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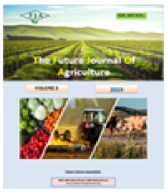
The Future Journal of Agriculture

Print ISSN: 2687-8151 Online ISSN: 2687-8216

Future Science Association



Future J. Agric., 3 (2022) **12-25** **OPEN ACCES**

DOI: 10.37229/fsa.fja.2022.08.10

IMPACT OF SPRAYING POTASSIUM SALTS AND BACTERIAL BIOAGENTS ON GROWTH, YIELD AND FRUIT QUALITY AS WELL AS POWDERY MILDEW DISEASE CONTROL OF PEPPER

Manal A. Mandour*, Howida A. Metwaly and Ayat M. Ali

Central Lab. of Organic Agric. Res. Cent., Giza, **Egypt.**

***Corresponding author:** manalmandour1968@gmail.com **Received:** 18 June 2022 **; Accepted:** 10 Aug. 2022

ABSTRACT: Pepper (*Capsicum annuum* L.) is an important agricultural crop worldwide. A field experiment was conducted under sandy soil conditions during two summer seasons of 2020 and 2021 at the Experimental Farm of El-Kassasein, Hort. Res. Station, Ismailia Governorate, Egypt. Powdery mildew disease, caused by *Leveillula taurica* anamorph *Oidiopsis taurica* is one of the most serious diseases attacking pepper plants under greenhouse and open field conditions. In the present study, the effect of potassium salts and two bacterial bioagents (*Bacillus subtilis* and *Pseudomonas fluorescens*) as foliar spray on growth, yield, fruit quality and powdery mildew incidence and severity of pepper cv Bascara. Data revealed that, by combing potassium silicate and mixture of *P. fluorescens* plus *B. subtilis* significant increase was noticed in shoot dry weight / plant, K content and uptake by shoots, total chlorophyll in leaf tissues, average fruit weight, number of fruits/ plant, yield / plant and yield /fad., as well as potassium use efficiency, dry matter percentage, total soluble solids, vitamin C and total capsaicin in fruits of pepper. Regarding powdery mildew Incidence and severity, data revealed that the highest reduction in disease incidence was obtained when mixture of the bacterial bioagents was combined with potassium silicate. Hence, usage of bioagents and potassium salts are efficient as biocontrol method to manage disease and to improve cropping systems together with saving the natural balance.

Key words: Pepper, K salts, *Bacillus subtilis, Pseudomonas fluorescens*, growth, yield, fruit quality, powdery mildew.

INTRODUCTION

Pepper (*Capsicum annuum* L.) belongs to the family *Solanaceae*, which is an important group of vegetables extensively cultivated in Egypt and all over the world. The total cultivated area of pepper in Egypt reached 41,047 ha and producing 623,221 tons annually **(FAO, 2017).** Powdery mildew (*Leveillula taurica*) of pepper, one of the most prevalent and damaging diseases of pepper crops, is caused by the fungal pathogen Leveillula. This disease can be highly destructive both in greenhouses and in the field. Symptoms of powdery mildew include the growth of white mycelium on abaxial leaf surfaces and the development of chlorotic lesions on adaxial sides that become necrotic (**Tsror *et al.* 2004**). Combination between biological agents and natural salts gave intermediate effect on disease reduction and the produced fruit yield, but it could be of great interest, where the produced fruits are free of fungicides residue. Biological control using bacterial antagonists is an especially promising alternative to fungicides). Induced systemic resistance (ISR) mediated by bioagents was due to the upregulation of defense-related enzymes and by the accumulation of phenolic compounds in plants treated with *Bacillus* spp. (**Jayapala *et al*., 2019**). Further, many antagonistic bacteria are capable of secreting hydrolytic enzymes, such as cellulase, chitinase, and glucanase, which degrade fungal cell walls. *Pseudomonas fluorescens* produce siderophores, low-mass iron-chelating compounds produced by microorganisms under low-iron conditions. Also, increases in activities of peroxidase, polyphenol oxidase, phenylalanine ammonia-lyase, b-1,3-glucanase, chitinase and phenolics were found in treated plants compare with untreated plants. *Pseudomonas fluorescens* and *Bacillus subtilis* as bioagents were reported to suppress certain fungi causing root rot diseases in sweet pepper plants by producing a variety of microbial metabolites like siderophores and production of extracellular cell wall degrading enzymes, as chitinase that can lyse pathogen cell walls or plant growth regulators as IAA **(Yu *et al.*, 2011).** The cell wall degrading enzymes from *P. fluorescens* has a great potential in agriculture as active components in new fungicidal formulation as found by **El-Gamal *et al.* (2016).**

Radhakrishnan *et al.* (2017) reported that *Pseudomonas* and *Bacillus* species are capable of secreting antifungal metabolites that promote plant growth and prevent pathogen infection. *Pseudomonas* and *Bacillus* species play an important role in improving tolerance to biotic stresses (**Elanchezhiyan *et al.*, 2018).** *Pseudomonas fluorescens* and *Bacillus subtilis* as bioagents stimulated the growth of pepper plants compared to control **(El-Feky *et al.*, 2019)**.

Potassium (K) is involved in the merestimatic tissues and is indispensable to maintain the pressure of the cell turgur, which is required to expand the cell **(Rogalski, 1994 and Defan *et al.*, 1999)**. Moreover, it have a main function in osmoregulation, photosynthesis, transpiration, open and closure of stomatal and protein synthesis **(Cakmak, 2005 and Milford and Johnston, 2007)**, in addition translating of assimilates into sink organs and enzymes establishment **(Mengel and Kirkby, 2001).** Beneficial effects potassium fertilization mitigates the adverse effects of salinity in plants by increasing translocation and maintaining water balance within plants **(Greenwood and Karpinets, 1997)**. K fertilizer had a positive effect on fruit size, total soluble solids, ascorbic acid concentration, and fruit surface colour **(Lester *et al.* 2006).** All the foliar K salts, especially potassium sulfate at 1 g/l were effective in improving photosynthetic process, plant biomass, and total yield, total sugars, carotenoides, chlorophyll (a and b), and endogenous NPK of pepper. Increasing available K element for pepper plant by foliar fertilizer treatment could be an effective easily method that growers can be used for increasing pepper yield and quality **(EL-Mogy *et al.*, 2019)**. Spraying sweet pepper plants with potassium silicate at 1 g/ l increased the vegetative growth parameters, fruit set %, average fruit weight, yield and its components, fruit quality compared to control **(Abdel-Aziz and Geeth, 2018).**

Therefore, the aim of this research was to study the effect of foliar spray with potassium salts and some bacterial bioagents on growth, yield, fruit quality and the incidence and severity of powdery mildew in leaves of pepper cv Bascara under sandy soil conditions.

MATERIALS AND METHODS

This work was carried out during two summer seasons of 2020 and 2021 at the Experimental Farm of El-Kassasein, Hort. Res. Station, Ismailia Governorate, Egypt, to study the effect of potassium salts (K sulphate, K silicate and K citrate) and some bacterial bioagents (*Pseudomonas fluorescens* and *Bacillus subtilis*) as foliar spray on growth, yield, fruit quality and powdery mildew incidence and severity of pepper cv Bascara under sandy soil conditions.

The experiment consisted of 12 treatments, which were the combinations between three potassium salts (K sulphate, K silicate and K citrate) and two bacterial bioagents (*Bacillus subtilis*, Pseudomonas *fluorescens* and their mixture) as well as control.

These treatments were arranged in a split plot design with three replications. Potassium salts were randomly distributed in the main plots, while bioagents were arranged in the sub plots. Plot area was 9.8 m^2, which consisted of two ridges of 7 m long and 70 cm width. pepper transplants were transplanted in the open field on 15^{th} of April 2020 and 2021 at 25 cm apart in one side of the ridges**.**

Potassium sulphate 48% K_2O (K_2SO_4), potassium silicate 10% K_2O (K_2SiO_3) and potassium citrate 36.5% K_2O ($K_3C_6H_5O_7$) were applied at a rate 2.08 g/l, 10 ml/l and 2.7 ml/l, respectively. All potassium salts were sprayed four timers (30, 45, 60 and 75 days) after transplanting.

Source of the antagonistic bacteria

In this study, two antagonistic bacteria were used. *Bacillus subtilis* (MT110640) was isolated from rhizosphere of bean. *Pseudomonas fluorescens* (biotype A) 77K isolate was kindly provided by Dr. A.F. Abd El-Rahman from the Bacterial Diseases Research Department, Plant Pathology Research Institute, Agricultural Research Center, Giza, Egypt. this isolate was previously isolated from the rhizosphere of the plum plant and identified using the BIOLOG microplate system (**Abd El-Rahman, 2012).**

Bacterial suspension was multiplied by cultivating *B. subtilis* in nutrient broth medium, while *P. fluorescens* grown in King’s B broth (KB) using shaking flask submerged culture, where 500 ml conical flasks, each containing 200 ml of the respective media was inoculated by one ml bacterial inoculum of 48 h old culture and incubated in rotary shaking incubator (160 rpm) at 28±2ºC for 48 h. the two bio-agents were prepared as suspension at concentration of 9 x 10^8 cfu / ml. Suspensions were mixed with 0.5 % potassium soap to increase distribution of bio-agent on the surface of treated plants. All adjusted preparations were diluted using water at the rate of 1: 100. Diluted adjusted preparations were used to spray pepper plants every 15 days.

All bioagents treatments were sprayed four times 35, 50, 65 and 80 days after transplanting. Plants only received the same volume of water act as control. All foliar spray treatments were made early in the morning to avoid the rapid drought of solution droplets by the sun's heat, therefore remain the solution as long as possible on leaf surfaces. All treatments received equal amounts of N, P and K at 180, 60 and 96 kg /faddan in the form of ammonium sulphate (20.5 % N), calcium super phosphate (15.5 % P_2O_5) and potassium sulphate (48 % K_2O). One half of N and all phosphorus fertilizers rates were added to the soil before planting, while the rest amount of N and all K fertilizers were added after 40 and 70 days from transplanting. The other cultural practices for sweet pepper commercial production were used according to the instruction laid down by the Ministry of Agriculture, Egypt.

Recorded Data

Plant growth: Three plants from plot were randomly taken at 90 days after transplanting and the following data were recorded: Number of leaves, number of branches / plant and shoot dry weight/ plant (g).

Total chlorophyll (SPAD value)

Total chlorophyll in pepper leaf SPAD values were measured at 90 days after transplanting in both growing seasons, using a SPAD-502 meter (Konica-Minolta, Japan).

K content and uptake: Potassium contents in shoots at 90 days after transplanting in both growing seasons were determined according to the methods described by **Jackson (1970)**. The uptake of K per shoots was computed.

Total yield: Pepper fruits were harvested twice every week, fruits were picked all over the season for all plots and the following data were calculated, average fruit weight (gm), average number of fruits/ plant, total yield / plant (kg) and total yield/ fad. (ton).

Fruit quality: Dry matter contents (%), total soluble solids (T.S.S) were measured by hand Refractometer and ascorbic acid (Vitamin C) were assayed according to **A.O.A.C (1995). Total capsaicin** content in fruit (mg /100 g as dry weight) was determined by the method of **Popelka *et al*. (2017)**.

Powdery mildew assessment

Plants were grown under natural infection conditions and disease incidence and severity were evaluated once when disease had reached its highest level throughout the field (130 days after transplanting). Disease incidence was recorded as percentage of infected leaves. Powdery mildew severity was determined using the scale proposed by **Ullasa, *et al.* (1981),** of which: Resistant: no symptoms, moderately resistant: with 10% of the leaf area affected, moderately susceptible: with 11-20% of the leaf area affected, Susceptible: with 21-50% of the leaf area affected and highly susceptible: with 51% or more of the leaf area affected. The percentage of disease severity was calculated using the equation suggested by **Townsend and Heuberger (1943**) as follows:

$$P = \frac{\{a\ (\text{rating no.})\ x\ b\ (\text{no. leaves in rating category})\}}{N\ (\text{Total no. leaves})\ x\ K\ (\text{Highest rating value})} x\ 100$$

Statistical analysis: Recorded data were subjected to the statistical analysis of variance according to **Snedecor and Cochran (1967),** and means separation were done according to **Duncan (1958).**

RESULTS AND DISCUSSION

1. Plant growth

Effect of potassium salts

Data in Tables 1, 2 and 3 show that spraying pepper plants cv. Bascara with potassium silicate at 10 ml/l significantly increased number of branches/ plant, number of leaves/ plant and shoot dry weight / plant at 90 days after transplanting in both seasons followed by potassium sulphate (K sulphate) at 2.08 g /l. Potassium silicate at 10 ml/l gave the highest values of number of branches/ plant (5.21 and 5.08) and shoot dry weight (60.59 and 60.79 g) in the 1st and 2nd seasons , respectively. On the other hand, potassium citrate (K citrate) at 2.7 ml /l gave the lowest values of all plant growth traits .

The enhancing effect of potassium silicate or potassium sulphate on plant growth traits may be due to come together the favourable effect of potassium and silicon. Where, potassium acting important function in osmoregulation, photosynthesis, transpiration, open and closure of stomatal, protein synthesis, translating of assimilates into sink organs and enzymes establishment (**Milford and Johnston, 2007**). In addition, the effective role of silicon in the plant, as an improve of the architecture for showing more erect leaves. These results are harmony with **EL-Mogy *et al.*** (**2019**).

Effect of some bacterial bioagents

Foliar spray with *Bacillus subtilis* (B), *Pseudomonas fluorescens* (P) and their mixture (B+P) *significantly* increased number of branches/ plant, number of leaves/ plant and shoot dry weight / plant compared to control (unsprayed) at 90 days after transplanting in both seasons (Tables 1, 2 and 3). The mixture (B+P) gave the highest values, increased number of branches/ plant and shoot dry weight / plant (0.81 and 0.91), (9.34 and 9.38 g) over the control in the 1st and 2nd seasons, respectively. *Pseudomonas fluorescens* and *Bacillus subtilis* stimulated the growth of pepper plants compared to control **(El-Feky *et al*., 2019)**.

Table 1. Effect of foliar spray with potassium salts, two bioagents and their interaction on number of branches/ plant of pepper cv. Bascara at 90 days after transplanting during 2020 and 2021 seasons

Potassium salts (KS)	Bioagents				Mean (KS)
	Unsprayed	*B. Subtilis* (B)	*P. fluorescens* (P)	Mix B+P	
			2020 season		
K sulphate	4.10 e	4.42 d	4.64 c	4.77 c	4.48 B
K silicate	4.37 d	5.40 b	5.43 b	5.66 a	5.21 A
K citrate	3.67 f	3.93 e	4.04 e	4.12 e	3.94 C
Mean (bioagents)	4.04 C	4.58 B	4.70 B	4.85 A	
			2021 season		
K sulphate	4.21 de	4.32 cde	4.66 bcd	4.88 bc	4.51 B
K silicate	4.33 cde	5.16 ab	5.19 ab	5.66 a	5.08 A
K citrate	3.33 f	3.78 ef	3.90 ef	4.04 de	3.76 C
Mean (bioagents)	3.95 C	4.42 B	4.58 AB	4.86 A	

Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.
K sulphate= potassium sulphate 48 % K_2O at 2.08 g/l, K silicate= potassium silicate 10 % K_2O at 10 ml/l and K citrate = Potassium citrate containing 36.5 %K_2O at 2.6 ml/l

Effect of the interaction

The interaction between spraying with potassium silicate at 10 ml/l and mixture of (B+P) recorded maximum values of number of branches / plant, number of leaves/ plant and shoot dry weight / plant at 90 days after transplanting in both seasons, followed by the interaction between K silicate and *P. fluorescens* (Tables 1 to 3). Spraying with K salts and bioagents (B, P and their mixture B+P) increased number of branches / plant, number of leaves/ plant and shoot dry weight / plant compared to spraying with K salts without bioagents.

Table 2. Effect of foliar spray with potassium salts, two bioagents and their interaction on number of leaves / plant of pepper cv. Bascara at 90 days after transplanting during 2020 and 2021 seasons

Potassium salts (KS)	Bioagents				Mean (KS)
	Unsprayed	*B.Subtilis* (B)	*P.fluorescens* (P)	Mix B+P	
			2020 season		
K sulphate	103.03 de	104.22 de	105.05 d	109.81 c	105.53 B
K silicate	97.98 g	112.09 bc	112.75 b	117.46 a	110.07 A
K citrate	90.39 h	99.41 fg	101.64 ef	103.47 de	98.73 C
Mean (bioagents)	97.13 C	105.24 B	106.48 B	110.25 A	
			2021 season		
K sulphate	105.24 cd	107.52 c	107.54 c	117.50 b	109.45 B
K silicate	95.54 fg	117.94 b	118.71 b	122.47 a	113.66 A
K citrate	94.21 g	96.37 fg	98.75 ef	101.71 de	97.76 C
Mean (bioagents)	98.33 C	107.28 B	108.33 B	113.89 A	

Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.
K sulphate= potassium sulphate 48 % K_2O at 2.08 g/l, K silicate= potassium silicate 10 % K_2O at 10 ml/l and K citrate = Potassium citrate containing 36.5 %K_2O at 2.7 ml/l

Table 3. Effect of foliar spray with potassium salts, two bioagents and their interaction on dry weight of shoot/ plant of pepper cv. Bascara at 90 days after transplanting during 2020 and 2021 seasons

Potassium salts (KS)	Bioagents				Mean (KS)
	Unsprayed	*B.Subtilis* (B)	*P.fluorescens* (P)	Mix (B+P)	
			2020 season		
K sulphate	47.70 ef	51.36 d	51.95 d	55.49 c	51.62 B
K silicate	50.87 d	62.77 b	62.96 b	65.78 a	60.59 A
K citrate	42.62 g	45.67 f	46.92 ef	47.94 e	45.78 C
Mean (bioagents)	47.06 C	53.26 B	53.94 B	56.40 A	
			2021 season		
K sulphate	48.93 e	52.21 d	53.14 d	56.80 c	52.77 B
K silicate	53.50 d	60.05 b	61.04 b	68.58 a	60.79 A
K citrate	41.76 h	43.97 g	44.30 g	46.96 f	44.24 C
Mean (bioagents)	48.06 C	52.07 B	52.82 B	57.44 A	

Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.
K sulphate= potassium sulphate 48 % K_2O at 2.08 g/l, K silicate= potassium silicate 10 % K_2O at 10 ml/l and K citrate = Potassium citrate containing 36.5 %K_2O at 2.7 ml/l

2. Content and uptake of K and total chlorophyll

Effect of potassium salts

There were significant differences among K salts in contents and uptake K by shoots and total chlorophyll in leaf tissues of pepper. Using K silicate at the rate 10 ml/l gave the highest values of K content and uptake by shoots and total chlorophyll followed by K sulphate at 2.08 g/l after 90 days from transplanting in both seasons (Tables 4, 5 and 6). All the foliar applications with K salts, especially potassium silicate were effective in improving photosynthetic process and endogenous NPK of pepper (**EL-Mogy *et al.*, 2019)**. In this concern, **Kamal (2013)** who reported that spraying potassium silicate significantly enhanced total chlorophyll and potassium uptake of sweet pepper plants.

Effect of spraying bacterial bioagents

Spraying pepper plants with *B. subtilis*, *P. fluorescens* and their mixture (B+P) increased K content and uptake by shoot and total chlorophyll in leaf tissues compared to control. The mixture of (B+P) gave the highest values of content and uptake of K by shoot and total chlorophyll followed by B. *subtilis* (Tables 4, 5 and 6).

Table 4. Effect of foliar spray with potassium salts, two bioagents and their interaction on K content in shoot of pepper cv. Bascara at 90 days after transplanting during 2020 and 2021 seasons

Potassium salts (KS)	Bioagents				Mean (KS)
	Unsprayed	*B.Subtilis* (B)	*P.fluorescens* (P)	Mix (B+P)	
			2020 season		
K sulphate	3.82 d	3.97 c	4.07 b	4.17 a	4.00 B
K silicate	3.97 c	4.06 b	4.07 b	4.15 a	4.06 A
K citrate	3.70 f	3.78 de	3.76 e	3.93 c	3.79 C
Mean (bioagents)	3.83 D	3.93 C	3.96 B	4.08 A	
			2021 season		
K sulphate	3.75 d	3.87 bcd	4.00 bc	4.29 a	3.97 B
K silicate	3.86 cd	4.19 a	4.20 a	4.28 a	4.13 A
K citrate	3.88 bcd	3.87 cd	3.82 d	4.01 b	3.89 B
Mean (bioagents)	3.83 C	3.97 B	4.00 B	4.19 A	

Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.
K sulphate= potassium sulphate 48 % K_2O at 2.08 g/l, K silicate= potassium silicate 10 % K_2O at 10 ml/l and K citrate = Potassium citrate containing 36.5 %K_2O at 2.7 ml/l

Table 5. Effect of foliar spray with potassium salts, two bioagents and their interaction on K uptake by shoot (mg / plant) of pepper cv. Bascara at 90 days after transplanting during 2020 and 2021 seasons

Potassium salts (KS)	Bioagents				Mean (KS)
	Unsprayed	*B.Subtilis* (B)	*P.fluorescens* (P)	Mix (B+P)	
			2020 season		
K sulphate	1822 fg	2039 de	2114 d	2314 c	2072 B
K silicate	2020 de	2548 b	2562 b	2730 a	2465 A
K citrate	1577 h	1726 gh	1764 fg	1884 ef	1737 C
Mean (bioagents)	1806 C	2104 B	2146 B	2309 A	
			2021 season		
K sulphate	1835 ef	2021 cd	2126 c	2437 b	2104 B
K silicate	2065 c	2516 b	2564 b	2935 a	2520 A
K citrate	1620 g	1702 fg	1692 fg	1883 de	1724 C
Mean (bioagents)	1840 C	2079 B	2127 B	2418 A	

Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.
K sulphate= potassium sulphate 48 % K_2O at 2.08 g/l, K silicate= potassium silicate 10 % K_2O at 10 ml/l and K citrate = Potassium citrate containing 36.5 %K_2O at 2.7 ml/l

Table 6. Effect of foliar spray with potassium salts, two bioagents and their interaction on total chlorophyll (SPAD) in leaf of pepper cv. Bascara at 90 days after transplanting during 2020 and 2021 seasons

Potassium salts (KS)	Bioagents				Mean (KS)
	Unsprayed	*B.Subtilis* (B)	*P.fluorescens* (P)	Mix (B+P)	
			2020 season		
K sulphate	55.42 de	57.52 cd	58.18 c	69.15 b	60.06 B
K silicate	59.97 c	70.30 b	70.52 ab	73.18 a	68.49 A
K citrate	50.73 f	51.15 f	50.55 f	52.54 ef	51.24 C
Mean (bioagents)	55.37 C	59.65 B	59.75 B	64.95 A	
			2021 season		
K sulphate	54.80 e	58.48 d	58.52 d	60.42 cd	58.05 B
K silicate	62.92 c	67.26 b	67.36 b	71.21 a	67.18 A
K citrate	47.77 g	49.25 fg	49.62 fg	51.60 f	49.56 C
Mean (bioagents)	55.16 C	58.33 B	58.50 B	61.07 A	

Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.
K sulphate= potassium sulphate 48 % K_2O at 2.08 g/l, K silicate= potassium silicate 10 % K_2O at 10 ml/l and K citrate = Potassium citrate containing 36.5 %K_2O at 2.7 ml/l

Effect of the interaction

The interaction between K salts and bioagents had significant effect on content and uptake of K by shoot and total chlorophyll in leaf tissues (Tables 4, 5 and 6). The interaction between K silicate and mixture bioagents (B+P) gave the highest values of K content and uptake by shoots and total chlorophyll in leaf tissues followed by the interaction between K silicate and the bioagent *B. subtilis* or *P. fluorescens* in both seasons.

3- Yield and its components

Effect of potassium salts

Spraying peeper plants cv. Bascara with K silicate at 10 ml/ l increased average fruit weight (22.06 and 21.35 g) and number of fruits/ plant (19.35 and 19.18), yield / plant (409.88 and 438.24 g / plant) and yield /fad. (8.116 and 8.715) in the 1st and 2nd seasons, respectively followed by spraying with K sulphate at 2.08 g/l. Spraying with K citrate at 2.7 ml/l recorded the lowest values of all yield and its components in both seasons. There were significant differences among K salts in average fruit weight , number of fruits/ plant , yield / plant and yield /fad. of pepper (Table 7 to 10).

Potassium (K) is involved in the merestimatic tissues and is indispensable to maintain the pressure of the cell turgur, which is required to expand the cell **(Rogalski, 1994 and Defan *et al*., 1999)**. Moreover, it have a main function in osmoregulation, photosynthesis, transpiration, open and closure of stomatal and protein synthesis **(Cakmak, 2005 and Milford and Johnston, 2007)**, in addition translating of assimilates into sink organs and enzymes establishment **(Mengel and Kirkby, 2001).** Beneficial effects potassium fertilization mitigates the adverse effects of salinity in plants by increasing translocation and maintaining water balance within plants **(Greenwood and Karpinets, 1997)**.

All the foliar K salts, especially potassium silicate, were effective in improving total yield of pepper. Increasing available K element for pepper plant by foliar fertilizer treatment could be an effective easily method that growers can be used for increasing pepper yield (EL-**Mogy *et al.*, 2019)**.

Effect of spraying with bacterial bioagents

Foliar spray with bioagents (*B. subtilis*, *P. fluorescens* and their mix B+P) increased yield and its components of pepper compared to with control. Mix of bioagents (B+P) gave average fruit weight (21.40 and 20.75 g), number of fruits/ plant (20.32 and 19.64), yield / plant (408.17 and 435.38 g / plant) and yield /fad. (8.094 and 8.649) in the 1st and 2nd seasons, respectively, followed by *B. subtilis* and *P. fluorescens* in both seasons (Tables 7 to 10).

Table 7. Effect of foliar spray with potassium salts, two bioagents and their interaction on average fruit weight (g) of pepper cv. Bascara during 2020 and 2021 seasons

Potassium salts (KS)	Bioagents				Mean (KS)
	Unsprayed	*B.Subtilis* (B)	*P.fluorescens* (P)	Mix (B+P)	
			2020 season		
K sulphate	20.18 e	20.85 cd	20.97 bc	21.51 b	20.87 B
K silicate	21.15 bc	22.39 a	22.28 a	22.42 a	22.06 A
K citrate	19.25 g	19.47 fg	19.91 ef	20.27 de	19.72 C
Mean (bioagents)	20.19 C	20.90 B	21.05 B	21.40 A	
			2021 season		
K sulphate	19.27 de	20.22 bc	20.34 bc	20.86 b	20.17 B
K silicate	20.32 bc	21.72 a	21.61 a	21.75 a	21.35 A
K citrate	18.47 f	18.89 ef	19.31 de	19.66 cd	19.08 C
Mean (bioagents)	19.35 C	20.27 B	20.42 AB	20.75 A	

Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.
K sulphate= potassium sulphate 48 % K_2O at 2.08 g/l, K silicate= potassium silicate 10 % K_2O at 10 ml/l and K citrate = Potassium citrate containing 36.5 %K_2O at 2.7 ml/l

Table 8. Effect of foliar spray with potassium salts, two bioagents and their interaction on number of fruits/ plant of pepper cv. Bascara during 2020 and 2021 seasons

Potassium salts (KS)	Bioagents				Mean (KS)
	Unsprayed	*B.Subtilis* (B)	*P.fluorescens* (P)	Mix (B+P)	
			2020 season		
K sulphate	18.27 h	18.75 f-h	19.10 d-f	20.23 b	19.08 B
K silicate	18.91 e-g	19.48 cd	20.00 b	21.02 a	19.85 A
K citrate	18.33 h	18.50 gh	19.33 c-e	19.72 bc	18.97 B
Mean (bioagents)	18.50 D	18.91 C	19.47 B	20.32 A	
			2021 season		
K sulphate	17.72 g	18.19 e-g	18.53 d-f	19.62 ab	18.51 B
K silicate	18.24 e-g	18.90 b-e	19.40 bc	20.19 a	19.18 A
K citrate	17.78 g	17.95 fg	18.75 c-e	19.13 b-d	18.40 B
Mean (bioagents)	17.91 D	18.34 C	18.89 B	19.647 A	

Table 9. Effect of foliar spray with potassium salts, two bioagents and their interaction on yield / plant (g) of pepper cv. Bascara during 2020 and 2021 seasons

Potassium salts (KS)	Bioagents				Mean (KS)
	Unsprayed	*B.Subtilis* (B)	*P.fluorescens* (P)	Mix (B+P)	
			2020 season		
K sulphate	341.46 de	367.80 c	376.90 c	409.27 b	373.86 B
K silicate	370.64 c	410.51 b	419.23 b	439.13 a	409.88 A
K citrate	328.40 e	339.08 e	362.06 cd	376.10 c	351.41 C
Mean (bioagents)	346.83 D	372.46 C	386.06 B	408.17 A	
			2021 season		
K sulphate	368.69 de	390.94 cd	400.53 c	435.15 b	398.83 B
K silicate	399.95 c	436.16 b	445.60 b	471.27 a	438.24 A
K citrate	352.85 e	360.20 e	384.86 cd	399.72 c	374.41 C
Mean (bioagents)	373.83 D	395.77 C	410.33 B	435.38 A	

Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.
K sulphate= potassium sulphate 48 % K_2O at 2.08 g/l, K silicate= potassium silicate 10 % K_2O at 10 ml/l and K citrate = Potassium citrate containing 36.5 %K_2O at 2.7 ml/l

Table 10. Effect of foliar spray with potassium salts, two bioagents and their interaction on total yield /fad. (ton) of pepper cv. Bascara during 2020 and 2021 seasons

Potassium salts (KS)	Bioagents				Mean (KS)
	Unsprayed	*B.Subtilis* (B)	*P.fluorescens* (P)	Mix (B+P)	
			2020 season		
K sulphate	6.773 d	7.283 c	7.480 c	8.109 b	7.411 B
K silicate	7.339 c	8.167 b	8.269 b	8.692 a	8.116 A
K citrate	6.521 d	6.703 d	7.193 c	7.480 c	6.974 C
Mean (bioagents)	6.877 D	7.384 C	7.647 B	8.094 A	
			2021 season		
K sulphate	7.337 d-f	7.771 de	7.949 d	8.629 bc	7.921 B
K silicate	7.969 cd	8.686 b	8.843 ab	9.364 a	8.715 A
K citrate	7.006 f	7.144 ef	7.620 d-f	7.955 cd	7.431 C
Mean (bioagents)	7.437 C	7.867 B	8.137 B	8.649 A	

Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.
K sulphate= potassium sulphate 48 % K_2O at 2.08 g/l, K silicate= potassium silicate 10 % K_2O at 10 ml/l and K citrate = Potassium citrate containing 36.5 %K_2O at 2.7 ml/l

Effect of the interaction

The interaction between K silicate at 10 ml/l and bioagents (B+P) significantly increased average fruit weight, number of fruits/ plant, yield / plant and yield /fad. with no significant differences between the interaction between K silicate and *P. fluorescens* or *B. subtilis* with respect to average fruit weight in both seasons (Tables 8 to 10). Treating K salts with bioagents increased yield and its components compared to K salts as single treatment.

4. Fruit quality

Effect of potassium salts

Spraying with K silicate at 10 ml/l significantly increased dry matter content, total soluble solids (TSS) and Vit. C as well as capsaicin content in fruits with no significant differences with K sulphate at 2.08 g /l with respect to Vit. C in both seasons (Tables 11 to 14). K fertilizer had a positive effect on fruit size, total soluble solids, ascorbic acid concentration, and fruit surface colour

(Lester *et al.* 2006). The obtained results are in accordance with **El-Bassiony *et al*. (2010)**. They indicated that there were significant differences between potassium salts regarding fruit quality of pepper. In this regard, **Kamal (2013)** defined that foliar spraying with potassium silicate induced an increasing in total sugars and total soluble solids (%) of sweet pepper fruits.

Effect of using bacterial bioagents

Spraying with *B. subtilis*, *P. fluorescens* and their mix (B+P) increased dry matter percentages (%), TSS and Vit C as well as total capsaicin content in pepper fruits compared to control treatment and B+P recorded maximum values of dry matter (%) , TSS and Vit. C as well as total capsaicin content in fruits followed by P and B in both seasons (Tables 11 to 14).

Effect of the interaction

The interaction between K silicate at 10 ml/l and mixture of (B+P) significantly increased dry matter content, TSS, Vit. C and total capsaicin content in fruits of pepper (Tables 11 to 144). Adding bacterial bioagents with K salts increased dry matter content , TSS and Vit. C as well as total capsaicin content in fruits compared to K salts only. Pseudomonas have stimulated the plant growth by improving uptake of minerals into the host plants particularly phosphate production of IAA, production of cytokinin, regulating ethylene production in roots and solubilizing nutrients such as phosphorus. Likewise, Bacillus play an important role in plant growth promotion by production of GA_3 and IAA, production of cytokinin, synthesize various types of lipopeptides and zinc solubilization (**Abd El-Rahman and Shaheen, 2016 and Naveen *et al*., 2019).**

Table 11. Effect of foliar spray with potassium salts, two bioagents and their interaction on dry matter in fruits (%) of pepper cv. Bascara during 2020 and 2021 seasons

Potassium salts (KS)	Bioagents				Mean (KS)
	Unsprayed	*B. Subtilis* (B)	*P. fluorescens* (P)	Mix (B+P)	
			2020 season		
K sulphate	7.32 e	8.21 d	8.22 d	9.14 c	8.22 B
K silicate	9.11 c	9.51 b	9.60 b	9.90 a	9.53 A
K citrate	6.93 g	7.12 f	7.23 ef	8.12 d	7.35 C
Mean (bioagents)	7.78 C	8.28 B	8.35 B	9.05 A	
			2021 season		
K sulphate	7.92 h	8.81 fg	9.02 ef	9.63 ab	8.84 B
K silicate	9.13 de	9.48 bc	9.32 cd	9.79 a	9.43 A
K citrate	6.52 j	6.81 i	8.00 h	8.66 g	7.49 C
Mean (bioagents)	7.85 D	8.36 C	8.78 B	9.36 A	

Table 12. Effect of foliar spray with potassium salts, two bioagents and their interaction on TSS in fruits (brix) of pepper cv. Bascara during 2020 and 2021 seasons

Potassium salts (KS)	Bioagents				Mean (KS)
	Unsprayed	*B.Subtilis* (B)	*P.fluorescens* (P)	Mix (B+P)	
			2020 season		
K sulphate	5.29 ef	5.36 ef	5.40 e	5.76 d	5.45 B
K silicate	6.29 c	6.50 b	6.45 b	7.29 a	6.63 A
K citrate	5.00 h	5.13 gh	5.23 fg	5.68 d	5.26 C
Mean (bioagents)	5.52 C	5.66 B	5.69 B	6.24 A	
			2021 season		
K sulphate	5.68 efg	5.80 ef	5.82 def	6.06 cd	5.84 B
K silicate	6.29 c	6.79 b	6.82 b	7.22 a	6.78 A
K citrate	5.35 h	5.50 gh	5.60 fg	5.90 de	5.58 C
Mean (bioagents)	5.77 C	6.03 B	6.08 B	6.39 A	

Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.
K sulphate= potassium sulphate 48 % K_2O at 2.08 g/l, K silicate= potassium silicate 10 % K_2O at 10 ml/l and K citrate = Potassium citrate containing 36.5 %K_2O at 2.7 ml/l

Table 13. Effect of foliar spray with potassium salts, two bioagents and their interaction on vitamin C (mg /100 g fresh weight) of pepper cv. Bascara during 2020 and 2021 seasons

Potassium salts (KS)	Bioagents				Mean (KS)
	Unsprayed	Bacillus (B)	Pseudomonas (P)	B+P	
			2020 season		
K sulphate	103.42 d	106.98 c	107.82 c	111.45 b	107.42 A
K silicate	102.88 d	107.07 c	108.39 c	115.61 a	108.49 A
K citrate	93.54 e	95.86 e	94.17 e	103.39 d	96.74 B
Mean (bioagents)	99.95 C	103.30 B	103.46 B	110.15 A	
			2021 season		
K sulphate	103.76 cd	107.02 bc	108.60 bc	113.28 ab	108.16 A
K silicate	98.79 de	105.69 c	105.29 c	116.81 a	106.65 A
K citrate	89.22 f	90.78 f	90.12 f	95.03 ef	91.29 B
Mean (bioagents)	97.26 C	101.16 B	101.34 B	108.37 A	

Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.
K sulphate= potassium sulphate 48 % K_2O at 2.08 g/l, K silicate= potassium silicate 10 % K_2O at 10 ml/l and K citrate = Potassium citrate containing 36.5 %K_2O at 2.7 ml/l

Table 14. Effect of foliar spray with potassium salts, two bioagents and their interaction on total capsaicin content (mg/100g as dry weight) in fruits of pepper cv. Bascara during 2020 and 2021 seasons

Potassium salts (KS)	Bioagents				Mean (KS)
	Unsprayed	***B.Subtilis*** **(B)**	***P.fluorescens*** **(P)**	Mix (B+P)	
			2020 season		
K sulphate	71.55 ef	77.04 d	77.93 d	83.24 c	77.44 B
K silicate	76.31 d	94.16 b	94.44 b	98.67 a	90.89 A
K citrate	63.93 g	68.51 f	70.38 ef	71.91 e	68.68 C
Mean (bioagents)	70.597 C	79.903 B	80.917 B	84.607 A	
			2021 season		
K sulphate	73.40 e	78.32 d	79.71 d	85.20 c	79.15 B
K silicate	80.25 d	92.58 b	92.56 b	102.87 a	92.06 A
K citrate	62.64 g	65.96 f	66.45 f	70.44 e	66.37 C
Mean (bioagents)	72.09 C	78.95 B	79.57 B	86.17 A	

Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.
K sulphate= potassium sulphate 48 % K_2O at 2.08 g/l, K silicate= potassium silicate 10 % K_2O at 10 ml/l and K citrate = Potassium citrate containing 36.5 %K_2O at 2.7 ml/l

5. Percentage of Powdery mildew incidence and severity

5.1 Effect of potassium salts

There were significant differences among potassium salts in incidence and severity of powdery mildew percentage on pepper leaves and potassium silicate gave the lowest values of incidence of powdery mildew (23.25 and 23.83 %) followed by potassium sulphate (Table 15). Also, severity of powdery mildew was reduced and only recorded 18.47 and 18.60 %, followed by potassium sulphate (Table 16). These results are in agreement with **Reuveni *et al.* (1995)** and **Dallagnola *et al.* (2012)** those obtained by in this regard, spraying plants with K silicate gave good control for fungal diseases as mentioned by **Sakr (2016) and Ali and Ayoub (2017)**.

Effect of spraying with bacterial bioagents

Treating pepper plants with *B. subtilis*, *P. fluorescens* and their mix (B+P) decreased the incidence of powdery mildew (%) in leaves compared to control (Table 15). Mix of Bioagents

(B+P) reduced the powdery mildew incidence on pepper leaves to 26.96 and 25.33% in the 1st and 2nd seasons, respectively. Spraying pepper plants with *B. subtilis*, *P. fluorescens* and their mixture (B+P) decreased the severity of powdery mildew (%) in leaves compared to control (Table 16). Combining *B. subtilis* plus *P. fluorescens* reduced the powdery mildew severity on pepper leaves to 19.91 and 18.73 % in the 1st and 2nd seasons, respectively. **Kim (2013)** reported that *Bacillus* sp. BS061 significantly reduced disease incidence of powdery mildew. **Farag *et al.* (2018)** found that foliar spray with bioagent (*Bacillus subtilis*) and amendment pepper plants with compost reduced the number of infected leaves and powdery mildew severity as well as increased the yield compared to control (compost).

Zalte *et al.* (2013) stated that interaction among the different bacterial bioagents revealed that *P. fluorescens* had a good growth potential and antagonist when mixed with *B. subtilis.* induction of systemic resistance by *P. fluorescens* was correlated with the accumulation of chitinase and b-1,3-glucanase. These enzymes act upon the fungal cell wall resulting in degradation and loss of inner contents of cells **(Benhamou *et al.*, 1996 and Stein, 2005).** *Bacillus* sp. as beneficial rhizobacteria, was analyzed for the ability to improve plant health of chili by suppressing anthracnose disease. Induction of resistance against invading pathogen is through enhancing the activities of defense-related enzymes such as subtilin, bacilysin, mycobacillisyn, iturin, oligomycin A, kanosamine and zwittermicin and higher accumulation of phenolic compounds in the host plant (**Silva *et al*., 2004. and Naveen *et al.*, 2019**).

Effect of the interaction

It statistically significant over control and at par with all other potassium salts, when K silicate combined with bacterial bioagents led to decreased the incidence and severity of powdery mildew on pepper leaves. The incidence of powdery mildew was significantly reduced and only 16.67 and 18. 67 % disease was recorded in the 1st and 2nd seasons, respectively by the interaction between K silicate and mixture of beneficial bacteria (Table 15). Also potassium salts with bioagents decreased the incidence of powdery mildew compared to potassium salts alone.

The severity of powdery mildew was significantly reduced (12.72 and 12.50 % in the 1st and 2nd seasons, respectively) by the interaction between K silicate and mix of bioagents (Table 16). **Radhakrishnan *et al.* (2017)** reported that *Pseudomonas* and *Bacillus* species are capable of secreting antifungal metabolites that promote plant growth and prevent pathogen infection. *Pseudomonas* and *Bacillus* species play an important role in improving tolerance to biotic stresses **(Elanchezhiyan *et al*., 2018).** Further, plants treated with *P. fluorescens* increases in activities of peroxidase, polyphenol oxidase, phenylalanine ammonia-lyase, b-1,3-glucanase, chitinase and phenolics (**Anand *et al*., 2010.)**

Table 15. Effect of foliar spray with potassium salts, two bioagents and their interaction on disease incidence (%) of powdery mildew on pepper during 2020 and 2021 seasons

Potassium salts (KS)	Bioagents				Mean (KS)
	Unsprayed	*B. Subtilis* (B)	*P. fluorescens* (P)	Mix (B+P)	
			2020 season		
K sulphate	46.67 bc	40.00 d	35.00 e	29.00 f	37.66 B
K silicate	35.00 e	21.67 g	19.67 g	16.67 h	23.25 C
K citrate	51.67 a	47.67 b	44.33 c	35.23 e	44.72 A
Mean (bioagents)	44.44 A	36.44 B	33.00 C	26.96 D	
			2021 season		
K sulphate	41.67 b	33.33 c	31.67 d	25.00 e	32.91 B
K silicate	31.67 d	25.00 e	20.00 f	18.67 g	23.83 C
K citrate	50.65 a	41.67 b	40.49 b	32.33 cd	41.28 A
Mean (bioagents)	41.33 A	33.33 B	30.72 C	25.33 D	

Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.
K sulphate= potassium sulphate 48 % K_2O at 2.08 g/l, K silicate= potassium silicate 10 % K_2O at 10 ml/l and K citrate = Potassium citrate containing 36.5 %K_2O at 2.7 ml/l

Table 16. Effect of foliar spray with potassium salts, two bioagents and their interaction on disease severity (%) of powdery mildew on pepper during 2020 and 2021 seasons

Potassium salts (KS)	Bioagents				Mean (KS)
	Unsprayed	*B.subtilis* (B)	*P. fluorescens* (P)	Mix (B+P)	
			2020 season		
K sulphate	34.62 b	27.83 c	24.23 d	19.96 e	26.66 B
K silicate	26.80 c	18.78 e	15.58 f	12.72 g	18.47 C
K citrate	41.82 a	35.45 b	34.83 b	27.07 c	34.79 A
Mean (bioagents)	34.41 A	27.35 B	24.88 C	19.91 D	
			2021 season		
K sulphate	35.42 b	25.50 cd	20.52 e	18.88 e	25.08 B
K silicate	28.27 c	18.01 ef	15.64 f	12.50 g	18.60 C
K citrate	40.66 a	37.90 b	35.33 b	24.83 d	34.68 A
Mean (bioagents)	34.78 A	27.13 B	23.83 C	18.73 D	

Values having the same alphabetical letter(s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.
K sulphate= potassium sulphate 48 % K_2O at 2.08 g/l, K silicate= potassium silicate 10 % K_2O at 10 ml/l and K citrate = Potassium citrate containing 36.5 %K_2O at 2.7 ml/l

Conclusion

A combined strategy of high productivity and powdery mildew control consisting of using potassium salts and biological control (bioagents) *P. fluorescens* and *B. subtilis* was evaluated. From the foregoing results, it could be concluded that, the interaction between K silicate and bacterial bioagents increased all plant growth parameters, yield and its components, fruit quality of pepper. Also, this treatment reduced disease incidence and severity of pepper powdery mildew. This provides a unique opportunity to control disease and increase productivity without using synthetic chemicals.

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RESEARCH ARTICLE

Impact of spraying potassium salts and bacterial bioagents on growth, yield and fruit quality as well as powdery mildew disease control of pepper

Authors' contributions

Author details: Manal A. Mandour, Howida A. Metwaly and Ayat M. Ali,
Central Lab. of Organic Agric. Res. Cent., Giza, **Egypt**

Funding: NA

Ethics approval and consent to participate: Not applicable
Consent for publication: Not applicable
Competing interests
The authors declare that they have no competing interests.

Received: 18 June 2022 **; Accepted:** 10 Aug. 2022