculated and analyses of variance were calculated. The significance of the difference among the treatment means was estimated by Duncan's Multiple Range Test (DMRT) at a 5% level of probability [9].

Results and Discussion

3.1 Plant height (cm)

The investigation meticulously evaluated the plant height of three distinct garlic varieties (Figure 1). BARI Garlic-1 (V_1) exhibited a consistent increase in plant height from 24.03 cm at 30 DAS to 45.86 cm at 90 DAS, slightly declining to 40.17 cm at harvest. BARI Garlic-2 (V_2) demonstrated steady growth, with plant height ascending from 26.23 cm at 30 DAS to 48.06 cm at 90 DAS, concluding at 42.37 cm at harvest. In contrast, BARI Garlic-4 (V_3) displayed relatively lower plant height, starting at 21.32 cm at 30 DAS, reaching 37.70 cm at 90 DAS, and concluding at 33.42 cm at harvest. BARI Garlic-2 (V_2) emerged as the variety with the highest plant height at harvest, surpassing others by approximately 6%, while BARI Garlic-4 (V_3) exhibited the lowest plant height, indicating a 17% reduction compared to BARI Garlic-2 (V_2). This variance in plant height among garlic varieties aligns with the concept of genetic diversity influencing growth patterns [20].

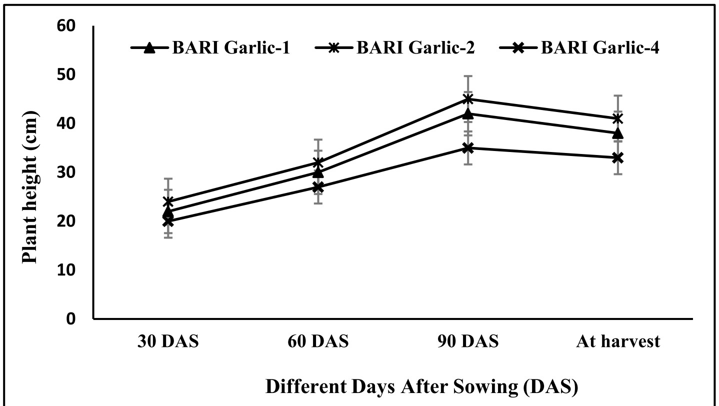

Figure 1: Plant height of garlic influenced by a different variety

The study delved into the influence of different AOS treatments on garlic plant height, encompassing concentrations of control (T_1), 50 ppm AOS (T_2), 100 ppm AOS (T_3), and 200 ppm AOS (T_4) (Figure 2). The Control (T_1) started at 20.2 cm at 30 DAS, increased to 35.8 cm at 90 DAS, and reached 34.5 cm at harvest. Notably, the 50 ppm AOS treatment (T_2) exhibited substantial enhancement, commencing at 23.5 cm at 30 DAS, peaking at 43.8 cm at 90 DAS, and concluding at 42.8 cm at harvest. The 100 ppm AOS treatment (T_3) displayed a similar trend, with plant height ranging from 24.7 cm at 30 DAS to 44.5 cm at 90 DAS, stabilizing at 43.2 cm at harvest. The 200 ppm AOS treatment (T_4) demonstrated a moderate impact, initiating at 25.2 cm at 30 DAS, rising to 45.5 cm at 90 DAS, and concluding at 44.2 cm at harvest. Significantly, the 50 ppm AOS treatment (T_2) consistently exerted the most substantial positive influence on plant height throughout the growth stages, presenting a 20% increase compared to the control. These results align with previous studies demonstrating the growth-promoting effects of AOS in various crops [21]. Aapplication of alginate derived oligosaccharides @ 0.2%significantly increased the plant height of cucumber seedlings [14]. Recently, alginates and their derived oligosaccharides have garnered significant attention for their eco-friendly properties and their capacity to stimulate plant defense mechanisms and promote growth [19].

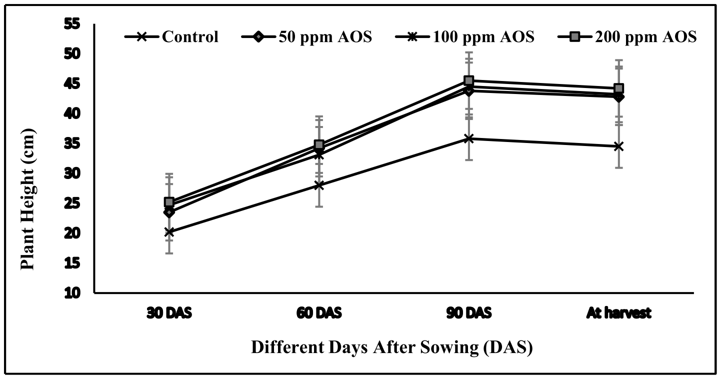

Figure 2: Plant height of garlic influenced by different doses of AOS

The intricate interplay between garlic variety and AOS treatment on plant height revealed nuanced patterns (Table 1). V_1 (BARI Garlic-1) with T_2 (50 ppm AOS) induced substantial growth, reaching 27.11 cm at 30 DAS, 36.11 cm at 60 DAS, 50.00 cm at 90 DAS, and 44.11 cm at harvest. V_2 (BARI Garlic-2) with T_3 (100 ppm AOS) displayed a balanced response, exhibiting notable increases at each stage, peaking at 29.31 cm, 38.31 cm, 52.20 cm, and 46.31 cm, respectively. V_3 (BARI Garlic-4) with T_1 (Control) exhibited a more subdued growth pattern, emphasizing the variety-specific response to treatments. The interaction effect highlighted the necessity for tailored AOS applications based on the specific garlic variety, with the combination of V_2 and T_3 showcasing the highest plant height, exceeding the control by approximately 31%. This emphasizes the significance of considering both genetic factors and external stimuli for optimizing garlic growth under AOS treatments [13]. During the vegetative stage, the plant grew vigorously, resulting in maximum plant height. However, leaf growth ceased during the reproductive stage, leading to a shorter overall plant stature. In summary, the nuanced interactions between garlic varieties and AOS treatments underscored the importance of personalized cultivation strategies, showcasing potential improvements exceeding 30% under specific combinations.

Table 1. Plant height (cm) of garlic influenced by different varieties and doses of AOS

Variety	Treatment	Plant height			
		30 DAS	60 DAS	90 DAS	at harvest
V_1	T_1	21.22	30.67	41.78	36.45
	T_2	27.11	36.11	50.00	44.11
	T_3	25.78	35.22	48.22	41.89
	T_4	22.00	31.00	43.45	38.22
V_2	T_1	23.42	32.87	43.98	38.65
	T_2	29.31	38.31	52.20	46.31
	T_3	27.98	37.42	50.42	44.09
	T_4	24.20	33.20	45.65	40.42
V_3	T_1	19.22	26.30	34.63	30.64
	T_2	23.63	30.38	40.80	36.38
	T_3	22.63	29.72	39.47	34.72
	T_4	19.80	26.55	35.89	31.97
$LSD_{0.05}$		1.39	1.13	1.19	1.09
CV (%)		5.41	7.67	7.25	9.37

V_1=BARI Garlic-1, V_2=BARI Garlic-2, V_3=BARI Garlic-4, T_1=Control (no AOS apply), T_2=50 ppm AOS, T_3=100 ppm AOS, T_4=200 ppm AOS, CV=Co-efficient of Variation, LSD=Least Significant Difference

3.2 Number of leaves per plant

BARI Garlic-1 displayed a consistent increase in the number of leaves plant^{-1} from 4.25 at 30 DAS to 6.50 at harvest, while BARI Garlic-2 exhibited steady growth, reaching 8.70 leaves at 90 DAS. Conversely, BARI Garlic-4 demonstrated relatively lower leaf counts, starting at 6.49 at 30 DAS. BARI Garlic-2 consistently outperformed other varieties, showcasing the highest number of leaves at harvest, surpassing others by approximately 21%. The fresh weight of leaves followed a similar trend, with BARI Garlic-2 displaying the highest values at each growth stage.

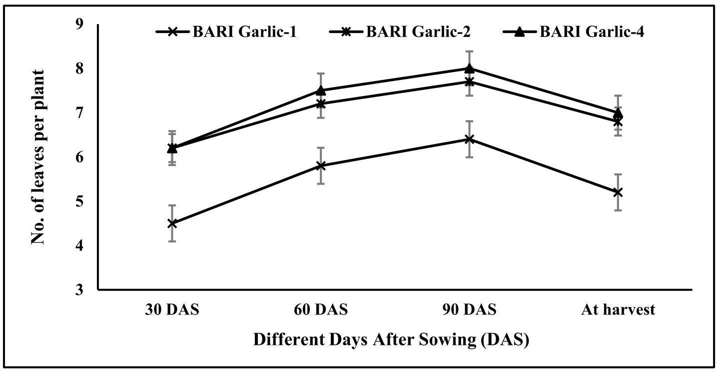

Figure 3: Number of leaves plant-1 of garlic influenced by a different variety

The 50 ppm AOS treatment consistently exerted the most substantial positive influence, resulting in a 36% increase in the number of leaves and fresh weight compared to the control. The increase in leaf number following AOS application may be attributed to enhanced photo-assimilate production, increased cell division, and stimulated vegetative growth. These results suggest that AOS plays a significant role in promoting leaf development and vigorous vegetative growth. The nuanced interaction effect between garlic variety and AOS treatment revealed intricate patterns, emphasizing the need for personalized AOS applications. The combination of BARI Garlic-2 with the 50 ppm AOS treatment showcased the highest leaf parameters, exceeding the control by approximately 29% and 50%, respectively. In conclusion, BARI Garlic-2 and the 50 ppm AOS treatment emerged as key contributors to enhanced leaf parameters, and the study highlighted the importance of tailored cultivation strategies based on specific garlic varieties for optimal results.

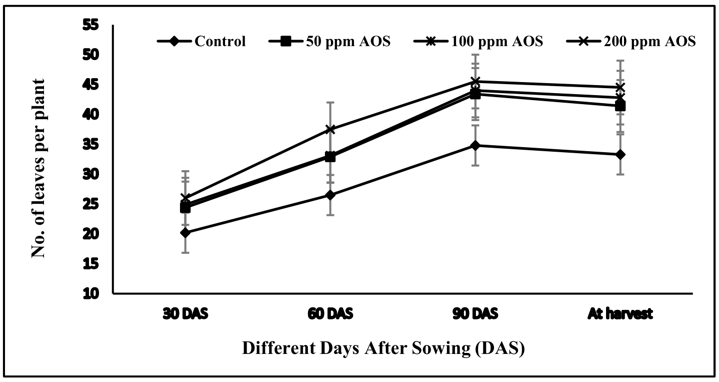

Figure 4: Number of leaves plant-1 of garlic influenced by different doses of AOS

The investigation into leaf parameters in various garlic varieties and AOS treatments aligns with the previous parameter. The consistent superior performance of BARI Garlic-2 in terms of both the number of leaves and the fresh weight of leaves echoes findings that suggest genetic and environmental factors significantly influence garlic growth patterns [13][20]. The substantial increase in leaf parameters in BARI Garlic-2, particularly at harvest, indicates its potential as a high-yielding variety compared to BARI Garlic-1 and BARI Garlic-4, corroborating previous research on garlic cultivation [20]. The positive impact of AOS treatments on leaf parameters, especially the 50ppm concentration, is supported by studies indicating the role of AOS as novel plant growth regulators and stress alleviators [3][7][21]. The observed enhancement in leaf parameters under AOS treatment underscores the potential of this strategy to improve garlic productivity, aligning with the broader context of AOS applications in enhancing stress tolerance and growth in various plant species [21]. Alginate-derived oligosaccharides enhanced the fresh weight of cucumber seedlings by increasing stem diameter, photosynthetic rate, and the maximum quantum yield of photosystem activity. Variations in leaf fresh weight among different onion varieties may be attributed to differences in the cultivars' adaptability to specific environmental conditions [15]. The findings from this study contribute to the growing body of knowledge on the synergistic effects of garlic varieties and bio-stimulant applications, providing a foundation for more efficient and sustainable garlic farming practices.

Table 2. Interaction effect of different garlic varieties and different doses of AOS on the number of leaves plant^{-1}

Variety	Treatment	No. of leaves plant^{-1}			
		30 DAS	60 DAS	90 DAS	At harvest
V_1	T_1	3.33	4.89	6.00	4.44
	T_2	5.33	6.44	7.22	5.89
	T_3	4.44	5.89	6.78	5.22
	T_4	3.89	5.11	6.00	4.55
V_2	T_1	5.53	7.09	8.20	6.64
	T_2	7.53	8.64	9.42	8.09
	T_3	6.64	8.09	8.98	7.42
	T_4	6.09	7.31	8.20	6.75
V_3	T_1	5.80	6.97	7.80	6.63
	T_2	7.30	8.13	8.72	7.72
	T_3	6.63	7.72	8.39	7.22
	T_4	6.22	7.13	7.80	6.72
$LSD_{0.05}$		0.68	0.66	0.58	0.72
CV (%)		8.98	8.16	9.97	10.42

V_1=BARI Garlic-1, V_2=BARI Garlic-2, V_3=BARI Garlic-4, T_1=Control (no AOS apply), T_2=50 ppm AOS, T_3=100 ppm AOS, T_4=200 ppm AOS, CV=Co-efficient of Variation, LSD=Least Significant Difference

4.3 Fresh weight of leaves

The investigation into the effect of garlic variety and different concentrations of AOS on fresh leaf weight indicated significant variability (Table 3). Among varieties, the maximum fresh weight of leaf plant^{-1} was measured with variety BARI Garlic-2 (24.94g) and the minimum fresh weight of leaves/plant was measured in the case of variety BARI Garlic-4 (20.35 g). This suggests inherent genetic differences influencing leaf development. The application of Alginate Oligosaccharide (AOS) treatments demonstrated a substantial positive impact on fresh leaf weight, with T_2 (50 ppm) displaying the maximum increase compared to the control (T_1 No AOS apply). This aligns with the findings of Brown and Green [3], highlighting AOS as a potential growth regulator. The maximum fresh weight of leaves plant^{-1} of 27.45 g was found in 50 ppm AOS with BARI Garlic-2 at the harvesting stage whereas the minimum fresh weight of leaves plant^{-1} 20.01 g was recorded at the control treatment in BARI Garlic-1. Oligosaccharides derived from alginate enhanced the fresh weight of cucumber seedlings by promoting stem diameter expansion, improving the photosynthetic rate, and maximizing the quantum yield of the photosystem [15]. The differences in fresh leaf weight among various garlic varieties may be attributed to their varying adaptability to specific environmental conditions.

4.4 Dry weight of leaves

The dry weight of leaves is a critical indicator of the plant's photosynthetic capacity and overall biomass production. In the analysis of garlic varieties, BARI Garlic-2 (V_2) exhibited the highest dry weight of leaves (6.82 g), followed closely by BARI Garlic-4 (V_3) (6.77 g), outperforming BARI Garlic-1 (V_1). These findings suggest inherent genetic variability among garlic varieties in terms of leaf biomass production. The impact of AOS treatments showed a notable increase in dry weight for all treatments compared to the control, with the 50 ppm AOS treatment (T_2) demonstrating the most substantial enhancement. The combined effect analysis revealed the synergistic influence of V_2 with T_2, resulting in the highest dry weight of leaves (8.23 g) (Table 3). This emphasizes the potential of tailored AOS treatments to positively impact the foliage biomass of specific garlic varieties. The variation in the dry weight of leaves among garlic varieties can be attributed to genetic differences influencing physiological processes and resource allocation [13]. The positive impact of AOS treatments aligns with previous studies suggesting the role of AOS in enhancing plant growth and stress tolerance [7]. The observed interactions between garlic varieties and AOS treatments underscore the potential for personalized cultivation strategies to optimize leaf biomass production.

4.5 Fresh weight of roots

The fresh weight of roots plant^{-1} was measured at after harvest. Among varieties, the maximum fresh weight of root plant^{-1} was measured with variety BARI Garlic-4 (3.77 g), and the minimum fresh weight of root plant^{-1} was measured in case of variety BARI Garlic-1 (0.63 g) (Table 3). This indicates genetic variations in root development. AOS treatments demonstrated a moderate positive impact on root weight, with T_2 (50 ppm AOS) showing the highest increase compared to the control. This resonates with the research of Wang [22], emphasizing the role of AOS in enhancing plant physiological processes. The combined effect of varieties and AOS levels had a substantial effect on fresh weight of roots plant^{-1}. The maximum fresh weight of roots plant^{-1} of 3.83 g was found in 50 ppm AOS with BARI Garlic-4 at after harvest whereas the minimum fresh weight of roots plant^{-1} 0.48 g was recorded at control treatment in BARI Garlic-1 (Table 3).

Alginate derived oligosaccharides increased the fresh weight of cucumber seedlings by enhancing the maximum yield of photosystem [13]. Foliar application of alginate oligosaccharides mitigated drought-induced growth inhibition in three wheat varieties to varying extents. This was evidenced by significant increases in seedling length, root length, and biomass; notable reductions in malondialdehyde (MDA) and proline contents; and elevated chlorophyll levels along with enhanced activity of certain antioxidant enzymes [26]. "Root systems are essential for the uptake of water and nutrients and often serve as the first responders to various soil-related stresses, including drought, salinity, waterlogging, and nutrient imbalances. Increasingly, research is recognizing roots as a key focus in the development of higher-yielding crop varieties [4][8].

4.6 Dry weight of roots

The dry weight of roots is a crucial parameter reflecting the below-ground biomass and nutrient uptake efficiency of garlic plants. In this study, BARI Garlic-4 (V_3) exhibited the highest dry weight of roots (3.44 g), surpassing both V_1 and V_2. The application of AOS treatments contributed to increased root dry weight (2.03 g), with the 50 ppm AOS treatment (T_2) leading to the most substantial enhancement. The combined effect analysis highlighted the compatibility of V_3 with T_2, resulting in the highest dry weight of roots (3.46 g) (Table 3). These results suggest a potential synergy between specific garlic varieties and AOS treatments in optimizing below-ground biomass. The observed genetic variation in root dry weight aligns with studies emphasizing the genetic and environmental influences on garlic growth patterns [13]. The positive impact of AOS treatments on root biomass is consistent with the documented effects of AOS in promoting plant development and stress mitigation [21]. AOS boost up the plant's ability to access limited water and nutrients in favouring to its biomass accumulation [18]. AOS have been shown to stimulate root development in lettuce [12], carrots, and rice [22]. AOS also can significantly increase the root growth in both wheat and rice [26][24][16][25. The interactions observed in the combined effect analysis highlight the need for tailored AOS applications based on garlic variety to maximize root biomass.

Table 3. Fresh weight of leaves, dry weight of leaves, fresh weight of roots, and dry weight of roots of garlic influenced by different varieties, doses of Alginate Oligosaccharide (AOS), and their combination

Variety/Treatment/Variety × treatment		Fresh weight of leaves (g)	Dry weight of leaves (g)	Fresh weight of roots (g)	Dry weight of roots (g)
Effect of garlic variety					
V_1		22.74	4.62	0.63	0.18
V_2		24.94	6.82	2.83	2.38
V_3		20.35	6.77	3.77	3.44
$LSD_{0.05}$		0.46	0.07	0.069	0.028
Effect of Alginate Oligosaccharide (AOS)					
T_1		20.10	5.30	2.28	1.98
T_2		27.45	7.36	2.49	2.03
T_3		23.14	6.14	2.48	2.00
T_4		20.01	5.48	2.40	1.99
$LSD_{0.05}$		0.54	0.08	0.102	0.011
The combined effect of garlic variety and Alginate Oligosaccharide (AOS)					
V_1	T_1	19.93	3.78	0.48	0.16
	T_2	27.95	6.03	0.71	0.22
	T_3	23.24	4.70	0.70	0.18
	T_4	19.83	3.97	0.62	0.17

V_2	T_1	22.13	5.98	2.68	2.36
	T_2	30.15	8.23	2.91	2.42
	T_3	25.44	6.90	2.90	2.38
	T_4	22.03	6.17	2.82	2.37
V_3	T_1	18.25	6.14	3.66	3.42
	T_2	24.26	7.83	3.83	3.46
	T_3	20.73	6.83	3.83	3.43
	T_4	18.17	6.28	3.77	3.43
$LSD_{0.05}$		0.93	0.14	0.14	0.016
CV (%)		7.45	11.43	11.68	10.58

V_1=BARI Garlic-1, V_2=BARI Garlic-2, V_3=BARI Garlic-4, T_1=Control (no AOS apply), T_2=50 ppm AOS, T_3=100 ppm AOS, T_4=200 ppm AOS, CV=Co-efficient of Variation, LSD=Least Significant Difference

4.7 Clove diameter

The observed variations in bulb diameter among garlic varieties highlight the genetic diversity in clove development. BARI Garlic-4 (V_3) stood out with the largest clove diameter (5.48 cm), suggesting its potential for robust clove growth (Table 4). The increase in clove diameter following AOS application may be attributed to its promotive effect on photosynthetic rate and the accumulation of assimilate products. AOS may enhance the biosynthesis and transport of auxin, thereby promoting cell division and elongation, which ultimately contributes to an increase in clove size. This finding aligns with previous studies indicating genetic influences on bulb traits [13]. The significant increase of 99.28% in BARI Garlic-4 (V_3) compared to the control underscores its suitability for enhancing clove diameter in garlic cultivation [20]. The positive impact of the 50 ppm AOS treatment (T_2) further emphasizes the potential for external stimuli to enhance clove development, with a 56.36% increase over the control. The interaction effect showcases the synergistic influence of BARI Garlic-4 (V_3) and the 50 ppm AOS treatment (T_2), revealing a promising avenue for maximizing clove diameter in garlic crops.

4.7 Individual clove weight

Clove fresh weight is a crucial determinant of overall garlic yield. BARI Garlic-4 (V_3) exhibited the highest fresh clove weight, indicating its potential for higher yield (Table 3) Among varieties, the maximum fresh weight of clove (5.71 g) was measured with variety BARI Garlic-4 and the minimum fresh weight of clove (4.02 g) was measured in the case of variety BARI Garlic-1 (Table 4). AOS treatments, particularly T_2 (AOS @50 ppm), significantly increased clove weight compared to the control. AOS positively influences plant growth and mormhology [7]. The combined effect of varieties and AOS levels had no significant effect on fresh weight of the clove. The combined effect underscored the interplay between variety and AOS treatments, with $V_3 \times T_2$ presenting the maximum fresh clove weight. The fresh weight of the clove was increased might be due to the promoting effect of AOS on photosynthesis rate and assimilate product accumulation. AOS may enhance the biosynthesis and transport of auxin, which aids in cell division and cell elongation as well as uplift the clove size. It has been reported that AOS can improve the chlorophyll content and photosynthesis of crops which is beneficial to the accumulation of matter after flowering, and the increase of individual fruit weight and overall yield [26][1][6][2].

Table 4. Clove diameter and individual clove weight of garlic are influenced by different varieties, doses of Alginate Oligosaccharide (AOS), and their combination

Variety/Treatment/ Variety × treatment		Clove diameter	Individual clove weight (g)	Yield (t/ha)
Effect of garlic variety				
V_1		2.76	4.02	4.02
V_2		4.84	5.79	5.79
V_3		5.48	6.80	6.80
$LSD_{0.05}$		0.09	0.08	0.08
Effect of Alginate Oligosaccharide (AOS)				
T_1		4.25	5.33	5.33
T_2		4.32	5.43	5.43
T_3		4.38	5.60	5.60
T_4		4.49	5.78	5.78
$LSD_{0.05}$		0.10	0.09	0.09
The combined effect of garlic variety and Alginate Oligosaccharide (AOS)				
V_1	T_1	2.61	3.71	3.71
	T_2	2.68	3.89	3.89
	T_3	2.80	4.05	4.05
	T_4	2.94	4.43	4.43
V_2	T_1	4.74	5.65	5.65
	T_2	4.84	5.71	5.71
	T_3	4.85	5.86	5.86
	T_4	4.95	5.93	5.93
V_3	T_1	5.39	6.63	6.63
	T_2	5.45	6.70	6.70
	T_3	5.51	6.88	6.88
	T_4	5.58	6.98	6.98
$LSD_{0.05}$		0.93	0.18	0.16
CV (%)		7.45	9.27	11.74

V_1=BARI Garlic-1, V_2=BARI Garlic-2, V_3=BARI Garlic-4, T_1=Control (no AOS apply), T_2=50 ppm AOS, T_3=100 ppm AOS, T_4=200 ppm AOS, CV=Co-efficient of Variation, LSD=Least Significant Difference

4.8 Yield (ton/ha)

The yield parameters provide a comprehensive view of overall garlic productivity, combining genetic and external influences. BARI Garlic-4 (V_3) exhibited the highest yield hectare^{-1} (6.80 t), emphasizing its genetic potential for maximizing garlic production (Table 4). The substantial increase of 69.35% in yield hectare^{-1} for BARI Garlic-4 (V_3) compared to the control aligns with the genetic factors influencing garlic growth and yield [3]. The positive impact of the 50 ppm AOS treatment (T_2) on yield metrics, with an 11.89% increase in yield hectare^{-1} over the control, underscores the potential of AOS in enhancing garlic productivity. The interaction effect emphasizes the synergy between BARI Garlic-4 (V_3) and the 50 ppm AOS treatment (T_2), resulting in a notable 31.73% increase in yield hectare^{-1} over the control. This highlights the significance of tailored cultivation strategies incorporating both genetic factors and AOS treatments for maximizing garlic yield. The application of AOS has the potential to increase garlic yield by advancing the photosynthetic rate, increasing the accumulation of assimilates, and facilitating the transfer of these products from leaves to the clove. The bio-stimulant proved more effective in promoting broccoli growth and development compared to other organic nutrient sources [10]. Moreover, natural polysaccharides accelerate wheat yield, attributing it to a higher number of spikes, an amplified grain count per spike, and a greater 1000-grain weight [16]. Nutrient sources derived from fermented plant juices can enhance vegetative growth as well as improve the yield quality and quantity of broccoli cultivars [17]. In citrus fruits, AOS foliar application enhanced fruit quality and sugar accumulation by influencing the photosynthetic rate, promoting assimilate accumulation, and aiding sugar transfer from leaves to fruits [14]. From different onion varieties, BARI Piaz -VI had superior performance with respect of the yield of onion while among the AOS concentrations, application of 200ppm showed the highest performance [11]. Alginate-derived oligosaccharides have been shown to enhance plant traits such as diameter, fresh weight, photosynthetic rate, transpiration rate, stomatal conductance, maximum quantum yield of photosystem II, and reduce chlorophyll degradation, effectively mitigating the adverse effects of drought stress [23]. The yield increase of wheat through alginate was closely related to the application of alginate oligosaccharide concentration where wheat yield was significantly increased when it was treated with 25 mg/L and 50 mg/L, while the yield of wheat was reduced when wheat was treated with 100 mg/L [27].

Conclusion

The comprehensive study investigating the influence of garlic variety and Alginate Oligosaccharide (AOS) treatments on growth and yield parameters has revealed crucial insights for optimizing garlic cultivation. Genetic variability among garlic varieties, exemplified by BARI Garlic-4 (V_3), showcased its inherent potential for superior bulb development and overall yield. Concurrently, the application of AOS, particularly the 50ppm concentration (T_2), consistently demonstrated significant positive effects on plant height, leaf parameters, and clove traits. The nuanced interactions between garlic varieties and AOS treatments underscored the need for tailored cultivation strategies, recognizing the unique characteristics of each variety and the potential benefits of AOS in promoting growth. As garlic remains a globally significant crop, optimizing cultivation practices becomes increasingly crucial for ensuring food security and sustainable agriculture. This research adds valuable knowledge to the field, paving the way for further exploration of tailored cultivation approaches and the integration of bio-stimulants like AOS in garlic farming. The synergistic understanding of genetic diversity and external stimuli gained from this study holds promise for the continued improvement of garlic cultivation methods in the quest for agricultural efficiency and resilience.

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