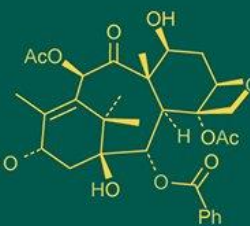
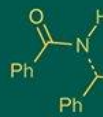


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Impact of integrated nutrient management on vegetative growth of Pak choi (*Brassica rapa* L. var. *chinensis*) under protected conditions

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Abstract

Integrated Nutrient Management has been proposed as an alternative strategy for increasing productivity through better utilization of nutrients along with keeping the healthiness of the soil without using chemicals fertilizers. In this connection, an attempt was made in the current study to assess the effect of different Integrated Nutrient Management techniques on the performance of Pak choi (*Brassica rapa* L. var. *chinensis*) grown in the protected environment. This study was done in the Rabi season of 2025-26 at the Centre of Excellence on Protected Cultivation and Precision Farming, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India. The experiment consisted of fifteen different treatments including Recommended Dose of Fertilizer, vermicompost, seaweed extract, *Azotobacter* and Phosphate Solubilising Bacteria arranged in a randomized block design having three replications each. The significant results were observed for plant height, leaf length, leaf width, leaf area and plant spread, while the number of leaves per plant was statistically insignificant. The highest plant height (34.15 cm) and the maximum number of leaves per plant (12.57) was obtained from T₄ treatment i.e., RDF + Vermicompost @ 2.5 t ha⁻¹ + *Azotobacter*. On the other hand, RDF + Seaweed extract @ 25 kg ha⁻¹ + *Azotobacter* (T₆) was associated with maximum leaf length (29.79 cm), leaf width (12.92 cm), leaf area (206.12 cm²) and plant spread (41.30 cm). Superior growth attributes observed in these combinations could be explained by improved nutrition, enhanced biological nitrogen fixation, chlorophyll production, and stimulation of physiological activities due to active ingredients of seaweed. In summary, these results indicate that integrated application of inorganic fertilizers with organic amendments and beneficial microbes is a potential approach for improving growth and nutrient utilization efficiency in Pak choi plants in protected cultivation systems.

Keywords: *Azotobacter*, integrated nutrient management, Pak choi, protected cultivation, seaweed extract; vermicompost

1. Introduction

Pak choi (*Brassica rapa* L. var. *chinensis*), popularly referred to as bok choy or Chinese cabbage, is one of the most prominent leaf vegetables that belongs to the family Brassicaceae. It is grown in large quantities in China, Korea, Japan and many Southeast Asian countries and has also found its way into the farms in India due to its short growing cycle, fast-growing nature and high productivity. The vegetable is rich in vitamins such as A, C and K, foliates, dietary fiber, calcium, potassium, iron and various antioxidants, thus forming a major constituent of healthy human diet, according to Rubatzky and Yamaguchi [22].

Protected cultivation has become one of the most efficient ways of producing high value vegetable crops through creation of favorable microenvironment for maximum plant growth and development. It helps in overcoming negative impacts of variable environmental conditions as well as improving crop establishment and productivity. However, vegetable production under protected cultivation system requires regular use of chemical fertilizers to attain maximum yield. Overuse of such fertilizers can lead to low soil fertility levels, disruption of beneficial microbes and decrease in nutrient-use efficiency, thus impacting the sustainability of vegetable production, as indicated by Vessey [9] and Bhattacharyya [10]. Therefore, the concept of Integrated Nutrient Management has become increasingly popular as an eco-friendly strategy to increase crop yield via judicious use of inorganic fertilizers, organic nutrients and microorganisms.

Integrated Nutrient Management not only helps in ensuring constant availability of nutrients but also improves various soil characteristics including physical, chemical and biological aspects, nutrient use efficiency and minimizes environmental hazards caused by indiscriminate fertilization practices, as stated by Vessey^[9], Bhattacharyya and Jha^[10] and Edwards *et al.*^[13].

From various sources of organic nutrients, vermicompost is regarded as one of the most effective soil amendments due to its ability to provide easily available macro and micronutrients along with humus, enzymes and microorganisms. Vermicompost improves soil structure, aeration, moisture holding capacity and microbial action and thus provides a conducive environment for better root growth and nutrient uptake. Constant mineralization of nutrients from vermicompost results in their continuous availability during the entire crop growth period and thereby increases crop growth and development, as supported by Edwards *et al.*^[13], Arancon *et al.*^[14], Lazcano and Domínguez^[15] and Atiyeh *et al.*^[16].

Seaweed extracts have been found effective natural biostimulants due to their capacity to influence various physiological and biochemical processes in plants. Seaweed extracts are rich sources of bioactive substances like auxins, cytokinins, gibberellin-like substances, betaines, amino acids, polysaccharides, and micronutrients that facilitate chlorophyll synthesis, stimulation of photosynthesis, enhanced nutrient use efficiency, antioxidant metabolism, and abiotic stress tolerance. These physiological activities together contribute towards vegetative growth and crop productivity as documented by Khan *et al.*^[1], Calvo *et al.*^[2], Van Oosten *et al.*^[3], Rouphael and Colla^[4], Bulgari *et al.*^[5], Craigie^[6], du Jardin^[7] and Yakhin *et al.*^[8].

Biofertilizers are an essential component of integrated nutrient management in agriculture due to their biological process of improving the availability of nutrients. *Azotobacter* is capable of fixing atmospheric nitrogen and produces growth regulators like IAA, gibberellins, and cytokinins while phosphate-solubilizing bacteria (PSB) solubilize insoluble phosphorus to available forms through organic acid secretion. The joint use of these materials improves the activity of the rhizosphere, promotes the development of roots, and increases the efficiency of utilization of nutrients, thus promoting sustainable production of vegetables, according to Vessey^[9], Bhattacharyya and Jha^[10], Glick^[11], Sharma *et al.*^[12], Backer *et al.*^[18], Colla *et al.*^[19], Kloepper *et al.*^[20], and Bashan and de-Bashan^[21].

Although the benefits provided by each one of these treatments have been well documented in many vegetable crops, the integrated application of these materials in Pak choi grown under a protected environment has not been adequately studied yet. Also, there is a lack of comparative studies on the impact of the combination of inorganic fertilizers, organic nutrients, seaweed biostimulant and beneficial microorganisms under a same protected growing environment. This type of information is important to find an efficient and sustainable management practice that allows improving plant vegetative development without compromising the fertility of soils under intensive cropping conditions.

Thus, the present study was conducted to evaluate the effect of some different practices of integrated management of nutrients that include recommended amount of fertilizers

(RDF), vermicompost, seaweed extract, *Azotobacter* and phosphate solubilizing bacteria on the vegetative growth of Pak choi.

2. Materials and Methods

The present study was carried out in the year 2025-26 during the Rabi season at the Centre of Excellence on Protected Cultivation and Precision Farming, Department of Vegetable Science, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India. The geographical coordinates of the experimental field were 21°16' N latitude and 81°36' E longitude, while the elevation was 289.56 m above mean sea level. The agro-climatic zone for the region was that of Chhattisgarh Plains with dry sub-humid climate. The mean annual rainfall was 1200-1400 mm, mostly occurring from June to September.

Healthy seedlings of Pak choi (*Brassica rapa* L. var. *chinensis*) cv. Tasty Green were grown under protected cultivation conditions in paired row planting system at spacing of 120 × 30 × 30 cm (120 cm between paired rows, 30 cm between rows in a pair and 30 cm between plants). The experiment was laid out in a RBD consisting of 15 treatments with three replications. The recommended dose of fertilizer (RDF) was 150:100:125 kg N:P₂O₅:K₂O ha⁻¹. The vermicompost, sea weed extract, *Azotobacter*, and phosphate solubilizing bacteria (PSB) were used depending on treatment combinations. Vermicompost and Seaweed extract (granular) were incorporated into the soil before transplanting as per the treatment combinations. In the case of biofertilizer application, the roots of the seedlings were dipped in the suspension of *Azotobacter* and PSB each for 30 min before transplanting.

2.1 Statistical Analysis

Analysis of Variance (ANOVA) was applied to the experimental data, suitable for RBD by using OPSTAT software package^[23]. Effectiveness of treatment was tested at 5% significance level, and the mean values of the treatments were compared through CD method whenever F-test proved to be significant.

3. Results

3.1 Plant Height (cm)

The growth of plant height was significantly affected by various Integrated Nutrient Management treatments up to 20 and 40 DAT (Table 2). Out of all the treatments, T₄ (RDF + Vermicompost @ 2.5 t ha⁻¹ + *Azotobacter*) had the highest plant height of 24.04 cm and 34.15 cm up to 20 and 40 DAT, respectively, while statistically on par with T₆, T₅, and T₇. The lowest plant height was achieved by T₁ (RDF only), having 18.84 cm and 28.90 cm at 20 and 40 DAT, respectively.

3.2 Number of Leaves per Plant

There was no significant difference in the number of leaves per plant among different integrated nutrient management treatments both at 20 and 40 days after treatment (DAT) (Table 2). However, there were numerical differences between different treatments. Maximum number of leaves per plant was noted for treatment T₄, where number of leaves per plant was 8.74 and 12.57 leaves at 20 and 40 DAT respectively, while minimum number of leaves per plant was recorded in T₁ (RDF only).

3.3 Leaf Length (cm)

Leaf Length

Significantly, leaf length was affected by various treatments of integrated nutrient management at two observational periods (Table 2). The highest value of leaf length was obtained from the treatment T₆ (RDF + Seaweed extract @ 25 kg ha⁻¹ + *Azotobacter*) as 25.61 cm at 20 DAT and 29.79 cm at 40 DAT. However, it was statistically at par with treatments T₇ and T₄. The lowest leaf length was found with T₁ (RDF only) as 21.40 cm at 20 DAT and 24.99 cm at 40 DAT.

3.4 Leaf Width (cm)

Leaf width varied significantly between the treatments under integrated nutrient management at both growth stages (Table 3). The maximum leaf widths were seen in case of T₆ (RDF + seaweed extract @ 25 kg ha⁻¹ + *Azotobacter*) with 9.09 cm and 12.92 cm at 20 DAT and 40 DAT, respectively. This treatment showed statistical equality with T₇ and T₅. The minimum leaf width was recorded in case of T₁ (RDF only) with 6.44 cm and 9.87 cm at 20 and 40 DAT, respectively.

3.5 Leaf Area (cm²)

Integrated Nutrient Management practices had a considerable impact on the leaf area at both the observation periods (Table 3). Out of all the treatments tested, T₆ (RDF + Seaweed extract @ 25 kg ha⁻¹ + *Azotobacter*) produced the maximum leaf area of 177.52 cm² at 20 DAT and 206.12 cm² at 40 DAT. The treatment was statistically comparable to T₇. The minimum leaf area was obtained with T₁ (RDF alone), which was 104.78 cm² and 122.37 cm² at 20 and 40 DAT, respectively.

3.6 Plant Spread (cm)

The plant spread was influenced to a large extent by the treatments of the integrated nutrient management at both 20 and 40 DAT (see Table 3). The highest plant spread was observed in treatment T₆ (RDF + Seaweed extract @ 25 kg ha⁻¹ + *Azotobacter*) with values 24.00 cm and 41.30 cm at 20 and 40 DAT, respectively, and was statistically similar to T₇ and T₅. The lowest plant spread was recorded in treatment T₁ (RDF only) with values of 19.00 cm and 34.47 cm at the respective stages.

4. Discussion

4.1 Plant Height

Integrated nutrient management has significantly contributed to the increment in the height of plants in Pak choi grown under protective cultivation with the maximum value attained under T₄ (RDF + Vermicompost @ 2.5 t ha⁻¹ + *Azotobacter*). The increment in plant height is due to the combination of the effects of both vermicompost and *Azotobacter* that have resulted in an increase in nutrient uptake and stimulation of various physiological processes that support vegetative growth. Vermicompost provides nutrients, humic substances, and beneficial microorganisms that help improve soil structure and activities of roots while *Azotobacter* increases biological nitrogen fixation and production of phytohormones like IAA, gibberellins, and cytokinins. This leads to cell division, elongation, and formation of chlorophyll and, thus, increases photosynthesis and plant height.

The current results agree with those by Vessey^[9], Bhattacharyya and Jha^[10] and Edwards *et al.*^[13] who suggested that the application of organic nutrients and plant growth-promoting rhizobacteria together helps in enhancing vegetative growth through nutrient use efficiency and physiological activity.

4.2 Number of Leaves per Plant

However, while the leaf number per plant was not affected significantly by different nutrient management regimes, the plants subjected to integrated nutrient management always showed slightly higher leaf number than the control plants. Given that leaf development is mainly controlled by genetic ability of the particular cultivar, the effect of nutrients applied externally is usually not as pronounced as leaf size and plant biomass. Still, the steady supply of nutrients from the vermicompost along with biological nitrogen fixation by *Azotobacter* created optimal physiological conditions for leaf development and prevented leaf senescence. The tendency shows that integrated nutrient management promoted active vegetative development during the entire life span of the crop. Such effects have already been observed by Calvo *et al.*^[2], Arancon *et al.*^[14] and Atiyeh *et al.*^[16] who stated that integrated use of organic sources of nutrients and microorganisms stimulates the development of healthy vegetation in vegetable crops.

4.3 Leaf Length

The marked increase in leaf length in treatment T₆ (RDF + Seaweed extract @ 25 kg ha⁻¹ + *Azotobacter*) indicates the importance of seaweed based biostimulants for the growth of foliage. Seaweed extract has many bioactive components such as auxins, cytokinins, gibberellic acid like materials, amino acids, betaines and polysaccharides that help in controlling the process of cell division and elongation in growing tissues. Moreover, seaweed extract increases chlorophyll synthesis, increases nitrate reductase and Ribulose biphosphate carboxylase activity and facilitates assimilate transportation; all this leads to the growth of leaves. The synergistic effect of *Azotobacter* due to biological nitrogen fixation and production of plant hormones results in an increased metabolic activity and root growth. All these results are in agreement with the observations of Khan *et al.*^[1], Van Oosten *et al.*^[3] and Craigie^[6].

4.4 Leaf Width

The increase in leaf width after the use of seaweed extract along with *Azotobacter* indicated better cell expansion during the growth of leaves. The bioactive components available in seaweed extract such as alginates, laminarins, fucoidans and betaines help in osmoregulation, membrane stability, and antioxidation, thus providing ideal conditions inside the cells for growth. The components present in the seaweed extract also trigger the functioning of endogenous hormones and chlorophyll synthesis, thus improving carbon assimilation. In turn, this results in better growth of mesophyll and cell expansion, thus giving rise to broad leaves with better photosynthesis. This has also been observed by du Jardin^[7], Rouphael and Colla^[4] and Backer *et al.*^[18].

4.5 Leaf Area

The area of leaves has a direct association with the photosynthetic capacity of the plants and is essential for biomass accumulation. The significant increase in the area of leaves in treatment T₆ suggests that the integrated management of nutrients has helped improve the development of the assimilating surfaces. Chlorophyll synthesis, increased carbon fixation, and effective transport of the assimilates under the influence of biostimulant from seaweed may have helped in leaf enlargement. Moreover, increased nitrogen availability by *Azotobacter* would have aided in protein synthesis and sustained photosynthesis, leading to the formation of larger leaves. The development of an increased area of the photosynthetically active surface increases light absorption and improves the source-sink balance. The current results are in agreement with the findings of Bulgari *et al.* ^[5], Khan *et al.* ^[1], and Colla *et al.* ^[19], who demonstrated the positive influence of biostimulants along with beneficial microorganisms on leaf

development and photosynthesis in horticultural crops.

4.6 Plant Spread

Plant spread is indicative of the overall canopy structure and vegetative vigor of the crop. The significant increase in canopy spread under T₆ indicates the effect of integrated nutrient management in maintaining balanced shoot growth and effective biomass distribution. Biostimulants from seaweed improve enzymatic activity, chlorophyll synthesis, and carbohydrate metabolism, thus making the assimilates available for vegetative growth. Meanwhile, the application of *Azotobacter* contributes to increased rhizosphere activity and continuous biological nitrogen fixation for further shoot growth. The joint contribution of these processes leads to the lateral spread of the canopy, better light absorption, and improved general vigor of the crop in the protected cultivation environment. Similar effects were observed in studies carried out by Rouphael and Colla ^[4], Kloepper *et al.* ^[20], and Bashan and de-Bashan ^[21].

Table 1: Details of treatment combinations

Treatment Notation	Treatment Details
T ₁	RDF (Control)
T ₂	RDF + Vermicompost @ 2.5 t ha ⁻¹
T ₃	RDF + Seaweed extract @ 25 kg ha ⁻¹
T ₄	RDF + Vermicompost @ 2.5 t ha ⁻¹ + <i>Azotobacter</i>
T ₅	RDF + Vermicompost @ 2.5 t ha ⁻¹ + Phosphate solubilizing bacteria
T ₆	RDF + Seaweed extract @ 25 kg ha ⁻¹ + <i>Azotobacter</i>
T ₇	RDF + Seaweed extract @ 25 kg ha ⁻¹ + Phosphate solubilizing bacteria
T ₈	RDF + Vermicompost @ 1.87 t ha ⁻¹ + <i>Azotobacter</i>
T ₉	RDF + Vermicompost @ 1.87 t ha ⁻¹ + Phosphate solubilizing bacteria
T ₁₀	RDF + Seaweed extract @ 18.7 kg ha ⁻¹ + <i>Azotobacter</i>
T ₁₁	RDF + Seaweed extract @ 18.7 kg ha ⁻¹ + Phosphate solubilizing bacteria
T ₁₂	RDF + Vermicompost @ 1.25 t ha ⁻¹ + <i>Azotobacter</i>
T ₁₃	RDF + Vermicompost @ 1.25 t ha ⁻¹ + Phosphate solubilizing bacteria
T ₁₄	RDF + Seaweed extract @ 12.5 kg ha ⁻¹ + <i>Azotobacter</i>
T ₁₅	RDF + Seaweed extract @ 12.5 kg ha ⁻¹ + Phosphate solubilizing bacteria

Table 2: Effect of integrated nutrient management treatments on plant height, number of leaves and leaf length of Pak choi at 20 and 40 days after transplanting (DAT)

Treatment	Plant Height (cm)		Number of Leaves plant ⁻¹		Leaf Length (cm)	
	20 DAT	40 DAT	20 DAT	40 DAT	20 DAT	40 DAT
T ₁	18.84	28.90	7.38	10.80	21.40	24.99
T ₂	20.92	29.23	7.60	11.47	23.03	26.50
T ₃	21.46	29.70	7.82	11.70	22.96	25.66
T ₄	24.04	34.15	8.74	12.57	24.54	27.70
T ₅	22.61	32.97	8.50	11.80	23.99	26.73
T ₆	23.98	32.80	8.36	11.74	25.61	29.79
T ₇	22.02	31.70	8.24	11.76	25.28	28.46
T ₈	21.13	31.07	7.90	10.92	22.19	26.70
T ₉	21.18	31.29	7.86	11.59	23.64	27.04
T ₁₀	21.05	30.38	7.80	11.20	23.98	26.51
T ₁₁	21.43	30.53	7.79	11.26	23.16	26.62
T ₁₂	21.17	30.67	8.20	11.65	22.86	26.88
T ₁₃	21.65	29.62	7.87	10.87	20.23	25.46
T ₁₄	20.86	29.52	7.77	10.80	22.09	26.04
T ₁₅	20.50	30.05	7.93	11.43	23.26	26.99
F-test	S	S	NS	NS	S	S
C.D. (5%)	2.43	2.74	—	—	1.85	2.40
SE(d)±	1.17	1.32	0.56	0.64	0.89	1.15

S = Significant; NS = Non-significant; C.D. = Critical Difference; SE(d) = Standard Error of difference; DAT = Days after transplanting. Treatment notations (T₁-T₁₅) are as detailed in Table 1.

Table 3: Effect of integrated nutrient management treatments on leaf width, leaf area and plant spread of Pak choi at 20 and 40 days after transplanting (DAT)

Treatment	Leaf Width (cm)		Leaf Area cm ²		Plant Spread (cm)	
	20 DAT	40 DAT	20 DAT	40 DAT	20 DAT	40 DAT
T ₁	6.44	9.87	104.78	122.37	19.00	34.47
T ₂	7.31	10.98	128.15	146.99	20.67	36.90
T ₃	7.24	11.63	133.47	140.81	21.33	37.41
T ₄	8.16	11.93	152.41	172.33	23.33	39.79
T ₅	8.02	11.32	145.57	162.21	23.33	40.43
T ₆	9.09	12.92	177.52	206.12	24.00	41.30
T ₇	8.88	12.69	169.93	191.53	23.67	40.92
T ₈	7.83	11.23	132.60	158.20	21.00	36.69
T ₉	7.48	11.25	134.51	153.60	21.51	36.76
T ₁₀	7.99	11.47	145.29	161.82	20.67	37.65
T ₁₁	7.95	11.46	140.40	160.63	19.67	37.65
T ₁₂	7.78	10.90	135.21	159.18	20.33	38.05
T ₁₃	7.54	11.31	116.04	145.78	21.25	35.11
T ₁₄	7.95	11.35	132.46	158.03	19.67	37.55
T ₁₅	7.93	11.35	140.08	162.36	20.67	37.46
F-test	NS	S	S	S	S	S
C.D. (5%)	—	1.28	22.79	28.14	2.99	3.18
SE(d)±	0.63	0.62	11.07	14.77	1.45	1.54

S = Significant; NS = Non-significant; C.D. = Critical Difference; SE(d) = Standard Error of difference; DAT = Days after transplanting. Treatment notations (T₁-T₁₅) are as detailed in Table 1.

Conclusion

From the current study, it was revealed that integrated nutrient management was highly successful in enhancing vegetative growth of Pak choi grown in protected environment. In terms of treatments used in the experiment, the combination of RDF + Vermicompost @ 2.5 t ha⁻¹ + *Azotobacter* (T₄) had the best performance in increasing plant height and number of leaves, while RDF + Seaweed extract @ 25 kg ha⁻¹ + *Azotobacter* (T₆) was more efficient in providing increased values of leaf length, leaf width, leaf area and plant spread. The increased performance in vegetative growth under such treatments can be explained by the interaction between nutrient availability, nutrient use efficiency, nitrogen fixation and biostimulation of plants through bioactive substances derived from seaweeds.

It is clear that inorganic fertilization coupled with organic amendments and microbes is a very good approach to nutrient management for growing Pak choi in protected environment. The identified nutrient management strategies can be recommended as a practice for achieving higher growth of plants.

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Conflicts of Interest

The authors have no conflicts of interest to declare regarding this manuscript.

Author Contributions

Kavita Verma: Conceptualization, experimentation, data collection, data analysis, manuscript preparation and editing.

Annu Verma: Supervision, review, technical guidance and final approval of the manuscript.

References

- Khan W, Rayirath UP, Subramanian S, Jithesh MN, Rayorath P, Hodges DM, *et al.* Seaweed extracts as biostimulants of plant growth and development. *J Plant Growth Regul.* 2009;28(4):386-399.
- Calvo P, Nelson L, Kloepper JW. Agricultural uses of plant biostimulants. *Plant Soil.* 2014;383(1-2):3-41.
- Van Oosten MJ, Pepe O, De Pascale S, Silletti S, Maggio A. The role of biostimulants and bioeffectors as alleviators of abiotic stress in crop plants. *Chem Biol Technol Agric.* 2017;4:5.
- Rouphael Y, Colla G. Biostimulants in agriculture. *Front Plant Sci.* 2020;11:40.
- Bulgari R, Franzoni G, Ferrante A. Biostimulants application in horticultural crops under abiotic stress conditions. *Agronomy.* 2019;9(6):306.
- Craigie JS. Seaweed extract stimuli in plant science and agriculture. *J Appl Phycol.* 2011;23(3):371-393.
- du Jardin P. Plant biostimulants: Definition, concept, main categories and regulation. *Sci Hortic.* 2015;196:3-14.
- Yakhin OI, Lubyantsev AA, Yakhin IA, Brown PH. Biostimulants in plant science: A global perspective. *Front Plant Sci.* 2017;7:2049.
- Vessey JK. Plant growth promoting rhizobacteria as biofertilizers. *Plant Soil.* 2003;255(2):571-586.
- Bhattacharyya PN, Jha DK. Plant growth-promoting rhizobacteria (PGPR): Emergence in agriculture. *World J Microbiol Biotechnol.* 2012;28(4):1327-1350.
- Glick BR. Plant growth-promoting bacteria: Mechanisms and applications. *Scientifica (Cairo).* 2012;2012:963401.
- Sharma SB, Sayyed RZ, Trivedi MH, Gobi TA. Phosphate solubilizing microbes: Sustainable approach for managing phosphorus deficiency in agricultural soils. *SpringerPlus.* 2013;2:587.

13. Edwards CA, Arancon NQ, Sherman RL, editors. Vermiculture Technology: Earthworms, Organic Wastes, and Environmental Management. Boca Raton (FL): CRC Press; 2011.
14. Arancon NQ, Edwards CA, Bierman P, Welch C, Metzger JD. Influences of vermicomposts on field strawberries: Part 1. Effects on growth and yields. *Bioresour Technol.* 2004;93(2):145-153.
15. Lazcano C, Domínguez J. The use of vermicompost in sustainable agriculture: Impact on plant growth and soil fertility. In: Miransari M, editor. *Soil Nutrients*. New York (NY): Nova Science Publishers; 2011. p. 1-23.
16. Atiyeh RM, Edwards CA, Subler S, Metzger JD. Pig manure vermicompost as a component of a horticultural bedding plant medium. *Bioresour Technol.* 2002;81(2):103-108.
17. Richardson AE, Barea JM, McNeill AM, Prigent-Combaret C. Acquisition of phosphorus and nitrogen in the rhizosphere and plant growth promotion by microorganisms. *Plant Soil.* 2009;321(1-2):305-339.
18. Backer R, Rokem JS, Ilangumaran G, Lamont J, Praslickova D, Ricci E, *et al.* Plant growth promoting rhizobacteria: Context, mechanisms of action, and roadmap to commercialization. *Plant Signal Behav.* 2018;13(11):e1471181.
19. Colla G, Hoagland L, Ruzzi M, Cardarelli M, Bonini P, Canaguier R, *et al.* Biostimulant action of protein hydrolysates: Unraveling their effects on plant physiology and microbiome interactions. *Front Plant Sci.* 2017;8:2202.
20. Kloepper JW, Lifshitz R, Zablotowicz RM. Free-living bacterial inocula for enhancing crop productivity. *Trends Biotechnol.* 1989;7(2):39-44.
21. Bashan Y, de-Bashan LE. How the plant growth-promoting bacterium *Azospirillum* promotes plant growth—A critical assessment. *Adv Agron.* 2010;108:77-136.
22. Rubatzky VE, Yamaguchi M. *World Vegetables: Principles, Production, and Nutritive Values*. 2nd ed. New York: Chapman & Hall; 1997.
23. OPSTAT. Online Statistical Analysis Software. Hisar: CCS Haryana Agricultural University. Available from: <http://14.139.232.166/opstat/>