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Effect of biofertilizers and biostimulants on growth, flowering and yield attributes of okra (*Abelmoschus esculentus* L. Moench)

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Abstract

The present investigation entitled “Effect of biofertilizers and biostimulants on growth, flowering and yield attributes of okra” was undertaken to evaluate the comparative effectiveness of different combinations of biofertilizers and biostimulants on crop growth, phenological development, reproductive behaviour and yield performance. The study comprised 21 treatment combinations involving Azotobacter, phosphate-solubilizing bacteria (PSB), potassium-solubilizing bacteria (KSB), seaweed extract and humic acid, along with an untreated control. The treatments included individual and combined applications of biofertilizers with seaweed extract and humic acid at 2 and 4 per cent concentrations. The experiment was evaluated during two consecutive years, and the data were subjected to pooled analysis to determine the consistency of treatment effects across seasons. The application of biofertilizers and biostimulants significantly influenced the phenological and reproductive development of the crop. The integrated treatments generally performed better than the simpler biofertilizer combinations, demonstrating the advantage of combining complementary microbial inoculants with biostimulant inputs. Among all the treatments, T₂₁, comprising Azotobacter + PSB + KSB + humic acid 4%, consistently recorded the most favourable response for the major phenological and reproductive parameters. T₂₁ recorded the minimum number of days to first flower appearance, with 32.60, 30.40 and 31.50 days during the first year, second year and pooled analysis, respectively, compared with 43.37, 41.34 and 42.36 days under the control. Similarly, the minimum days to 50 per cent flowering were recorded under T₂₁, with pooled value of 34.31 days compared with 47.31 days in the control. The treatment also produced the highest number of flowers per plant, recording 14.26, 13.02 and 13.64 flowers plant⁻¹ in the first year, second year and pooled analysis, respectively, whereas the control produced only 7.63, 6.39 and 7.01 flowers plant⁻¹. The integrated treatment also accelerated harvesting. T₂₁ recorded the earliest first picking, requiring 41.30, 40.48 and 40.89 days during the first year, second year and pooled analysis, respectively, while the control required 51.37, 49.55 and 50.46 days. The improvement in phenological development was subsequently reflected in the major yield attributes. T₂₁ recorded the highest number of fruits per plant, with 19.15, 18.01 and 18.58 fruits plant⁻¹, compared with 6.92, 6.22 and 6.57 fruits plant⁻¹ under the control. The pooled average fruit weight was also highest under T₂₁ (16.45 g), compared with 8.53 g under the control. Likewise, T₂₁ recorded the maximum number of seeds per fruit, with a pooled value of 41.68 compared with 28.30 under the control. The cumulative improvement in yield components resulted in the highest fruit yield per plant under T₂₁. The treatment recorded 396.97, 392.91 and 394.94 g plant⁻¹ in the first year, second year and pooled analysis, respectively, compared with 291.07, 287.01 and 289.04 g plant⁻¹ under the control, indicating that the complete biofertilizer consortium combined with humic acid was particularly effective in enhancing crop productivity.

Keyword: Biofertilizers, biostimulants, azotobacter, PSB, KSB, humic acid

Introduction

Okra (*Abelmoschus esculentus* (L.) Moench) is an important vegetable crop belonging to the family Malvaceae and possessing a chromosome number of 2n = 130. It is predominantly cultivated in tropical and subtropical regions and is believed to have originated in Tropical Africa. The crop is commonly known as bhindi or lady's finger and is valued for its tender, immature fruits, which are widely consumed as a vegetable. In addition to its nutritional importance, okra possesses medicinal and industrial significance, making it an important component of vegetable-

based agricultural production systems (Gaikwad *et al.*, 2021)^[6]. The productivity of okra is influenced by several interacting factors, including seed quality, nutrient availability, environmental conditions and plant physiological processes. Therefore, sustainable approaches capable of improving nutrient-use efficiency and plant growth are increasingly important for enhancing productivity without excessive dependence on conventional chemical inputs. These limitations have stimulated interest in alternative and complementary nutrient-management strategies that can improve crop productivity while maintaining soil fertility and biological activity (Tyagi *et al.*, 2016). Consequently, the integration of biological inputs and plant biostimulants has emerged as a promising component of sustainable crop production^[18].

Biofertilizers contain beneficial microorganisms that, when applied to seed, soil or plants, contribute to nutrient availability and plant growth through various biological processes. Nitrogen-fixing microorganisms can contribute biologically available nitrogen, while phosphate-solubilizing microorganisms improve the availability of otherwise less-soluble phosphorus compounds. Potassium-solubilizing microorganisms similarly contribute to the release of potassium from relatively unavailable sources. In addition to nutrient mobilization, beneficial microorganisms may produce growth-promoting substances and vitamins and can contribute to the suppression of certain soil-borne pathogens through antagonistic interactions (Nayak *et al.*, 2019; Sharma *et al.*, 2024). The presence of nitrogen-fixing, phosphate-mobilizing and other beneficial microorganisms can therefore improve the availability and utilization of plant nutrients and strengthen the biological functioning of the soil environment (Singh *et al.*, 2018)^[13, 16, 17].

Among the important biofertilizers, *Azotobacter*, phosphate-solubilizing bacteria (PSB) and potassium-solubilizing bacteria (KSB) perform complementary functions in plant nutrition. *Azotobacter* is associated with biological nitrogen contribution, whereas PSB and KSB facilitate the mobilization of phosphorus and potassium, respectively. Their combined application may therefore provide a broader nutritional benefit than the use of an individual microbial inoculant. Such integration is particularly relevant in vegetable crops such as okra, where rapid vegetative growth followed by continuous flowering and fruit development creates a substantial demand for nutrients throughout the growing season. The complementary activities of these microorganisms may improve nutrient acquisition and subsequently support plant growth, reproductive development and yield formation.

Biostimulants represent another important approach for improving crop performance. They are materials or substances capable of stimulating natural plant processes and improving crop growth, physiological efficiency, quality and productivity. Their beneficial effects may involve improved photosynthetic activity, nutrient acquisition, stress tolerance and translocation of photoassimilates towards developing plant organs. Thus, biostimulants may complement conventional nutrient-management practices by improving the efficiency with which plants utilize available resources rather than simply supplying nutrients directly. Among different biostimulant groups, seaweed extracts and humic substances have received considerable attention because of their potential influence on root development, nutrient uptake, physiological activity, flowering and yield.

Seaweed extract is a biologically active material containing a range of compounds that can stimulate plant growth and improve crop performance. Previous studies have demonstrated beneficial effects of seaweed-derived preparations on growth and yield in

different crops. Abdel *et al.* (2010) reported improved growth and yield responses in watermelon following seaweed extract application, while Koyama *et al.* (2012) observed increased tomato yield following repeated seaweed extract application. Sundharaiya *et al.* (2016) recorded significant improvements in growth, bulb attributes and yield of multiplier onion with seaweed extract, whereas Fatma *et al.* (2018) reported improvements in growth, physiological characteristics and tuber attributes of potato. Murtic *et al.* (2018) further demonstrated that seaweed extract could improve adaptability, yield and quality of cherry tomato under both normal and drought conditions. Nabti *et al.* (2016) highlighted the broader potential of seaweed-based biofertilizers in promoting plant growth and improving nutrient and water uptake^[4, 9, 11, 12].

Humic acid is another important biostimulant that can influence plant growth by improving the growing environment and supporting nutrient acquisition and utilization. Humic substances have been associated with improved root and shoot development, nutrient availability, plant growth and yield. Yildirim *et al.* (2007) reported positive effects of humic acid on fruit diameter, fruit length, fruit weight, number of fruits per plant and early yield in tomato. Kirn *et al.* (2010) observed a significant increase in crop yield following the application of potassium humate with recommended fertilizers. In okra, Gad *et al.* (2015) reported significant effects of humic acid on growth and yield, while Aboohanah (2016), Haider *et al.* (2017) and Pasha *et al.* (2021) also documented favourable responses in growth, root development, flowering and other crop attributes. These findings indicate that humic substances can serve as valuable components of integrated nutrient and biostimulant management^[2, 5, 7, 8, 15, 19].

Materials and Methods: The materials and the methods adopted during the course of present investigation entitled “Effect of biofertilizers and bio-stimulants on growth flowering and yield attributes of okra (*Abelmoschus esculentus* L.)” which was carried out during the year 2022-23 and 2023-24 under the climatic condition of Gwalior. The experiment was carried out in horticulture research farm of the College of Agriculture, R.V.S.K.V.V. Gwalior, situated in Grid zone at the latitude of 26° 13'N and longitude 76° 10'E with an altitude of 197 meters from mean sea level (MSL). The soil of the experimental field was alluvial, sandy clay loam in texture and classified as typic us ochrepts at sub group level. Planting of okra variety Pusa Bhindi - 5 was done in summer season with spacing of 45 cm row to row and 30 cm plant to plant in 21 plots, which replicated three times in Randomized Block Design. All the biofertilizer applied through foliar spray @ 2ml/lit. of water after 25 days of sowing. Bio-stimulants (Sea weed extract & Humic acid) used through foliar spray @ 2% & 4% after 30 days of sowing. The data on days to first flower appearance, days to 50% flowering, number of flowers per plant, days to first picking were recorded during the crop session. While data of number of fruits per plant, fruit yield per plant (g), number of seed per fruit were recorded at the time of harvesting.

Results and Discussion

Growth Parameters

Days to first flower appearance

A thorough study of the result presented in table 2 reveals that all the treatment combinations comprising of different biofertilizers and bio-stimulants exerted significant impact in the reduction of days to first flowering. The minimum days to first flowering during first year, second year and pooled data was observed in treatment combination T₂₁ (*Azotobacter*+ PSB + KSB + Humic acid 4%) i.e. 32.60, 30.40 and 31.50 (days). It was followed by

treatment T₁₇ (*Azotobacter*+ PSB + KSB+ Humic acid 2%) in the first year, found at par with treatment T₁₇, T₁₃ and T₉ in the second year and pooled data. While the maximum number days to first

flower appearance was recorded in T₁ (control) i.e. 43.37, 41.34 and 42.36 (days) during the first year, second year and pooled data.

Table 1: Details of treatment

T ₁	Control
T ₂	<i>Azotobacter</i> + PSB
T ₃	<i>Azotobacter</i> + KSB
T ₄	PSB + KSB
T ₅	<i>Azotobacter</i> + PSB + KSB
T ₆	<i>Azotobacter</i> + PSB + Sea weed extract 2%
T ₇	<i>Azotobacter</i> + KSB + Sea weed extract 2%
T ₈	PSB + KSB + Sea weed extract 2%
T ₉	<i>Azotobacter</i> + PSB + KSB + Sea weed extract 2%
T ₁₀	<i>Azotobacter</i> + PSB + Sea weed extract 4%
T ₁₁	<i>Azotobacter</i> + KSB + Sea weed extract 4%
T ₁₂	PSB + KSB + Sea weed extract 4%
T ₁₃	<i>Azotobacter</i> + PSB + KSB + Sea weed extract 4%
T ₁₄	<i>Azotobacter</i> + PSB + Humic acid 2%
T ₁₅	<i>Azotobacter</i> + KSB + Humic acid 2%
T ₁₆	PSB + KSB + Humic acid 2%
T ₁₇	<i>Azotobacter</i> + PSB + KSB + Humic acid 2%
T ₁₈	<i>Azotobacter</i> + PSB + Humic acid 4%
T ₁₉	<i>Azotobacter</i> + KSB + Humic acid 4%
T ₂₀	PSB + KSB + Humic acid 4%
T ₂₁	<i>Azotobacter</i> + PSB + KSB + Humic acid 4%

The advancement of flowering under the integrated treatments may be attributed to improved nutritional and physiological conditions of the plants. *Azotobacter*, PSB and KSB provide complementary functions associated with biological nitrogen contribution and mobilization of otherwise less-available phosphorus and potassium, thereby potentially improving the nutritional status of the crop. Humic acid may have further enhanced the effectiveness of the rhizosphere environment and nutrient acquisition processes. The resulting improvement in nutrient availability and plant growth could facilitate an earlier transition from vegetative to reproductive development. The beneficial influence of humic substances on plant growth and reproductive performance is consistent with the observations of Yildirim *et al.* (2007), who reported improvement in fruit number, fruit size, fruit weight and early yield in tomato following humic acid application. Dursun *et al.* (2013) similarly reported enhanced vegetative development under humic acid application, while Aboohanah (2016), Haider *et al.* (2017) and Pasha *et al.* (2021) reported favourable effects of humic acid on growth and flowering-related characteristics in okra [2, 3, 7, 15, 19].

Days to 50 % flowering

A critical analysis of the data presented in table 2 shows that all the treatment combinations comprising of different biofertilizers and bio-stimulants exerted prominent effect in the reduction of days to 50% flowering. The minimum days to 50% flowering during first year, second year and pooled data was observed in treatment combination T₂₁ (*Azotobacter*+ PSB + KSB + Humic acid 4%) i.e. 35.21, 33.41 and 34.31 (days). It was followed by treatment T₁₇ (*Azotobacter*+ PSB + KSB+ Humic acid 2%) in the first year, found at par with treatment T₁₇, T₁₃ and T₉ in the second year and pooled data. While the maximum number days to 50% flowering was recorded in T₁ (control) i.e. 48.30, 46.32 and 47.31 (days) during the first year, second year and pooled data.

The reduction in days to 50 per cent flowering indicates that the integrated treatments did not merely initiate flowering earlier but also promoted relatively rapid progression of the crop towards the main flowering phase. This may be important for synchronizing

reproductive development and extending the effective period available for fruit formation and harvest. The beneficial role of seaweed extract in promoting crop development has also been documented by Abdel *et al.* (2010), who reported improved growth and yield responses in watermelon following application of *Ascomyllum nodosum* extract. Koyama *et al.* (2012) observed increased tomato yield following seaweed extract application, while Sundharaiya *et al.* (2016) recorded significant improvement in growth and yield components of multiplier onion with 2 per cent seaweed extract. Nabti *et al.* (2016) described seaweed-based products as biostimulants capable of supporting plant growth, root and shoot development, nutrient and water uptake and plant adaptation. Thus, the relatively early flowering observed under treatments containing seaweed extract can be viewed within the broader context of enhanced plant physiological performance under biostimulant application [9, 12].

Number of flowers per plant

Through the critical analysis of the data presented in table 3 it was found that maximum number of flowers per plant was recorded in treatment combination T₂₁ (*Azotobacter*+ PSB + KSB + Humic acid 4%) i.e. 14.26, 13.02 and 13.64. It was also found at par with treatment T₁₇ and T₉. While the minimum number of flowers per plant was reported in T₁ (control) i.e. 7.63, 6.39 and 7.01 during the first year, second year and pooled data.

The increase in flower production is particularly relevant because it increases the potential reproductive sink and consequently provides greater opportunity for fruit formation. The higher flower production under T₂₁ may have resulted from improved plant nutritional status and enhanced physiological activity resulting from the complementary action of the three biofertilizers and humic acid. Humic substances are generally associated with improved nutrient availability and root activity, whereas microbial inoculants can contribute to nutrient acquisition through their respective functional activities. The present findings are in accordance with Haider *et al.* (2017), who reported earlier flowering and improved crop growth under humic acid application in okra. Pasha *et al.* (2021) also reported

improvements in plant height, leaf production, branching, leaf area and chlorophyll under humic acid application and suggested that improved soil fertility, nutrient and water availability and nutrient uptake could contribute to enhanced plant growth. These observations support the interpretation that improved reproductive development in the present study was associated with a more favourable plant nutritional and physiological environment [7, 15].

Days to first picking

Through the study of the data presented in table 3 it was found that all the treatment combinations of different biofertilizers and bio-stimulants imposed significant impact in the reduction of days to first picking. The minimum days to first picking during first year, second year and pooled data was observed in treatment combination T₂₁ (*Azotobacter*+ PSB + KSB + Humic acid 4%) i.e. 41.30, 40.48 and 40.89 (days). It was found at par with treatment T₁₃ and T₁₀ in the first year, second year and pooled data. While the maximum number days to first picking was recorded in T₁ (control) i.e. 51.37, 49.55 and 50.46 (days) during the first year, second year and pooled data. The reduction in days to first picking indicates that the integrated treatments accelerated not only flower initiation but also the subsequent progression from flowering to harvestable fruit development. From a production perspective, early harvest can be advantageous because it permits earlier realization of yield and may provide a longer effective harvesting period under favourable crop conditions.

Yield parameters

Number of fruits per plant: The data presented in table 4 shows that treatment combination T₂₁ (*Azotobacter*+ PSB + KSB + Humic acid 4%) exerted most prominent effect on the number of fruits per plant with 19.15, 18.01 and 18.58. It was followed by treatment T₁₇. Whereas, minimum number of fruits per plant was observed in T₁ (control) i.e. 6.92, 6.22 and 6.57 during the first year, second year and pooled data.

The present findings are in agreement with Yildirim *et al.* (2007) [19], who reported that humic acid application positively influenced fruit diameter, fruit length, fruit weight, number of fruits per plant and early yield in tomato. Their findings provide direct support for the role of humic substances in improving fruit production. Similarly, Abdel *et al.* (2010) reported enhanced growth and yield responses in watermelon following the application of *Ascophyllum nodosum* seaweed extract. Koyama *et al.* (2012) [9] also observed an increase in tomato yield following repeated application of seaweed extract, although fruit characteristics were not altered. These observations indicate that biostimulants may influence productivity through improvement in overall plant performance rather than necessarily altering every individual fruit characteristic. The present results are further supported by Sundharaiya *et al.* (2016), who recorded significant improvement in plant growth, bulb characteristics and yield of multiplier onion with 2% seaweed extract. Meena *et al.* (2017) [10] likewise reported significant improvement in fruit number and other yield-related characteristics of cucumber with the application of humic acid and micronutrients. Thus, the present increase in fruit number under T₂₁ is consistent with the broader evidence that humic substances and seaweed-derived biostimulants can positively influence reproductive performance and yield formation.

Average fruit weight (g): Through the analysis of the data presented in table 4 it was observed that maximum average fruit

weight was recorded in treatment combination T₂₁ (*Azotobacter*+ PSB + KSB + Humic acid 4%) i.e. 16.97, 15.93 and 16.45 (g). It was followed by treatment T₁₇. While the minimum average fruit weight was reported in T₁ (control) i.e. 9.01, 8.05 and 8.53 (g) during the first year, second year and pooled data.

The increase in average fruit weight under T₂₁ may be associated with improved nutrient acquisition and utilization resulting from the combined activity of the biofertilizers. PSB and KSB may have contributed to improved phosphorus and potassium availability, respectively, while *Azotobacter* may have contributed to biological nitrogen enrichment. Humic acid may additionally have enhanced the efficiency of nutrient availability and utilization. The combined influence of these factors could have promoted greater assimilate production and translocation towards developing fruits, thereby increasing fruit weight. The present findings are corroborated by Yildirim *et al.* (2007) [19], who reported positive effects of humic acid application on fruit weight and other fruit characteristics in tomato. Meena *et al.* (2017) also reported significant improvement in fruit weight along with other fruit characteristics in cucumber following the application of humic acid and micronutrients. These findings are consistent with the present observation that humic acid-containing treatments, particularly the complete microbial consortium combined with 4% humic acid, produced heavier fruits. The beneficial role of humic substances is also supported by Kim *et al.* (2010), who reported a significant increase in yield following the application of potassium humate along with recommended fertilizers. Dursun *et al.* (2013) observed enhanced leaf, stem and root growth in tomato and eggplant seedlings at the tested humic acid concentrations, while Gad *et al.* (2015) reported significant effects of humic acid on growth and yield of okra, with 10% producing the highest response among the tested concentrations. Aboohanah (2016) similarly observed significant improvement in growth and root parameters of okra following humic acid application. Collectively, these studies indicate that the beneficial response observed under T₂₁ may be related to the capacity of humic substances to improve the growing environment and support plant development [2, 3, 5, 8, 10].

Number of seeds per fruit

A keen observation of the data presented in table 5 reveals that the application of biofertilizers and bio-stimulants have significant effect on the number of seeds per fruit. Maximum number of seeds per fruit was observed in treatment combination T₂₁ (*Azotobacter*+ PSB + KSB + Humic acid 4%) i.e. 42.12, 41.23 and 41.68. It was followed by treatment T₁₇. While the minimum number of seeds per fruit was reported in T₁ (control) i.e. 28.75, 27.86 and 28.30 during the first year, second year and pooled data. The higher seed number under T₂₁ may indicate improved reproductive development and more favourable conditions during flowering, fertilization and subsequent fruit development. The availability of essential nutrients, particularly nitrogen, phosphorus and potassium, is closely associated with plant growth and reproductive processes. In the present treatment combination, these nutrient-related effects may have been complemented by the biostimulatory influence of humic acid. Nevertheless, because physiological processes such as pollen viability, fertilization success and embryo development were not directly measured in the present experiment, the proposed mechanism should be considered a plausible interpretation of the observed response. The broader findings of Yildirim *et al.* (2007) support the positive influence of humic acid on fruit-related characteristics, while Abdel *et al.* (2010) demonstrated improved growth and yield responses following seaweed extract application

in watermelon. Meena *et al.* (2017)^[10] also reported improvement in several fruit and yield attributes of cucumber with humic acid and micronutrient application. Although these studies do not establish a direct one-to-one relationship with seed number in the present crop, their findings provide supporting evidence for the beneficial influence of biostimulant-based nutrient management on reproductive and yield-related performance^[19].

Fruit yield per plant

Through the analysis of the data presented in table 5 it was observed that maximum fruit yield per plant was recorded in treatment combination T₂₁ (*Azotobacter* + PSB + KSB + Humic acid 4%) i.e. 396.97, 392.91 and 394.94 (g). It was followed by treatment T₁₇. While the minimum fruit yield per plant was reported in T₁ (control) i.e. 291.07, 287.01 and 289.04 (g) during the first year, second year and pooled data.

The higher fruit yield under T₂₁ can be interpreted as the cumulative result of its superior performance for the individual yield components. The treatment produced the highest number of fruits per plant, the highest average fruit weight and the highest number of seeds per fruit. Thus, the enhancement in fruit yield was not attributable to improvement in a single component but appeared to be associated with simultaneous improvement in several yield-determining attributes. This integrated response is particularly important when evaluating combined biofertilizer and biostimulant treatments. The present findings are in accordance with Yildirim *et al.* (2007)^[19], who observed improvement in fruit yield and fruit characteristics with humic acid application in tomato. Abdel *et al.* (2010) reported enhanced growth and yield responses in watermelon following seaweed extract application. Koyama *et al.* (2012)^[9] also recorded increased tomato yield with seaweed extract application, even though fruit characteristics remained unchanged. These observations support the possibility that biostimulants can enhance crop productivity through their influence on overall plant performance and yield formation. The results are further supported by Sundharaiya *et al.* (2016), who reported significant improvement in yield and yield-related bulb attributes of multiplier onion with seaweed extract. Murtic *et al.* (2018)^[11] found that 2% seaweed extract improved adaptability, yield and quality of cherry tomato under both regular and drought-stress conditions. Such findings are relevant because they demonstrate that biostimulant applications can contribute to productivity across differing growing conditions.

The superiority of the integrated treatment containing all three biofertilizers is also important in interpreting the treatment response. The performance of T₅, consisting of *Azotobacter* + PSB + KSB without an additional biostimulant, was better than several two-component biofertilizer combinations, indicating the potential advantage of combining complementary microbial functions. However, further improvement was evident when the complete microbial combination was supplemented with seaweed extract or humic acid. Among these, T₂₁ consistently produced the strongest response. This pattern suggests that the biostimulant component may have complemented the nutrient-mobilizing functions of the microbial inoculants rather than acting independently. Such an interpretation is consistent with the concept of integrated nutrient and biostimulant management, in which improved nutrient availability and plant physiological efficiency operate simultaneously.

The response to humic acid concentration also provides an important observation. T₁₇, containing *Azotobacter* + PSB + KSB + humic acid 2%, generally ranked immediately after T₂₁, whereas T₂₁ contained humic acid at 4%. The better overall performance of T₂₁ within the tested range indicates a favourable response to the higher humic acid concentration when combined with the complete biofertilizer consortium. However, the present data should be interpreted as a treatment response within the concentrations evaluated and should not be taken as evidence that increasing humic acid concentration indefinitely would continue to improve crop performance. The positive responses to humic acid reported by Yildirim *et al.* (2007), Kim *et al.* (2010), Gad *et al.* (2015), Haider *et al.* (2017), Meena *et al.* (2017) and Pasha *et al.* (2021) similarly demonstrate that humic substances can influence plant growth and yield, although optimum responses depend upon crop, environment, formulation and application rate. Seaweed extract treatments also demonstrated considerable effectiveness, particularly when combined with the complete biofertilizer consortium. T₉, comprising *Azotobacter* + PSB + KSB + seaweed extract 2%, and T₁₃, comprising the same biofertilizers with seaweed extract 4%, were among the better-performing treatments for several reproductive characteristics. The improvement is consistent with the findings of Abdel *et al.* (2010), Koyama *et al.* (2012), Fatma *et al.* (2018) and Murtic *et al.* (2018), who reported beneficial effects of seaweed-derived biostimulants on crop growth, yield and plant adaptability. The findings of Nabti *et al.* (2016) further support the broader role of seaweed-based biofertilizers in improving plant growth and nutrient and water uptake^[4, 5, 7, 8, 9, 10, 11, 12, 15, 19].

Table 2: Effect of biofertilizers and bio-stimulants on days to first flower appearance and days to 50% flowering

Treatments	Days to first flower appearance			Days to 50% flowering		
	I st Year	II nd Year	Pooled	I st Year	II nd Year	Pooled
T ₁	43.37	41.34	42.36	48.30	46.32	47.31
T ₂	38.45	36.37	37.41	42.34	40.45	41.39
T ₃	40.38	38.38	39.38	45.37	43.33	44.35
T ₄	42.44	40.44	41.44	47.36	45.34	46.35
T ₅	36.47	34.38	35.43	40.45	38.38	39.42
T ₆	35.38	33.36	34.37	38.34	36.33	37.34
T ₇	39.40	37.37	38.39	44.41	40.47	42.44
T ₈	41.37	39.49	40.43	46.41	41.39	43.90
T ₉	34.41	32.48	33.44	38.37	36.37	37.37
T ₁₀	36.48	34.39	35.43	36.71	34.34	35.52
T ₁₁	37.37	37.09	37.23	39.45	37.38	38.42
T ₁₂	42.48	40.44	41.46	47.36	45.29	46.33
T ₁₃	34.40	32.42	33.42	37.33	35.33	36.33
T ₁₄	40.56	26.38	33.47	44.49	42.20	43.35
T ₁₅	39.45	37.37	38.41	42.41	40.41	41.41
T ₁₆	41.35	39.35	40.35	46.41	44.36	45.39

T ₁₇	33.35	32.47	32.91	36.71	34.34	35.52
T ₁₈	38.37	36.38	37.38	43.39	41.40	42.39
T ₁₉	39.43	37.39	38.41	45.33	43.33	44.33
T ₂₀	41.44	39.55	40.50	47.42	45.40	46.41
T ₂₁	32.60	30.40	31.50	35.21	33.41	34.31
SEm ±	0.09	2.56	1.29	0.10	0.74	0.38
CD 5%	0.26	7.33	3.70	0.28	2.12	1.07

Table 3: Effect of biofertilizers and bio-stimulants on number of flowers per plant and days to first picking

Treatments	Number of flowers per plant			Days to first picking		
	I st Year	II nd Year	Pooled	I st Year	II nd Year	Pooled
T ₁	7.63	6.39	7.01	51.37	49.55	50.46
T ₂	9.23	7.99	8.61	46.45	44.58	45.51
T ₃	9.18	7.94	8.56	48.38	46.59	47.49
T ₄	7.73	6.49	7.11	50.44	48.65	49.55
T ₅	11.10	9.86	10.48	44.47	42.59	43.53
T ₆	11.69	10.45	11.07	43.38	41.57	42.48
T ₇	10.54	9.30	9.92	47.40	45.58	46.49
T ₈	9.33	8.09	8.71	49.37	47.70	48.54
T ₉	13.11	11.87	12.49	42.40	40.69	41.54
T ₁₀	11.93	10.69	11.31	41.35	40.68	41.01
T ₁₁	10.99	9.75	10.37	45.37	45.30	45.34
T ₁₂	10.33	9.09	9.71	50.48	48.65	49.56
T ₁₃	12.56	11.32	11.94	41.75	40.02	40.89
T ₁₄	12.27	11.03	11.65	48.56	46.80	47.68
T ₁₅	11.27	10.03	10.65	47.45	45.58	46.52
T ₁₆	9.77	8.53	9.15	49.35	47.56	48.45
T ₁₇	13.53	12.29	12.91	43.97	41.91	42.94
T ₁₈	12.66	11.42	12.04	46.37	44.59	45.48
T ₁₉	11.65	10.41	11.03	47.43	45.60	46.52
T ₂₀	9.34	8.10	8.72	49.44	47.76	48.60
T ₂₁	14.26	13.02	13.64	41.30	40.48	40.89
SEm ±	0.43	0.41	0.41	0.301	0.460	0.300
CD 5%	1.22	1.16	1.17	0.860	1.316	0.858

Table 4: Effect of biofertilizers and bio-stimulants on number of fruits per plant and average fruit weight (g)

Treatments	Number of fruits per plant			Average fruit weight (g)		
	I st Year	II nd Year	Pooled	I st Year	II nd Year	Pooled
T ₁	6.92	6.22	6.57	9.01	8.05	8.53
T ₂	13.29	12.15	12.72	13.00	11.95	12.48
T ₃	12.20	10.79	11.50	10.81	9.76	10.29
T ₄	10.08	9.60	9.84	10.71	9.69	10.20
T ₅	15.08	13.94	14.51	14.57	13.65	14.11
T ₆	15.55	14.41	14.98	15.12	14.19	14.65
T ₇	14.31	13.17	13.74	14.21	13.23	13.72
T ₈	12.38	11.24	11.81	11.50	10.45	10.98
T ₉	16.21	15.07	15.64	16.01	15.03	15.52
T ₁₀	15.94	14.80	15.37	15.27	14.31	14.79
T ₁₁	14.62	13.48	14.05	14.52	13.52	14.02
T ₁₂	12.65	11.51	12.08	12.10	11.02	11.56
T ₁₃	16.28	15.14	15.71	16.30	15.30	15.80
T ₁₄	16.07	14.93	15.50	15.44	14.51	14.98
T ₁₅	15.19	14.05	14.62	14.82	13.75	14.29
T ₁₆	14.12	12.98	13.55	13.91	12.98	13.44
T ₁₇	16.61	15.47	16.04	16.60	15.62	16.11
T ₁₈	16.11	14.97	15.54	15.91	14.95	15.43
T ₁₉	15.32	14.18	14.75	14.79	13.81	14.30
T ₂₀	13.83	12.69	13.26	13.62	12.66	13.14
T ₂₁	19.15	18.01	18.58	16.97	15.93	16.45
SEm ±	0.249	0.249	0.239	0.05	0.03	0.04
CD 5%	0.711	0.711	0.683	0.15	0.10	0.10

Table 5: Effect of biofertilizers and bio-stimulants on number of seeds per fruit and fruit yield per plant (g)

Treatments	Number of seeds per fruit			Fruit yield per plant (g)		
	I st Year	II nd Year	Pooled	I st Year	II nd Year	Pooled
T ₁	28.75	27.86	28.30	291.07	287.01	289.04
T ₂	34.56	33.68	34.12	347.64	343.57	345.61
T ₃	32.50	31.62	32.06	322.81	318.74	320.77
T ₄	31.08	30.20	30.64	317.34	313.27	315.31
T ₅	35.67	34.78	35.22	362.21	358.14	360.17
T ₆	37.81	36.92	37.36	372.34	368.27	370.31
T ₇	35.20	34.32	34.76	356.61	352.54	354.57
T ₈	32.73	31.85	32.29	332.51	328.44	330.47
T ₉	39.08	38.20	38.64	382.41	378.34	380.37
T ₁₀	38.16	37.28	37.72	376.81	372.74	374.77
T ₁₁	35.46	34.58	35.02	362.01	357.94	359.97
T ₁₂	34.09	33.20	33.64	341.77	337.71	339.74
T ₁₃	39.75	38.87	39.31	386.77	382.71	384.74
T ₁₄	38.65	37.77	38.21	377.27	373.21	375.24
T ₁₅	36.44	35.55	35.99	367.31	363.24	365.27
T ₁₆	34.91	34.12	34.52	356.41	352.34	354.37
T ₁₇	40.60	39.71	40.15	391.67	387.61	389.64
T ₁₈	38.73	37.80	38.26	382.24	378.17	380.21
T ₁₉	37.11	36.23	36.67	371.34	367.27	369.31
T ₂₀	33.74	32.86	33.30	352.31	348.24	350.27
T ₂₁	42.12	41.23	41.68	396.97	392.91	394.94
SEm ±	0.46	0.55	0.45	0.25	0.34	0.27
CD 5%	1.31	1.56	1.28	0.70	0.97	0.78

Conclusion

The present investigation demonstrated that integrated application of biofertilizers and biostimulants significantly improved the growth, flowering, yield attributes and yield of the crop compared with the control and simpler treatment combinations. Among the evaluated treatments, T₂₁ (Azotobacter + PSB + KSB + humic acid 4%) emerged as the most effective treatment across the two years and pooled analysis. It recorded earlier flowering (31.50 days), earlier 50% flowering (34.31 days), higher number of flowers per plant (13.64), more fruits per plant (18.58), greater average fruit weight (16.45 g), higher seeds per fruit (41.68), and maximum fruit yield per plant (394.94 g). Treatment T₁₇ (Azotobacter + PSB + KSB + humic acid 2%) generally ranked second. The superior performance of T₂₁ indicates the potential advantage of combining complementary biofertilizers with humic acid at the higher tested concentration. Overall, integrated biofertilizer-biostimulant management offers a promising approach for enhancing crop productivity and improving nutrient-use efficiency.

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Conflict of Interest

The authors declare no conflicts of interest with any institutions or researchers involved in similar studies.

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