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The Role of Seaweed Extract, Mixure of *Bacillus paramycoides* and *Azotobacter nigricans* and Potassium Phosphite Foliar Spray in Growth and Productivity of Potato

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ABSTRACT

Two field experiments were carried out at a private farm, El-Taweila Village, near El-Mansoura City, Dakahlia Governorate, Egypt during the two summer seasons of 2019/2020 and 2020/2021. The study aims to investigate the role of seaweed extract at 0.5 g/L, bacterial mixture of *Bacillus paramycoides* and *Azotobacter nigricans* at 1 cm^3/L and potassium phosphite at 2.5 cm^3/L individual or in combination as foliar applications on vegetative growth, tuber yield and tuber quality of potato cv. Kara. The obtained results showed that all studied treatments increased vegetative growth (plant height, leaves number per plant, stolons number per plant and fresh and dry weight per plant) and tuber yield (tuber weight, tuber dry matter, tubers number per plant and tuber yield per fed) as well as improved tuber quality (N, P, K, starch and carbohydrates percentages) compared to control. The results suggested spraying potato plants with seaweed at 0.5 g/L, the bacterial mixture of *Bacillus paramycoides* and *Azotobacter nigricans* at 1 cm^3/L and potassium phosphite at 2.5 cm^3/L to improve the vegetative growth and increase the tuber yield and quality under similar conditions of the study.

Keywords: Potato, productivity, seaweed, phosphite, bacteria

INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the important food crops in the world, ranking fourth after maize, rice and wheat (Mishra *et al*., 2019). It is a good source of carbohydrates, protein, fiber, vitamin C, vitamin B6, b-carotene, polyphenols, and minerals, i.e., potassium, magnesium and iron (Zaheer and Akhtar, 2016). Potato is a heavy feeder crop where it needs high amount of fertilizers for good growth and high productivity (Nityamanjari, 2018). Currently, increasing human population and extreme climate changes assimilate greater pressure on soil and water resources and affect the ability to produce sufficient food (Meena *et al*., 2016 and Shahzad *et al*., 2021), as the world will need 25–70 % above current production levels to meet crop demand in 2050 (Hunter *et al*., 2017). Consequently, chemical fertilizers and pesticides are used during the growing season to supply the crops with nutrient needs and protect them against pests, resulted in great environmental pollution, induced pest resistance and having potential risks to human health (Sansinenea, 2019). Therefore, using environmentally sustainable alternatives to agrochemicals such plant biostimulants (PBs) has attracted worldwide interest in recent years. Plant biostimulants are any substances or microorganisms applied to the plants for enhancing nutrition efficiency, abiotic stress tolerance and/or crop quality, irrespective of its nutrient content (du Jardin, 2015).

In recent times, seaweed extracts have been widely used in agriculture as plant biostimulants, improve plant growth and increase the productivity and the tolerance to abiotic and biotic stresses (Parađiković *et al*., 2019 and El-Boukhari *et al*., 2020). Seaweeds (macroalgae) include almost 10,000 species that are subdivided primarily into three categories depending on their pigmentation (Brown, Red and Green) and contribute to about 10 % of global maritime productivity (Khan *et al*., 2009 and Battacharyya *et al*., 2015). Seaweed and seaweed-derived products contain a wide variety of natural plant promoting substances such as auxins, cytokinins and gibberellins, macro-and micronutrients, proteins, carbohydrates, amino acids, osmo-protectants and antimicrobial compounds in addition to many different polysaccharides like galactans, fucoidan, laminarin, and alginates (Abido *et al*., 2020 and Ali *et al*., 2021a). Actually, seaweed extract foliar spray can be used for promoting plant growth, enhancing flowering and yield and improving nutritional content and quality as well as shelf life (Battacharyya *et al*., 2015). The positive effects depend on the type of the seaweed resource, the quality, and the composition of the extract, as well as application method and concentration (Ali *et al*., 2021a).

An important group of plant biostimulants is microorganisms including fungi and bacteria (Drobek *et al*., 2019). The useful bacteria include *Bacillus* spp., *Azotobacter* spp., *Enterobacter* spp., *Arthrobacter* spp., *Acinetobacter* spp., *Pseudomonas* spp., *Ochrobactrum* spp. and *Rhodococcus* spp. (Gaiero *et al*., 2013 and Saifulla *et al*., 2019) which can improve plant growth and mineral uptake, control plant pathogens and increase plant tolerance to different stresses (Hamid *et al*., 2021). These organisms can produce phytohormones like auxins, gibberellins and cytokinins, antifungals, fix nitrogen and solubilize phosphorous and other nutrients (Sansinenea, 2019). Microbial inoculants may contain a single or a mixture of

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microorganism strains that exhibit additive or synergistic effects (du Jardin, 2015).

Likewise, phosphite, a reduced form of phosphate, appears as a new biostimulator in horticulture (Gómez-Merino and Trejo-Téllez, 2015). Phosphites are alkaline salts of phosphorous acid, like potassium phosphite, which are widely used as fungicides (Schroetter *et al*., 2006). Phosphite (H_2PO_3-) contains one less oxygen (O) than phosphate, which makes its chemistry and behavior fully different (Lovatt and Mikkelsen, 2006). Phosphites (Phi) have received particular attention because they are eco-friendly and seem to be able to control crop diseases caused by pathogenic bacteria, oomycetes, fungi, and nematodes through enhanced plant defense responses (Deliopoulos *et al*., 2010 and Trejo-Téllez and Gómez-Merino, 2018). Nowadays, phosphite is appears as a new plant biostimulant, improving crop productivity, so it can be considered as a biostimulant, antibiotic and plant resistance inducer (Trejo-Téllez and Gómez-Merino, 2018). As a plant biostimulant, Phi has been shown to improve nutrient uptake and promotes root growth, yield and nutritional value of horticulture crops. Additionally, it can activate several molecular, biochemical, and physiological mechanisms leading to plant tolerance to abiotic stresses (Gómez-Merino and Trejo-Téllez, 2015 and 2016). It was reported that phosphite foliar treatment enhanced root growth and development in several crops, with a biomass increase by around 30 % (Swarup *et al*., 2020) and increased yield and quality (Lovatt and Mikkelsen, 2006).

Therefore, this study aims to investigate the role of seaweed extract, microbial inoculants (*Bacillus paramycoides* and *Azotobacter nigricans*) and potassium phosphite as a foliar spray on growth and productivity of potato.

MATERIALS AND METHODS

Bacterial isolates

The Gram-positive; *Bacillus paramycoides* ZW-5 and the Gram-negative; *Azotobacter nigricans* NEWG-1 were used in the current study. Later, both bacteria were molecular identified and deposited in the GenBank under accession numbers of MW876249 (Moussa *et al*., 2021) and LC485953 (Ghoniem *et al*., 2020), respectively.

Bacterial preparation

Nutrient broth medium containing (g L^{-1} distilled water), beef extract (1), yeast extract (2), peptone (5), and NaCl (5) was used to prepare the inoculum. The medium was autoclaved at 121°C for 15 min, then incubated under shaking (150 rpm at 28 °C for 2 days). The fermentation conditions for IAA producing were carried out on a nutrient broth medium, supported with 5 mM L-tryptophan. The medium pH was adjusted to 7±0.2 before autoclavation (121°C for 15 min). Inoculum at 5 % was used to inject 45 ml broth medium contained in 250-ml Erlenmeyer flasks. After incubation under shaking (150 rpm at 28 °C for 3 days), the culture was centrifuged at 5000 rpm for 20 min to obtain the supernatant. Indole acetic acid (IAA) and total phenolic contents were assayed in the culture supernatant using the method of Glickmann and Dessaux (1995) and Malik and Singh (1980), respectively. The pH of the final culture was measured using pH-meter (HI 9321 microprocessor pH-meter). Before the mixed culture of both bacteria, the antagonism test was carried out to ensure the compatible growth of both bacteria with each other.

Field trial

Two field experiments were carried out in a private farm, El-Taweila Village, near El-Mansoura City, Dakahlia Governorate, Egypt (31.114849 N, 31.409796 E) during the two successive seasons of 2019/2020 and 2020/2021. The study aims to investigate the role of seaweed extract, bacterial mixture of *Bacillus paramycoides* and *Azotobacter nigricans* and potassium phosphite, individually or in combination as a foliar spray on the growth and productivity of potato cv. Kara.

The experiment was arranged in a complete randomized block design with eight treatments and three replicates. The treatments were T1 (seaweed extract), T2 (bacterial mixture of *Bacillus paramycoides* and *Azotobacter nigricans*), T3 (potassium phosphite), T4 (mixture of T1 and T2), T5 (mixture of T1 and T3), T6 (mixture of T2 and T3), T7 (mixture of T1, T2 and T3) and T8 (control of untreated plants).

The experimental soil was clay loam with organic matter (2.58 %), EC (295 ds/cm), pH (7.8), available nitrogen (58.50 ppm), phosphorus (16.15 ppm) and potassium (346 ppm). The tubers were planted on 5th and 10th December in the first and second seasons of the study at a 20 cm distance. The tubers were treated with an antifungal compound before planting. The plot area was 8.4 m^2, which consists of 3 ridges (4 m long and 0.7 m width). The plants were sprayed three times, at 20 days after sowing, and repeated every 15 days. Seaweed extract (Alga bright, a commercial product) consists of *Ascophyllum nodosum* alga extract and 16 % potassium alginate was sprayed at the rate of 0.5 g/L. The bacterial mixture of *B. paramycoides* and *A. nigricans* was prepared as previously described and mixed in equal portions, then diluted at the rate of 1 cm^3/L immediately before spraying. Potassium phosphite (H_2KO_3P) was sprayed at 2.5 cm^3/L. Potato plants were fertilized with the recommended rates (180 kg N, 75 kg P_2O_5 and 90 kg K_2O). Normal farming practices were followed as recommended by the Egyptian Ministry of Agriculture and Land Reclamation recommendations.

Studied characters

Vegetative growth

Five plants from each plot were chosen randomly in both seasons at 70 days from planting to determine plant height (cm), leaves number/plant, stolons number/plant, fresh weight (g) and dry weight (g).

Tuber yield

At the harvest time, the following parameters were measured, i.e., tuber weight (g), tuber dry matter (%), tubers number/plant and tuber yield/fed (ton).

Tuber quality

A representative sample of ten healthy tubers from each plot was selected to determine total nitrogen (%) according to AOAC (1990), phosphorus and potassium (%) according to Rangana (1977) and total carbohydrates using the method described by Hodge and Hofreiter (1962).

Starch content (%) in tubers was determined according to the formula described by Burton (1984) as follows:

$$\textbf{Starch} = 17.55 + 0.891\ (\textbf{Dry matter \%} - 24.18)$$

Statistical analysis

The obtained data were analyzed according to Snedecor and Cochran (1990). Duncan's multiple range test at 0.05 of probability level was used to compare the differences among means. The statistical analysis was performed using CoStat version 6.400, 1998-2008 CoHort Software.

RESULTS AND DISCUSSION

Secretion of bioactive compounds

Initially, an antagonism test was carried out between both bacteria to ensure the compatibility between both microbes. No antagonistic effect was observed between both bacteria. So, they were mixed in a combined treatment. Both *B. paramycoides* and *A. nigricans* were screened for the bioactive compounds (IAA and total phenol) production and their final culture pH (Table 1). The results indicated that *B. paramycoides* was better in the secretion of total phenol (11.54 µg/ml) than *A. nigricans*. On the other hand, *A. nigricans* secreted the higher amount of IAA. However, the mixed culture of both bacteria showed marked increments in both bioactive compounds than the individual inoculation.

Table 1. Screening of both *B. paramycoides* and *A. nigricans*, as well as their mixture for the production of bioactive compounds and their final culture pH.

Bacterium	IAA (µg/ml)	Total phenol (µg/ml)	Final culture pH
B. paramycoides	8.43	11.54	8.47
A. nigricans	19.47	8.58	7.53
Mixture	32.87	16.63	7.07

Vegetative growth

The data of the field trial (Table 2) show the effect of studied foliar treatments, i.e., seaweed extract, the bacterial mixture, K-phosphite and their combinations in growth parameters of potato. Compared with control (untreated plants) all foliar treatments increased plant height, leaves number/plant, stolons number/plant and fresh and dry weight of the plant in the two studied seasons. Sprayed potato plants with (seaweed + bacterial mixture + K-phosphite) recorded significant high values followed by (seaweed + K-phosphite) in the two seasons while the untreated plants came in the last order. The positive effect of seaweed extract, bacterial mixture and K-phosphite was reported by Purwantisari *et al.* (2019), Uysal and Kantar (2020), Wadas and Dziugieł (2020) and Xi *et al.* (2020).

The studied treatments improved the vegetative growth of potato compared to control plants in both seasons of the experiment. Seaweeds have a positive impact on the growth characteristics of potato (Table 2) and that may be due to the presence of auxins, cytokinines, gibberellins and several nutrient elements, vitamins and organic matter (October, 2017). These components enhanced the growth of lateral roots, improved nitrogen assimilation and promoted the plant growth (Battacharyya *et al*., 2015), resulting in an increase in plant height, leaves number and plant fresh and dry weight (Table 2). Further, the betaine compound in seaweed extracts stimulates chlorophyll synthesis by the inhibition of chlorophyll degradation (Blunden *et al*., 1996).

In addition, PGPB can improve plant growth by different direct and indirect mechanisms. The direct mechanisms include fixing nitrogen and production of phytohormones such auxins (Table 1), gibberellins, cytokinins and ethylene and secondary metabolites (Figueiredo *et al*., 2016 and Vejan *et al*., 2016). The indirect contain producing inhibitory substances against phytopathogens, releasing siderophores and increasing the plant natural resistance (Sansinenea, 2019). Also, it was reported that *Bacillus* sp. was able to develop a symbiosis with potato roots (Keerthana *et al*., 2018), leading to alteration of root architecture (Sansinenea, 2019) and increased branching (Purwantisari *et al*., 2019), resulting in increased mineral absorption and improved plant growth.

Likewise, phosphite foliar treatment improves leaf water use efficiency and carbon assimilation and increases nitrate reductase-a key enzyme in N assimilation, resulting in increased assimilation of inorganic N to build up plant organs (Swarup *et al*., 2020). Also, the previous researcher found that phosphite treatment increased zeatin, one of cytokinins, in root tissues across all time points in wheat. In addition, phosphite influences primary metabolism and cell wall-associated processes (Liljeroth *et al*., 2016), which include the production of primary and secondary metabolites that are essential for plant growth and tolerance to different stresses (Han *et al*., 2021). In potato, Tambascio *et al.* (2014) found that potassium phosphite treatment increased plant leaf area and dry weight.

Table 2. Effect of seaweed extract, the bacterial mixture, potassium phosphite and their combinations on growth parameters of potato in 2019/2020 and 2020/2021 seasons.

Treatments	Plant height (cm)		Leaves No /plant		Stolons No /plant		Fresh weight /plant (g)		Dry weight /plant (g)	
	1 st	2 nd	1 st	2 nd	1 st	2 nd	1 st	2 nd	1 st	2 nd
T 1	61.00 c*	67.66 bc	25.00 c	31.66 b	8.00 c	8.33 de	204.14 e	220.56 e	15.21 ef	15.95 ef
T 2	55.66 e	62.00 e	22.00 d	26.33 d	7.83 c	8.00 e	197.63 f	219.40 e	15.53 ef	16.08 ef
T 3	58.33 d	66.00 cd	24.83 c	30.66 bc	8.83 b	9.33bcd	217.80 c	233.29 cd	17.02 cd	17.89 cd
T 4	62.16 bc	68.33 bc	25.16 c	31.00 b	8.66 b	8.66 cde	210.35 d	228.01 d	16.29 de	16.62 de
T 5	63.83 ab	69.66 b	28.33 b	35.00 a	9.00 b	10.33 b	228.42 b	245.41 b	19.54 b	19.76 ab
T 6	57.16 de	65.00 d	21.00 d	28.33 cd	8.66 b	9.66 bc	218.86 c	236.83 c	18.25 bc	19.05 bc
T 7	65.50 a	72.66 a	31.33 a	35.33 a	10.16 a	11.66 a	233.26 a	251.90 a	20.90 a	21.12 a
T 8	50.83 e	57.66 f	16.33 e	19.66 e	6.16 d	6.66 f	160.88g	183.82 f	14.38 f	14.92 f

T1 (seaweed extract), T2 (bacterial mixture of *B. paramycoides and A. nigricans*), T3 (potassium phosphite), T4 (mixture of T1 and T2), T5 (mixture of T1 and T3), T6 (mixture of T2 and T3), T7 (mixture of T1, T2 and T3), and T8 (control of untreated plants). Values in each column followed by the same letter are not significantly different at (P = 0.05).

Tuber yield

The effect of foliar treatments, i.e., seaweed extract, mixture of *B. paramycoides* and *A. nigricans*, K-phosphite and their combinations on potato tuber yield is presented in Table 3. Tuber weight, tuber dry matter, tubers number/plant and tuber yield/fed positively affected by aforementioned foliar treatments in the two seasons of 2019/20 and 2020/21. The highest values were obtained by (seaweed + bacterial mixture + K-phosphite) treatment (T7) followed by (seaweed + K-phosphite) treatment (T5). In general, all treatments significantly increased tuber yield and its components compared to control (T8). Similar results were noticed by Trdan *et al.* (2019), Ali *et al.* (2021b), Garai *et al.* (2021) and Han *et al.* (2021).

Table 3. Effect of seaweed extract, the bacterial mixture, potassium phosphite and their combinations on yield attributes of potato in 2019/2020 and 2020/2021 seasons.

Treatments	Tuber weight (g)		Tuber dry matter (%)		Tubers number /plant		Tuber yield /fed (ton)	
	1 st	2 nd	1 st	2 nd	1 st	2 nd	1 st	2 nd
T 1	156.67 c	157.18 c	15.53 e	16.08 ef	3.94 c	4.00 d	17.678 d	17.964 e
T 2	152.01 d	152.23 d	15.21 ef	15.95 ef	3.95 c	4.06 bcd	17.155 e	17.690 e
T 3	158.60 bc	159.87 bc	17.02 d	17.89 cd	3.96 c	4.05 cd	17.976 c	18.500 cd
T 4	157.84 bc	158.40 c	16.29 de	16.62 de	3.95 c	4.01 d	17.833 cd	18.178 de
T 5	159.62 ab	162.26 ab	19.54 b	19.76 ab	4.05 b	4.10 bc	18.490 b	19.047 b
T 6	157.91 bc	158.58 c	18.25 c	19.05 bc	3.99 c	4.13 b	18.028 c	18.738 bc
T 7	160.67 a	164.62 a	20.90 a	21.12 a	4.17 a	4.21 a	19.166 a	19.833 a
T 8	145.10 e	148.18 e	14.38 f	14.92 f	3.82 d	3.89 e	15.857 f	16.476 f

T1 (seaweed extract), T2 (bacterial mixture of *B. paramycoides and A. nigricans*), T3 (potassium phosphite), T4 (mixture of T1 and T2), T5 (mixture of T1 and T3), T6 (mixture of T2 and T3), T7 (mixture of T1, T2 and T3), and T8 (control of untreated plants). Values in each column followed by the same letter are not significantly different at (P = 0.05).

In the present study, seaweed extract improved potato tuber yield and its components (Table 3). Such increment may be due to the positive effect of plant growth regulators and macro and micronutrients existing in seaweed extract on potato vegetative growth which reflected on tuber yield. However, seaweed extract increased tuber content of phosphorous (Table 4), stimulated root mass, increased nutrient uptake, developed tuber formation and improved tuber yield of potato (October, 2017). In a study conducted by Issa *et al.* (2019), it was reported that tuber numbers, tuber weight, and tuber yield of potato increased compared to control due to seaweed extract treatment.

Concerning bacterial inoculation, the increase in tuber yield may be due to the increase in tubers number and weight (Table 3). Plant growth promoting rhizobacteria (PGPR) produce auxins, gibberellins and cytokines (Sansinenea, 2019) which contributed to the production of potato tubers. Also, (PGPR) can protect the plant organs against different phytopathogens (Kashyap *et al*., 2019). In this context, Tahir *et al.* (2019) found that rhizobacteria inoculation increased potato tuber weight grown in normal or salt stress conditions. In a similar way, Hassani *et al.* (2016) indicated that inoculated potato plants with *B. megaterium* and *B. subtilis* caused enhancement of the tuberization and yield.

As to phosphite (Phi), it may affect sugar metabolism, cause changes in internal hormonal, and stimulate the shikimic acid pathway, leading to increased tuber yield of potato (Lovatt and Mikkelsen, 2006). Additionally, Phi may induce many molecular, biochemical and physiological processes leading to increasing crop production (GómezMerino and Trejo-Téllez 2016).

Tuber quality

Potato tubers content of N, P, K, starch and carbohydrates were well responded to foliar treatments compared to untreated plants. Sprayed potato plants with seaweed extract plus the mixture of *B. paramycoides* and *A. nigricans* plus K-phosphite (T7) produced potato tubers with higher content of nutrients, starch and carbohydrates in comparison with other studied treatments. *B. paramycoides* and *A. nigricans* mixture + K-phosphite (T6) and *B. paramycoides* and *A. nigricans* mixture + seaweed extract (T5) foliar treatments came second and third, respectively. Disregard control, when compared the sole treatments, potassium phosphite surpassed seaweed and bacterial mixture treatments in all parameters. Similar findings were noticed by Abdel-Gaied *et al*. (2020) and El-Anany *et al.* (2020).

The enhancing effect of seaweed extract foliar treatment on the tubers content of N, P and K (Table 4) may be attributed to its role in regulating some root nutrient transporter genes (El-Boukhari *et al*., 2020) which led to more uptake of nutrients. Furthermore, seaweed could contribute to break down the polysaccharides of the cell wall and increasing sugar contents within the tuber tissues (Abido *et al*., 2020) which, in turn, enhanced the potato tuber quality.

Concerning bacterial treatment, it can improve the availability of N, P and K nutrients in potato tubers through the production of some organic acids and other chemicals, which stimulate plant growth and nutrient availability (Ali *et al*., 2021b). Moreover, PGPR increased root branching (Purwantisari *et al*., 2019) which led to increased mineral absorption and accumulation in tubers. Our results are in line with those found by Ali *et al.* (2021b) they showed that inculcated potato plants with PGPR significantly increased the uptake of N, P and K by 34%, 32% and 62%, respectively compared to the control.

Additionally, potassium phosphite produced potato tubers with higher values of N, P, K, starch and carbohydrtaes and that might be due to the role of phosphite in improving N mobilization resulting in a higher nutrient efficiency (Swarup *et al*., 2020). Furthermore, in sugarcane, K-phosphite probably improves soluble solids availability by releasing water-soluble inorganic ions like P and K, and signaling of phytoalexins synthesis and antimicrobial secondary metabolites which protect plants from pathogens (Moreira *et al*., 2019). In potato, Achary *et al*. (2017) found that phosphite foliar treatment increased pectin content and polygalacturonase activity and induced the formation of a new chitinase isoform in tubers. In another study, Xi *et al.* (2020) reported that some biosynthetic pathways of low-molecular-weight metabolites like glucose and fructose were activated by Phi application.

Table 4. Effect of seaweed extract, the bacterial mixture, potassium phosphite and their combinations on tuber quality of potato in 2019/2020 and 2020/2021 seasons.

Treatments	N %		P %		K %		Starch %		Carbohydrates %	
	1 st	2 nd	1 st	2 nd	1 st	2 nd	1 st	2 nd	1 st	2 nd
T 1	2.28 d	2.37 g	0.324 d	0.330 f	2.83 g	2.90 g	9.84 e	10.33 ef	24.99 de	25.50 d
T 2	2.33 d	2.42 f	0.331 c	0.342 e	2.92 f	3.00 f	9.55 ef	10.22 ef	25.33 cd	25.83 d
T 3	2.44 c	2.55 e	0.346 b	0.352 c	3.15 d	3.22 d	11.17 d	11.94 cd	25.50 bcd	26.24 c
T 4	2.50 c	2.60 d	0.340 b	0.345 d	3.05 e	3.10 e	10.52 de	10.81 de	25.71 bc	26.60 c
T 5	2.58 b	2.69 c	0.354 a	0.364 b	3.20 c	3.27 c	13.41 b	13.61 ab	26.02 abc	26.98 b
T 6	2.62 ab	2.72 b	0.357 a	0.365 b	3.25 b	3.32 b	12.26 c	12.97 bc	26.18 ab	27.11 b
T 7	2.67 a	2.77 a	0.360 a	0.369 a	3.29 a	3.39 a	14.63 a	14.82 a	26.47 a	27.61 a
T 8	2.18 e	2.26 h	0.314 e	0.322 g	2.70 h	2.74 h	8.82 f	9.30 f	24.59 e	25.06 e

T1 (seaweed extract), T2 (bacterial mixture of *B. paramycoides and A. nigricans*), T3 (potassium phosphite), T4 (mixture of T1 and T2), T5 (mixture of T1 and T3), T6 (mixture of T2 and T3), T7 (mixture of T1, T2 and T3), and T8 (control of untreated plants). Values in each column followed by the same letter are not significantly different at (P = 0.05).

CONCLUSION

From the finding of this study it can be concluded that spraying potato plants with seaweed extract at 0.5 g/L, the bacterial mixture of *B. paramycoides* and *A. nigricans* at 1 cm^3/L and K-phosphite at 2.5 cm^3/L three times, starting from 20 days after planting, and repeated every 15 days was effective practice for increasing potato growth and productivity and improving tuber quality under similar conditions of the study.

REFERENCES

Abdel-Gaied, T.G., M. S. Mikhail, A. I. Abdel-Alim, H. I. S. El-Nasr and H. Abd El-Khair (2020). Field application of bio-control agents and aqueous plant extracts for controlling bacterial soft rot and enhancement yield quality of *Solanum tuberosum* L. cv. Diamond. Bulletin of the National Research Centre, 44(82): 2-11.

Abido, A. I. A., A. A. A. Alkharpotly, S. A. El-Hakim and A. N. Abd El-Aziz (2020). Processing potato growth performance as affected by foliar application of seaweed extract and boron. J. Adv. Agric. Res., 25(1): 66-85.

Achary, V. M. M., B. Ram, M. Manna, D. Datta, A. Bhatt, M. K. Reddy and P. K. Agrawal (2017). Phosphite: a novel P fertilizer for weed management and pathogen control. Plant Biotechnology Journal, 15: 1493-1508.

Ali, A. M., M. Y. M. Awad, S. A. Hegab, A. M. Abd El Gawad and M. A. Eissa (2021b). Effect of potassium solubilizing bacteria (*Bacillus cereus*) on growth and yield of potato. Journal of Plant Nutrition, 44 (3): 411-420.

Ali, O., A. Ramsubhag and J. Jayaraman (2021a). Biostimulant properties of seaweed extracts in plants: implications towards sustainable crop production. Plants, 10, 531: 1-27.

AOAC (1990). Association of official agricultural chemists. Methods of analysis, 15th edition, Washington, D.C. USA.

Battacharyya, D., M. Z. Babgohari, P. Rathor and B. Prithiviraj (2015). Seaweed extracts as biostimulants in horticulture. Scientia Horticulturae, 196: 39-48.

Blunden, G., T. Jenkins and Y.W. Liu (1996). Enhanced leaf chlorophyll levels in plants treated with seaweed extract. J. Appl. Phycol., 3: 13-19.

Burton, W.G. (1984). The potato. Chapman and Hall, London, 319 p.

Deliopoulos, T., P.S. Kettlewell and M.C. Hare (2010). Fungal disease suppression by inorganic salts: a review. Crop Prot., 29: 1059-1075.

Drobek, M., M. Frac and J. Cybulska (2019). Plant biostimulants: importance of the quality and yield of horticultural crops and the improvement of plant tolerance to abiotic stress-a review. Agronomy, 9(335): 1-18.

du Jardin, P. (2015). Plant biostimulants: definition, concept, main categories and regulation. Scientia Horticulturae, 196: 3-14.

El-Anany, A. M. A., Y. M. M. Osman and M. M. M. Abd El-Aal (2020). Studies on improving potato growth, yield and quality. Annals of Agric. Sci., Moshtohor, 58(4): 963-976.

El-Boukhari, M. E., M. Barakate, Y. Bouhia and K. Lyamlouli (2020). Trends in seaweed extract based biostimulants: manufacturing process and beneficial effect on soil-plant systems. Plants, 9(3): 1-23.

Figueiredo, M.V. B., A. Bonifacio, A. C. Rodrigues and F. F. deAraujo (2016). Plant growth-promoting Rhizobacteria: key mechanisms of action. In: Choudhary, D. K. and A. Varma (Eds), Microbial-mediated induced systemic resistance in plants. Springer Science Business Media Singapore, pp: 23–37.

Gaiero, J.R., C.A. McCall, K.A. Thompson, N.J. Day, A.S. Best and K.E. Dunfield (2013). Inside the root microbiome: bacterial root endophytes and plant growth promotion. Am. J. Bot., 100: 1738-1750.

Garai, S., K. Brahmachari, S. Sarkar, M. Mondal, H. Banerjee, M. K. Nanda and K. Chakravarty (2021). Impact of seaweed sap foliar application on growth, yield, and tuber quality of potato (*Solanum tuberosum* L.). J. Appl. Phycol., 33: 1893-1904.

Ghoniem, A.A., N. El. El-Naggar, W.I.A. Saber, M.S. El-Hersh and A.Y. El-khateeb (2020). Statistical modeling-approach for optimization of Cu^{2+} biosorption by *Azotobacter nigricans* NEWG-1; characterization and application of immobilized cells for metal removal. Scientific Reports, 10: 9491.

Glickmann, E. and Y. Dessaux (1995). A critical examination of the specificity of the salkowski reagent for indolic compounds produced by phytopathogenic bacteria. Applied and Environmental Microbiology, 61: 793-796.

Gómez-Merino, F.C. and L. I. Trejo-Téllez (2015). Biostimulant activity of phosphite in horticulture. Scientia Horticulturae, 196: 82-90.

Gómez-Merino, F.C. and L. I. Trejo-Téllez (2016). Conventional and novel uses of phosphite in horticulture: potentialities and challenges. Italus Hortus., 23(2):1-13.

Hamid, B., M. Zaman, S. Farooq, S. Fatima, R.Z. Sayyed, Z.A. Baba, T.A. Sheikh, M.S. Reddy, H. El Enshasy, A. Gafur and N. L. Suriani (2021). Bacterial plant biostimulants: a sustainable way towards improving growth, productivity, and health of crops. Sustainability, 13, 2856: 1-24.

Han, X., Y. Xi, Z. Zhang, M. A. Mohammadi, J. Joshi, T. Borza and G. Wang-Pruski (2021). Effects of phosphite as a plant biostimulant on metabolism and stress response for better plant performance in *Solanum tuberosum*. Ecotoxicology and Environmental Safety, 210: 1-13.

Hassani, F., A. Asgharzadih, M. Ardakani and A. Hamidi (2016). The impact of potato mini-tuber inoculation with plant growth promoting rhizobacteria on tuber yield and nutrients uptake. Journal of Crops Improvement, 17(4): 911-924.

Hodge, J.E. and B.T. Hofreiter (1962). Determination of reducing sugars and carbohydrates. In: Whistler, R.L. and M.L. Wolfrom (Eds), Methods in carbohydrate chemistry. Academic Press, New York, pp: 380-394.

Hunter, M.C., R. G. Smith, M. E. Schipanski, L. W. Atwood and D. A. Mortensen (2017). Agriculture in 2050: recalibrating targets for sustainable intensification. BioScience, 67(4): 386–391.

Issa, R., M. Boras and R. Zidan (2019). Effect of seaweed extract on the growth and productivity of potato plants. International Journal of Agriculture & Environmental Science, 6 (2): 83-89.

Kashyap, B. K., M. K. Solanki, A. K. Pandey, S. Prabha, P. Kumar and B. Kumari (2019). *Bacillus* as plant growth promoting rhizobacteria (PGPR): a promising green agriculture technology. In: Ansari, R.A. and I. Mahmood (Eds), Plant health under biotic stress. Springer Nature Singapore Pte Ltd, pp: 219-236.

Keerthana, U., K. Nagendran, T. Raguchander, K. Prabakar, L. Rajendran and G. Karthikeyan (2018). Deciphering the role of *Bacillus subtilis* var. *amyloliquefaciens* in the management of late blight pathogen of potato, *Phytophthora infestans*. Proc. Natl. Acad. Sci., India, Sect. B Biol. Sci., 88: 1071-1080.

Khan, W., U. P. Rayirath, S. Subramanian, M. N. Jithesh, P. Rayorath, D. M. Hodges, A. T. Critchley, J. S. Craigie, J. Norrie and B. Prithiviraj (2009). Seaweed extracts as biostimulants of plant growth and development. J. Plant Growth Regul., 28: 386-399.

Liljeroth, E., A. Lankinen, L. Wiik, D.D. Burra, E. Alexandersson and E. Andreasson (2016). Potassium phosphite combined with reduced doses of fungicides provides efficient protection against potato late blight in large-scale field trials. Crop Protection, 86: 42-55.

Lovatt, C. J. and R.L. Mikkelsen (2006). Phosphite fertilizers: What are they? Can you use them? What can they do? Better Crops, 90(4): 11-13.

Malik, C. P. and M. B. Singh (1980). Estimation of total phenols in plant enzymology and histoenzymology. In: Malik, C. P. and M. B. Singh (Eds.), Plant enzymology and histo-enzymology: a text manual. New Delhi, Kalyani Publishers.

Meena, V.S., B.R. Maurya, S.K. Meena, R.K. Meena, A. Kumar, J.P. Verma and N.P. Singh (2016). Can *Bacillus species* enhance nutrient availability in agricultural soils? In: Islam, M.T., M. Rahman, P. Pandey, C.K. Jha and A. Aeron (Eds), Bacilli and Agrobiotechnology. Springer International Publishing AG, Switzerland, pp: 367-395.

Mishra, V., P. Pandey and A. K. Singh (2019). A study on bio-efficacy of *Bacillus subtilis* based bio fungicide on late blight, yield and yield attributes of potato (*Solanum tuberosum* L.) cv. Kufri Jyoti. The Pharma Innovation Journal, 8(6): 493-500.

Moreira, B.R.A., R. S. Viana, L. A. M. Lisboa, P. R. M. Lopes, P. A. M. Figueiredo, S. B. Ramos, C. S. B. Bonini, V. D. R. Trindade, M. G. O. Andrade and A. May (2019). Jasmonic acid and k-phosphite enhance productivity and technological quality of sugarcane crop. Journal of Agricultural Science, 11(14): 254-264.

Moussa, Z., D.B. Darwish, S.S. Alrdahe and W.I.A. Saber (2021). Innovative artificial-intelligence- based approach for the biodegradation of feather keratin by *Bacillus paramycoides*, and cytotoxicity of the resulting amino acids. Frontiers in Microbiology, 12: 731262.

Nityamanjari, M. (2018). Effect of fertilizers on growth and productivity of potato- a review. International Journal of Agriculture Sciences, 10(4): 5183-5186.

October, J.R.V. (2017). Seaweed extract effects on potato (*Solanum tuberosum* 'bp1') and grape (*Vitis vinifera* var. sultana) production. PhD thesis, University of the Western Cape, South Africa, 153 p.

Parađiković, N., T. Teklić, S. Zeljković, M. Lisjak and M. Špoljarević (2019). Biostimulants research in some horticultural plant species - a review. Food Energy Secur., 1-17.

Purwantisari, S., S. Parman, Karnoto and K. Budihardjo (2019). The growth and the production of potato plant supplemented by plant growth promoting rhizobacteria (PGPR). Journal of Physics, Conf. Series, 1217: 1-5.

Rangana, S. (1977). Manual for analysis of fruit and vegetable products. Tata-McGraw-Hill, New Delhi, India.

Saifulla, M., T. YellaGoud, S. V. Manjunatha, T. G. Manu and G. Rajesh (2019). Microbe-assisted plant growth ameliorations. In: Ansari, R.A. and I. Mahmood (Eds), Plant health under biotic stress. Springer Nature Singapore Pte Ltd, pp: 99-108.

Sansinenea, E. (2019). *Bacillus* spp.: as plant growth-promoting bacteria. In: Singh, H.B., C. Keswani, M. S. Reddy, E. Sansinenea and C. García-Estrada (Eds), Secondary metabolites of plant growth promoting rhizomicroorganisms. Springer Nature Singapore, pp: 225-237.

Schroetter, S., D. Angeles-Wedler, R. Kreuzig and E. Schnug (2006). Effects of phosphite on phosphorus supply and growth of corn (*Zea mays*). Landbauforschung Völkenrode, 3/4(56): 87-99.

Shahzad, A., S. Ullah, A. A. Dar, M.F. Sardar, T. Mehmood, M. A. Tufail, A. Shakoor and M. Haris (2021). Nexus on climate change: agriculture and possible solution to cope future climate change stresses. Environ. Sci. Pollut. Res., 28: 14211–14232.

Snedecor, G.W. and W.G. Cochran (1990). Statistical Methods 6 ed. The Iowa state, Univ. Press, Amer, Iowa, U.S.A.

Swarup, R., U. Mohammed, J. Davis and S. Rossall (2020). Role of phosphite in plant growth and development. White paper, 1-13. https :// www .nottingham .ac .uk/ biosciences /documents /research /2020-research-documents/swarup-uon-phosphite-white-paper-april-2020.pdf

Tahir, M., I. Ahmad, M. Shahid, G. M. Shah, A. U. Farooq, M. Akram, S. A. Tabassum, M. A. Naeem, U. Khalid, S. Ahmad and A. Zakir (2019). Regulation of antioxidant production, ion uptake and productivity in potato (*Solanum tuberosum* L.) plant inoculated with growth promoting salt tolerant *Bacillus* strains. Ecotoxicology and Environmental Safety, 178: 33-42.

Tambascio, C., F. Covacevich, M. C. Lobato, C. Lasa, D. Caldiz, G. Dosio and A. Andreu (2014). The application of k phosphites to seed tubers enhanced emergence, early growth and mycorrhizal colonization in potato (*Solanum tuberosum*). American Journal of plant Sciences, 5: 132-137.

Trdan, S., F. Vučajnk, T. Bohinc and M. Vidrih (2019). The effect of a mixture of two plant growth-promoting bacteria from Argentina on the yield of potato, and occurrence of primary potato diseases and pest-short communication. Acta Agriculturae Scandinavica, Section B-Soil & Plant Science, 69(1): 89-94.

Trejo-Téllez, L. I. and F. C. Gómez-Merino (2018). Phosphite as an inductor of adaptive responses to stress and stimulator of better plant performance. In: Vats, S. (Eds), Biotic and abiotic stress tolerance in plants. Springer Nature Singapore, pp: 203-238.

Uysal, A. and F. Kantar (2020). Effect of *Bacillus subtilis* and *Bacillus amyloliquefaciens* culture on the growth and yield of off-season potato (*Solanum tuberosum* L.). Acta Agronómica, 69(1): 26-31.

Vejan, P., R. Abdullah, T. Khadiran, S. Ismail and A.N. Boyce (2016). Role of plant growth promoting Rhizobacteria in agricultural sustainability-a review. Molecules, 21(5): 1-17.

Wadas, W. and T. Dziugieł (2020). Changes in assimilation area and chlorophyll content of very early potato (*Solanum tuberosum* L.) cultivars as influenced by biostimulants. Agronomy, 10(3): 1-11.

Xi, Y., X. Hana, Z. Zhanga, J. Joshib, T. Borzab, M. M. Aqaa, B. Zhanga, H. Yuana and G. Wang-Pruskia (2020). Exogenous phosphite application alleviates the adverse effects of heat stress and improves thermotolerance of potato (*Solanum tuberosum* L.) seedlings. Ecotoxicology and Environmental Safety, 190: 1-12.

Zaheer, K. and M. H. Akhtar (2016). Potato production, usage, and nutrition-a review. Critical Reviews in Food Science and Nutrition, 56(5): 711-721.

دور الرش الورقى بمستخلص الطحالب البحرية ، خليط بكتريا الباسيلس والأزوتوباكتر ، وفوسفيت البوتاسيوم فى نمو وإنتاجية محصول البطاطس

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الملخص

أجريت تجربتان حقليتان في مزرعة خاصة بقرية الطويلة بالقرب من مدينة المنصورة - محافظة الدقهلية - مصر خلال العروة الصيفية لموسمى 2020/2019 و 2021/2020 لدراسة تأثير الرش الورقى بمستخلص الطحالب البحرية (0.5 جم/لتر) ، خليط بكتريا الباسيلس والأزوتوباكتر (1 سم^3/لتر) وفوسفيت البوتاسيوم (2.5 سم^3/لتر) وتوليفاتهم المختلفة على النمو والإنتاجية والجودة لمحصول البطاطس. أظهرت النتائج المتحصل عليها أن جميع المعاملات تحت الدراسة أدت إلى تحسين النمو الخضرى (ارتفاع النبات ، عدد الأوراق ، عدد السيقان الأرضية ، الوزن الطازج والوزن الجاف) ، وزيادة محصول الدرنات ومكوناته (وزن الدرنة ، نسبة المادة الجافة بالدرنة ، عدد الدرنات/نبات و محصول الدرنات للفدان) والمحتوى الكيماوى للدرنات (النيتروجين ، الفوسفور ، البوتاسيوم ، النشا و الكربوهيدرات) مقارنة بمعاملة الكنترول. تم الحصول على أفضل النتائج عند رش النباتات بكل من مستخلص الطحالب البحرية + خليط البكتريا + فوسفيت البوتاسيوم ، لذلك يمكن التوصية باستخدام هذه المعاملة رشا على الأوراق ثلاث مرات بداية من 20 يوم بعد الزراعة ثم تكرر كل 15 يوم وذلك للحصول على أعلى إنتاجية وأفضل جودة لمحصول البطاطس تحت ظروف البحث والظروف المماثلة.