RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
57 (1) 241-250, 2025
http://doi.org/10.54910/sabrao2025.57.1.23
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

BIOLOGICAL AND NANOFERTILIZATION EFFECTS ON GROWTH AND YIELD-RELATED TRAITS OF SPRING POTATO (*SOLANUM TUBEROSUM* L.)

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SUMMARY

The potato (*Solanum tuberosum* L.) field experiment commenced in the spring growing season of 2023 at the Musayyib project area, Babil Governorate, Iraq. The study aimed to determine the effects of biofertilization with four levels (without adding + full recommended fertilizer, addition of 10 g mixture of four types of bacterial fertilizer + half of the recommended fertilizer, addition of 10 g fungal biofertilizer (mycorrhiza) + half of the recommended fertilizer, and addition of 10 g mixture of bacterial and fungal biofertilizers + half of the recommended fertilizer) symbolized as B0, B1, B2, and B3, respectively. The nanofertilizer used had two nano-fertilization concentration, which had a positive effect on the average tuber (0 + full fertilizer recommendation and 2 g L^{-1} + half the fertilizer recommendation), denoted as N0 and N1, respectively, on the growth and tuber yield of three potato cultivars (Rashida, Sifra, and Arizona). The results showed cultivar Arizona was superior to the rest of the cultivars in emergence speed, plant height, chlorophyll content, tuber weight, and plant yield, with average values of 36.73 days, 60.29 cm, 48.30 mg 100 g^{-1}, 123.8 g, and 0.955 kg $plant^{-1}$, respectively. The B3 biofertilization treatment (bacterial and fungal fertilizer) and nanofertilizer (2 g L^{-1}) showed significant superiority in emergence seed, plant height, chlorophyll content, tuber weight, and plant yield.

Keywords: Potato (*Solanum tuberosum* L.), biofertilization, bacterial and fungal fertilizer, nanofertilizer, growth and tuber yield traits, chlorophyll content

Key findings: Potato (*Solanum tuberosum* L.) cultivar Arizona emerged superior over the rest of the cultivars in speed of emergence, chlorophyll content, tuber weight, and plant tuber yield. Biofertilization treatment B3 (a mixture of bacterial and fungal fertilizers) and nanofertilizer (2 g L^{-1}) showed significant superiority in most traits.

Communicating Editor: Dr. A.N. Farhood

Manuscript received: January 21, 2024; Accepted: March 29, 2024.

Citation: Mahmood OH, Alnuaimi JJJ, Al-Zubaidi AH (2025). Biological and nanofertilization effects on growth and yield-related traits of spring potato (*Solanum tuberosum* L.). *SABRAO J. Breed. Genet.* 57(1): 241-250. http://doi.org/10.54910/sabrao2025.57.1.23.

INTRODUCTION

Potato (*Solanum tuberosum* L.) belongs to the family Solanaceae and considerably one of the most important tuber vegetable crops in the Arab countries and worldwide. Its ranking is fourth globally for production and economic importance after wheat, corn, and rice (Mohammadi *et al.,* 2023). It constitutes the largest percentage of the daily food in most of the countries, as a rich source of energy and nutrients. For every 100 g of peeled potatoes contain moisture content (70%–85%) and dry matter (15%–30%), consisting of starch (10%–25%), protein (1%–2%), and mineral salts (1%). These mineral salts break down to 70% as potassium salts, in addition to phosphorus, manganese, sodium, iron, iodine, magnesium, calcium, and a fair percentage of fiber (0.5 g), and the amount of available calories (76) (Hassan, 2003).

Past studies conducted on potato genotypes revealed significant variations among the cultivars for vegetative growth and tuber yield characteristics. Cultivars greatly influence the quantity and quality of the tuber yield, and judging the superiority of any potato cultivar is not valid unless all grown genotypes are under similar environmental conditions (Slater *et al.,* 2016). In Iraq, the potato cultivation and production faces many problems. The most crucial is the unsuitable environmental conditions in some areas, as well as, the availability of specific factors for the continuation of growing seasons in spring and fall, requiring the potato cultivars with early planting and medium early planting (Al-Jabawi, 2019).

Biofertilizers play an important role in improving the natural, chemical, and biological characteristics of the cultivated soil. Biofertilizers are one of the materials used in agricultural fields. The biofertilizers are natural preparations containing a group of beneficial microorganisms with an active and effective role in improving the soil fertility. These microorganisms supply the plants with their nutritional needs through various elements they transform through vital activities from their unready to ready forms for absorption by crop plants. In addition, biofertilizers also provide them with other substances encouraging and stimulating plant growth, such as, plant hormones, fixing atmospheric nitrogen through their symbiotic and non-symbiotic living, and protecting the host plant from some pathogens. Biofertilizers are also vital in reducing the use of chemical fertilizers by about 25% and, thus, decreasing the crop production cost. It also participates in biological resistance to some plant pests and diseases (Adavi and Tadayoun, 2014).

Nanotechnology is one of the sciences concerning the study and processing of materials on the atomic scale of 10^{-9} of a meter because nanomaterials have properties that differ from traditional dimensions and exceeding 100 nanometers (Saleh, 2015). Nanomaterial has benefitted various fields, including medicine, science, engineering, and agriculture, such as, plant protection, improving seed germination, and plant nutrition and growth. Nanofertilizers are also unique due to their small size and large surface area, increasing the absorption surface and, thus, enhancing the speed and output of the metabolism process and photosynthesis (Singh *et al.,* 2016).

In modern agriculture, nanofertilizers represent a new frontier and an expectation to become a major driving force in the near future by enhancing the efficiency of fertilizers' use and overcoming nutritional enrichment. Nanofertilizer is the best alternative because nanomaterials are environment-friendly and help in environmental sustainability (Mishra *et al.,* 2017). The latest study aimed to determine the extent of the three potato cultivars' response to biological and nanofertilization under prevailing environmental conditions.

MATERIALS AND METHODS

The presented potato field experiment proceeded during the spring of 2023 at the Musayyib project area, Babil Governorate, Iraq (located below 44 E longitudes and 32 N latitudes). The study aimed to determine the effects of bio- and nanofertilization on the growth and yield of three potato cultivars. The experiment had a randomized complete block design (RCBD) with factorial arrangements and three replications. The first factor was biofertilization with four levels (without addition + full fertilizer recommendation, addition of 10 g mixture of four types of bacterial fertilizer + half of the recommended fertilizer, addition of 10 g of fungal biofertilizer (mycorrhiza) + half of the recommended fertilizer, and addition of 10 g mixture of bacterial and fungal biofertilizers + half of the recommended fertilizer), symbolized as B0, B1, B2, and B3, respectively. The second factor was nanofertilizer with two concentrations (0 + full dose of the recommended fertilizer and 2 g L^{-1} + half of the recommended fertilizer), labeled as N0 and N1, respectively. The third factor was three potato cultivars (Rashida, Sifra, and Arizona), denoted as V1, V2, and V3, respectively.

Preparing the land well consisted of its division into three sectors for cultivation. Potato planting on furrows measured two meters long and one meter wide. Three furrows for each experimental unit had the area of each experimental unit measuring 6 m^2 (2 m^2 × 3 m^2). Planting the tubers comprised eight tubers per row on one side of the furrow, with a distance of 25 cm between two tubers. The number of tubers per experimental unit was 24, totaling 72 experimental units in three replications. Fertilization followed the recommendations for potato crop using NPK fertilizer (Hassan, 2003; Hassan, 2016). The planting took place in the spring on January 15, 2023, with the foliar spraying of nanofertilizer carried out twice—the first, when the leaves appeared completely (45 days after planting) and the second, after 14 days of first foliar application and before flowering. The spraying happened early in the morning until the plants were completely wet. Adding adhesive material coincided with the spray solution to reduce its surface tension and ensure the spray solution sticks on the leaves for the longest time, boosting the spray solution's efficiency.

Data recorded

The estimation of field emergence speed was the days when the plants emerged from the surface of the soil; the period was five days between one reading and the next until all the experimental units germinated (Al-Fakhri and Khalaf, 1983). Plant height (cm) measurement began from the soil surface to the highest peak for five plants in each experimental unit and then, averaged. Leaf chlorophyll content (mg 100 g) estimation followed the methodology of Goodwin (1976). Tuber weight (g) for marketing incur calculation by taking the total tubers of five plants in each experimental unit and, then, weighing them using an electric balance to obtain the average weight of one tuber. The total marketable tuber yield plant^{-1} (kg plant^{-1}) also reached calculation by weighing the marketable tubers of all the plants and then, averaged.

Statistical analysis

All the recorded data for various growth and tuber yield traits assessment underwent the analysis of variance (ANOVA) as per the RCBD design (Gomez and Gomez, 1984). The use of least significant difference ($LSD_{0.05}$) test compared and separated the various groups of the means. All the analyses' processing employed the statistics software GenStat12.

RESULTS

Emergence speed

For emergence speed, significant differences occurred among the potato cultivars (Table 1). Cultivar Arizona excelled with the highest average of 36.73 days; however, it did not differ significantly from the cultivar Sifra at the average of 35.35 days, with cultivar Rashida providing the lowest average (33.46 days). Biofertilization treatments revealed nonsignificant differences in the speed of emergence. However, the nanofertilization treatments had a notable effect, and the N1 treatment indicated the uppermost average (36.21 days). Meanwhile, the comparison treatment (N0) gave the lowest average (34.14 days) for the season.

As for the interaction between cultivars and biofertilization treatments, substantial

Table 1. Effect of cultivars, bio- and nanofertilization, and their interaction on the speed of emergence in potato.

Treatments		Potato cultivars			Means (days)	
Nanofertilization	Biofertilization	Rashida (V1)	Sifra (V2)	Arizona (V3)	N × B	Nanofertilization means (days)
N_0 (0 g L^{-1})	B_0	30.74	37.51	33.78	34.01	34.14
	B_1	32.00	36.83	37.24	35.36	
	B_2	35.16	33.93	35.55	34.88	
	B_3	28.74	34.74	33.39	32.32	
N_1 (2 g L^{-1})	B_0	34.41	38.18	34.59	35.73	36.21
	B_1	36.11	30.72	35.60	34.14	
	B_2	33.19	35.00	37.91	35.37	
	B_3	37.34	35.88	45.67	39.63	
$LSD_{0.05}$	4.17				2.41	1.20
V × N		N_0	N_1		Cultivars means (days)	
	V_1	31.66	35.26		33.46	
	V_2	35.75	34.94		35.35	
	V_3	35.02	38.44		36.73	
$LSD_{0.05}$	2.08				1.47	
V × B		V_1	V_2	V_3	Biofertilization means (days)	
	B_0	32.57	37.84	34.19	34.87	
	B_1	34.05	33.77	36.42	34.75	
	B_2	34.18	34.46	36.73	35.12	
	B_3	33.04	35.31	39.58	35.98	
$LSD_{0.05}$	2.95				N.S.	

differences appeared among the interaction treatments (Table 1). The interaction treatment V3B3 resulted with the highest average for emergence speed (39.58 days), while the treatment V1B0 recorded with the lowest average (32.57 days). The interaction between the cultivars and nanofertilizer also had considerable differences, with the interaction treatment V3N1 recording the optimum average (38.44 days), and treatment V1N0 giving the lowest average (31.66 days). Significant differences also existed among the interactions of bio- and nano-fertilization treatments. The interaction treatment B3N1 displayed the maximum average (39.63 days), while treatment B3N0 provided the lowest average (32.32 days). Overall, interaction of the potato cultivars, biofertilization, and nanofertilization exhibited significant differences for the said trait. The triple interaction V3B3N1 was evidently with the premier average (45.67 days), while the interaction treatment V1B3N0 indicating the lowest average (28.16 days).

Plant height

For plant height, the potato cultivars revealed significant differences (Table 2). Cultivar Arizona V3 was visible with the tallest plants (60.29 cm), which did not differ significantly from the cultivar Sifra (59.38). However, the cultivar Rashida recorded with the lowest average (56.22 cm). Biofertilization treatments also positively affected plant height, with the treatment B3 recorded with the highest average plant height (62.69 cm); although, it did not vary significantly from treatment B2. Meanwhile, the comparison treatment (B0) manifested the lowest average for the said trait (52.92 cm). As for nanofertilization, considerable differences between the treatments emerged, with the treatment N1 recording the topmost average (59.79 cm), and the comparison treatment (N0) showing the lowest plant height (57.47 cm).

The interaction between the potato cultivars and biofertilization confirmed the existence of noteworthy differences among the various combinations (Table 2). The treatment V1B3 resulted with the tall plants (63.70 cm), while the treatment V1B0 emerged with the lowest average (45.65 cm). The interactions between the cultivars and nanofertilization revealed nonsignificant differences. Substantial variations resulted in the interaction of biofertilization and nanofertilization, with the treatment B3N1 recorded with the topmost

Table 2. Effect of cultivars, bio- and nanofertilization, and their interaction on the plant height in potato.

Treatments		Potato cultivars			Means (cm)	
Nanofertilization	Biofertilization	Rashida (V1)	Sifra (V2)	Arizona (V3)	N × B	Nanofertilization means (cm)
N_0 (0 g L^{-1})	B_0	45.33	62.80	53.08	53.73	57.47
	B_1	52.73	61.12	62.40	58.75	
	B_2	58.79	59.16	61.47	59.80	
	B_3	64.23	50.25	58.24	57.58	
N_1 (2 g L^{-1})	B_0	45.97	55.33	54.99	52.10	59.79
	B_1	61.59	53.88	62.38	59.28	
	B_2	57.91	58.53	63.45	59.96	
	B_3	63.18	73.97	66.28	67.81	
$LSD_{0.05}$	7.19				4.15	2.07
V × N		N_0	N_1		Cultivars means (cm)	
	V_1	55.27	57.16		56.22	
	V_2	58.33	60.43		59.38	
	V_3	58.80	61.78		60.29	
$LSD_{0.05}$	N.S				2.54	
V × B		V_1	V_2	V_3	Biofertilization means (cm)	
	B_0	45.65	59.06	54.03	52.92	
	B_1	57.16	57.50	62.39	59.02	
	B_2	58.35	58.85	62.46	59.88	
	B_3	63.70	62.11	62.26	62.69	
$LSD_{0.05}$	5.08				2.93	

plant height (67.81 cm). Meanwhile, the treatment B0N1 displayed the lowest average (53.73 cm). The interaction among the potato cultivars, biofertilization, and nanofertilization exhibited meaningful diversity for plant height. The interaction treatment V2B3N1 surfaced with the highest average plant height (73.97 cm), while the treatment V1B0N0 appeared with the lowest average for the said trait (45.33 cm).

Leaf chlorophyll content

The results showed significant variations among the potato cultivars for leaf chlorophyll content (Table 3). Cultivar Arizona provided the highest average of 48.30 mg 100 g^{-1}, with the cultivar Rashida recorded with the lowest average of chlorophyll content (35.16 mg 100 g^{-1}). The biofertilization treatments also had a positive effect. The treatment B3 appeared with the maximum average (45.09 mg 100 g^{-1}), which did not differ significantly from treatment B1, while the comparison treatment (B0) gave the lowest average of chlorophyll content (37.58 mg 100 g^{-1}). For nanofertilization treatments, the treatment N1 recorded with the supreme average of 46.36 mg 100 g^{-1}, while the control treatment (N0) occurred with the lowest chlorophyll content (37.25 mg 100 g^{-1}).

As for the interaction between the cultivars and biological fertilization, substantial dissimilarities existed between the treatments (Table 3). The treatment V3B3 recorded with the highest average of 50.35 mg 100 g^{-1}, while the treatment V1B0 exhibited the lowest average of chlorophyll content (26.33 mg 100 g^{-1}). The interaction between the cultivars and nanofertilization manifested significant differences, and the interaction treatment V3N1 recorded with the topmost average (50.77 mg 100 g^{-1}). Meanwhile, treatment V1N0 resulted with the lowest average (31.11 mg 100 g^{-1}). Conversely, nonsignificant differences between biofertilization and nanofertilization emerged for leaf chlorophyll content. However, the triple factors interaction among the potato cultivars, biofertilization, and nanofertilization revealed remarkable differences for leaf chlorophyll content. The interaction treatment V3B3N1 came up with the highest average (62.55 mg 100 g^{-1}), with the treatment V1B0N0 recorded with the lowest average for the said trait (24.28 mg 100 g^{-1}).

Tuber weight

For tuber weight, potato cultivars indicated significant differences (Table 4). Cultivar Arizona came out with the highest average of tuber weight (123.8 g), followed by the cultivar Sifra (V2), while the cultivar Rashida recorded the lowest average for the said trait (107.8 g).

Table 3. Effect of cultivars, bio- and nanofertilization, and their interaction on the chlorophyll content of leaves in potato.

Treatments		Potato cultivars			Means	
Nanofertilization	Biofertilization	Rashida (V1)	Sifra (V2)	Arizona (V3)	N × B	Nanofertilization means (mg 100 g^{-1})
N_0 (0 g L^{-1})	B_0	24.28	34.30	47.70	35.43	37.25
	B_1	35.70	26.52	46.98	36.40	
	B_2	34.65	30.43	50.49	38.52	
	B_3	29.80	47.95	38.15	38.63	
N_1 (2 g L^{-1})	B_0	28.38	46.90	43.91	39.73	46.36
	B_1	39.55	50.06	48.91	46.17	
	B_2	45.95	50.30	47.71	47.99	
	B_3	42.97	49.10	62.55	51.54	
$LSD_{0.05}$	10.25				N.S	2.96
V×N		N_0	N_1		Cultivars means (mg 100 g^{-1})(	
	V_1	31.11	39.21		35.16	
	V_2	34.80	49.09		41.94	
	V_3	45.83	50.77		48.30	
$LSD_{0.05}$	5.12				3.62	
V × B		V_1	V_2	V_3	Biofertilization means (mg 100 g^{-1})	
	B_0	26.33	40.60	45.80	37.58	
	B_1	37.62	38.29	47.95	41.29	
	B_2	40.30	40.36	49.10	43.25	
	B_3	36.38	48.52	50.35	45.09	
$LSD_{0.05}$	7.25				4.18	

Table 4. Effect of cultivars, bio- and nanofertilization, and their interaction on the weight of tubers in potato.

Treatments		Potato cultivars			Means (g)	
Nanofertilization	Biofertilization	Rashida (V1)	Sifra (V2)	Arizona (V3)	N × B	Nanofertilization means (g)
N_0 (0 g L^{-1})	B_0	92.1	115.0	103.9	103.7	112.7
	B_1	105.9	118.2	122.7	115.6	
	B_2	104.0	118.7	110.2	111.0	
	B_3	108.7	121.4	131.7	120.6	
N_1 (2 g L^{-1})	B_0	105.9	114.5	131.6	117.3	119.9
	B_1	116.9	120.9	124.1	120.6	
	B_2	105.9	114.5	129.9	116.8	
	B_3	123.1	115.1	135.8	124.6	
$LSD_{0.05}$	9.02				5.20	2.60
V × N		N_0	N_1		Cultivars means (g)	
	V_1	102.7	112.9		107.8	
	V_2	118.3	116.2		117.3	
	V_3	117.1	130.4		123.8	
$LSD_{0.05}$	4.51				3.19	
V × B		V_1	V_2	V_3	Biofertilization means (g)	
	B_0	99.0	114.7	117.8	110.5	
	B_1	111.4	119.5	123.4	118.1	
	B_2	104.9	116.6	120.1	113.9	
	B_3	115.9	118.2	133.7	122.6	
$LSD_{0.05}$	6.38				3.68	

Table 5. Effect of cultivars, bio- and nanofertilization, and their interaction on the total yield in potato.

Treatments		Potato cultivars			Means (kg plant^{-1})	
Nanofertilization	Biofertilization	Rashida (V1)	Sifra (V2)	Arizona (V3)	N x B	Nanofertilization means (kg plant^{-1})
N_0 (0 g L^{-1})	B_0	0.459	0.785	0.643	0.629	0.772
	B_1	0.761	0.838	0.898	0.832	
	B_2	0.644	0.841	0.728	0.738	
	B_3	0.704	0.880	1.086	0.890	
N_1 (2 g L^{-1})	B_0	0.668	0.786	1.032	0.829	0.877
	B_1	0.736	0.910	0.924	0.856	
	B_2	0.668	0.785	1.006	0.820	
	B_3	0.896	0.790	1.327	1.004	
$LSD_{0.05}$	0.136				0.078	0.039
V × N		N_0	N_1		Cultivars means (kg plant^{-1})	
	V_1	0.642	0.742		0.692	
	V_2	0.836	0.818		0.827	
	V_3	0.839	1.072		0.955	
$LSD_{0.05}$	0.068				0.048	
V × B		V_1	V_2	V_3	Biofertilization means (kg plant^{-1})	
	B_0	0.564	0.785	0.838	0.729	
	B_1	0.748	0.874	0.911	0.844	
	B_2	0.656	0.813	0.867	0.779	
	B_3	0.800	0.835	1.206	0.947	
$LSD_{0.05}$	0.096				0.055	

Biofertilization treatments also have a notable impact on tuber yield, and treatment B3 appeared with the maximum average for tuber weight (122.6 g), followed by treatment B1. Meanwhile, treatment B0 emerged with the lowest average for the trait (110.5 g). It was also noticeable that the nanofertilization treatments signified prominent differences, with the treatment N1 recording the superior average (119.9 g) and the control treatment N0 giving the lowest tuber weight (112.7 g).

As for the interaction between the cultivars and biofertilization, substantial variations existed for tuber weight (Table 4). The interaction treatment V3B3 manifested the highest average (133.7 g), while treatment V1B0 recorded the lowest average (99.0 g). The interaction between the potato cultivars and the nanofertilization concentrations also had a positive effect on the average tuber weight. Treatment V3N1 recorded the topmost average (130.4 g), while treatment V1N0 provided the lowest value for the said trait (102.7 g). The interaction treatments between biofertilization and nanofertilization had a notable superiority, with the treatment B3N1 recording the highest average (124.6 g) and treatment B0N0 with the lowest average for tuber weight (103.7 g). The interaction among the three study factors revealed significant differences for potato tuber weight. The interaction V3B3N1 showed the highest average (135.8 g), while the treatment V1B0N0 recorded the lowest tuber weight (92.1 g).

Tuber yield per plant

On tuber yield per plant, the potato cultivars exhibited significant differences (Table 5). Cultivar Arizona was visible with the highest average tuber yield per plant (0.955 kg plant^{-1}), followed by the cultivar Sifra; however, the cultivar Rashida was evident with the lowest average tuber yield per plant (0.692 kg plant^{-1}). The biofertilization treatments also positively affected tuber yield. The treatment B3 displayed the maximum average (0.947 kg plant^{-1}), followed by treatment B1, with the comparison treatment (B0) recording the lowest average (0.729 kg plant^{-1}). Moreover, remarkable diversities surfaced for the nanofertilization treatments, and the treatment N1 demonstrated the utmost average (0.877 kg plant^{-1}). Meanwhile, the control treatment

(N0) appeared with the lowest average of tuber yield per plant (0.772 kg plant^{-1}).

As for the interaction between the potato cultivars and biofertilization, significant differences showed for tuber yield per plant (Table 5). The treatment V3B3 recorded the highest average (1.206 kg plant^{-1}), while treatment V1B0 appeared with the lowest average for tuber yield (0.564 kg plant^{-1}). Likewise, the interaction between cultivars and nanofertilization significantly influenced the said trait, with the treatment V3N1 recording the topmost average (1.072 kg plant^{-1}), and treatment V1N0 giving the lowest average tuber yield per plant (0.642 kg plant^{-1}). The interaction between biofertilization and nanofertilization also considerably affected the tuber yield per plant, with the interaction B3N1 indicating the highest average (1.004 kg plant^{-1}), and the control treatment B0N0 exhibiting the lowest average for the said trait (0.629 kg plant^{-1}). The interaction among the potato cultivars, biofertilization, and nanofertilization provided significant differences for tuber yield. The triple interaction V3B3N1 was evidently with the highest average tuber yield per plant (1.327 kg plant^{-1}). Meanwhile, the combination V1B0N0 emerged with the lowest average for tuber yield (0.459 kg plant^{-1}).

DISCUSSION

Results revealed a significant effect of the potato cultivars on various growth and tuber yield characteristics. The reason for the increase in the cultivar Arizona for speed of emergence, plant height, chlorophyll content of the leaves, tuber weight, and the total tuber yield may be due to the genetic factors specific to each cultivar and the suitability of the cultivar to the prevailing environmental conditions, such as, temperature and lighting intensity (Al-Janabi, 2023). The study further reported notable differences among the cultivars for vegetative growth indicators and yield, depending on the genetic ability of the cultivars and the prevailing environmental conditions in the region during the growing season (Tessema *et al.,* 2020).

The biofertilizer addition also considerably affected the vegetative growth characteristics and potato tuber yield. The increase in emergence speed, plant height, leaf chlorophyll content, tuber weight, and the total tuber yield per plant may be because of the positive role of the biofertilizer, working to add growth stimulants, such as auxins and cytokinins. These substances play a remarkable role in enhancing the root mass and increasing efficiency of the nutrients' absorption from the soil, as the biofertilizers contain biologically active substances. These are enzymes, nutrients, plant hormones, and other substances stimulating the growth and development, positively influencing most of the characteristics of the vegetative growth (Almohammedi *et al.,* 2023).

Perhaps the reason for the increase in the vegetative growth could also be due to the role of the biofertilizer represented by the mycorrhizal fungus dissolving the phosphates and releasing the phosphorus elements. It works to dissolve and convert the phosphate to the ready form for uptake by crop plants (Ahemad and Kibret, 2014; Bhattacharyya and Jha, 2012). The reason for enhancement may refer to the fact that the biofertilizer works to make nutrients available for absorption by the plants. Additionally, it boosts the positive role of the microorganisms that enhance the biological activities in the soil and the readiness of the nutrients for absorption, as well as their biological resistance (Ahemad *et al.,* 2009; Haq *et al*., 2021; Nurul-Afza *et al*., 2023).

Nanofertilizers had a significant effect on the potato vegetative growth and tuber yield. The nanofertilizer notably increased the vegetative growth characteristics and tuber yield, represented by the speed of emergence, plant height, leaf chlorophyll content, tuber weight, and tuber yield per plant. The reason for the considerable increase in these traits may be due to the fertilizer nanoparticles entering the plant leaves through the stomata more quickly and transferring to the conveying vessels more efficiently (Wang *et al.,* 2013; Al-Nuaimi *et al.,* 2021). The said improvement in various growth and yield traits could also refer to the positive role of nitrogen, involved in the process of building proteins and nucleic acids, leading to the enhanced division of chloroplasts and enzyme activities responsible for the chlorophyll molecules' formation.

Potassium is also an important element and has substantially increased the plant growth and development through cell division and by boosting other biological activities. The cells expand as a result of providing the appropriate swelling pressure, plus their role in activating various enzymes responsible for building the synthetic material involved in building the plant structure. These resulted in an increase in vegetative growth indicators. Potassium is an osmotic regulator, affecting the process of opening and closing the stomata and the subsequent effects. Similarly, it affects the absorption of water and nutrients, activating the photosynthesis process and increasing manufactured carbohydrates, thus increasing cell elongation and division and improving plants' growth and yield traits (Claussen, 2005; Okur *et al.,* 2006).

CONCLUSIONS

Potato cultivar Arizona performed better than the two other cultivars for growth and tuber yield traits under the existing environmental conditions. Biofertilization (10 g from a mixture of bacterial and fungal biofertilizers + half of the recommended fertilizer) and nanofertilization with a concentration of 2 g L^{-1} also had a significant positive influence on the growth and tuber yield.

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