Plant Archives Volume 20 No. 2, 2020 pp. 8374-8388 **e-ISSN:2581-6063 (online), ISSN:0972-5210**

IMPACT OF POTASSIUM SOLUBILIZING BACTERIA ON GROWTH AND YIELD OF GARLIC

Amr M. Mounir[1*], Yasser M.M. Osman[2] and Ola A.A. Khalil[3]

[1]Natural Products Research Department, National Centre for Radiation Research and Technology (NCRRT),
Egyptian Atomic Energy Authority (EAEA), Cairo, Egypt.
[2]Potato and Vegetatively Propagated Vegetables Department, Horticultural Research Institute,
Agriculture Research Centre, Giza, Egypt.
[3]Radiation Microbiology Department, National Centre for Radiation Research and Technology (NCRRT),
Egyptian Atomic Energy Authority (EAEA), Cairo, Egypt.
*Corresponding author:Mounir_amr@yahoo.com

Abstract

This experiment was carried out during the two successive seasons of 2017/2018 and 2018/2019 to evaluate the effect of different levels of potassium sulphate 48% (0, 50, 75 and 100%) of recommended dose 150 Kg/feddan combined with soil inoculation with both irradiated and un-irradiated potassium solubilizing bacteria (KSB) (*Bacillus mucilaginous* HQ013329) on the production and the storability of garlic bulbs. *Bacillus mucilaginosus* HQ013329 exhibited high ratio of potassium solubilization after exposing to different doses of gamma radiation, the highest ratio was 38 mm at dose 3.5 KGy. The quantitative estimation of potassium for the un-irradiated and irradiated strains were 29.01 and 28.15 mg/L, respectively. The addition of 100 % and 75% of recommended K_2SO_4 to the soil combined with un-irradiated *Bacillus mucilaginosus* HQ013329 scored the highest values of vegetative characters such as plant length, leaf number per plant, bulb diameter and plant dry weight. Concerning total yield at harvest time and after curing, the previous treatments led to the highest cured yield, bulb diameter and bulb weight which had the highest concentration of total carbohydrates, free amino acids and protein content. The addition of 75% of K_2SO_4 combined with soil inoculation with un-irradiated *Bacillus mucilaginosus* HQ013329 reflect on the storage ability of garlic bulbs during storage period and decrease weight loss percentage and maintain bulbs during storage.

Key words: Garlic, potassium solubilizing bacteria, *Bacillus mucilaginosus,* gamma irradiation.

Introduction

Garlic (*Alllium sativum* L.) belongs to the family Liliaceae and is considered one of the oldest and important bulbous vegetable crops especially in Egypt and is next to onion in importance. The total area of garlic cultivated in Egypt was 12782 hectar with 286213 tonnes production (FAO, 2018). It is an important commercial crop with considerable economic income either for local market or for export. Garlic is used as spice because it has a unique aroma referred to the organic sulphur compound "Allicin" (Mahfooz *et al.,* 2016). Also it has an extraordinary role as anti-bacterial, antifungal, anti-cancer, lowering blood sugar and blood lipids (Agusti, 1990).

The enhancement of bulb characters depend on some factors, one of these factors is potassium fertilization (Barakat *et al.,* 2019). Potassium is one of the most important macro elements for different living organisms, it is ranked as the 7th abundant element in Earth crust, its total amount in soil ranged from 0.04-3%. It has a considerable and decisive roles such as giving plants resistance against biotic and abiotic stresses, biochemical and physiological functions in different plants such as promoting water absorption, keeping osmotic tension and turgor in plant cells, regulating stomata cell function and the translocation of carbohydrates synthesis through photosynthesis from leaves to different storage organs, nitrate reduction, regulating the permeability of cell membrane and maintain the protoplasm in a good degree of hydration. (Yang *et al.,* 2015; Gallegos-Cedillo *et al.,* 2016 and Hussain *et al.,* 2016). Rich land with potassium reflect on garlic yield, oil content and bulb size (Jahangir *et al.,* 2005).

Despite of the presence of potassium in abundant content in soil, only 1-2% of its content is available to plants, the rest are related to other minerals in unavailable form. The great amount of potassium in soil is presented in unavailable form to plant as a result of lopsided fertilizer consumption, the increase of crop yield (consuming soluble potassium) and the consumption of potassium in the soil system. Thus the decrease of potassium in the soil reflect on plant production and yield (Meena *et al.,* 2014a and Xiao *et al.,* 2017).

Several investigators reported that garlic plants growth, yield and storability were generally markedly advanced by potassium application (El-Morsy *et al.,* 2004; Ahmed *et al.,* 2010 and Osman, 2015).

Recently, soil degradation resulted from sequential cultivation became a serious problem in the production of different bulbous and root crops with good characters.

Due to limited availability of chemical fertilizers, biofertilizers are considered to be environmentally friendly, cost-effective, sustainable alternative to synthetic fertilizers, enhance agricultural production and diminish environmental pollution (Sattar *et al.,* 2018). Soil contain numerous microorganisms or rizosphere microflora. The presence of different microorganisms affect the fertility of soil through decomposition, mineralization and analysis as well as storage of nutrients (Parmar and Sindhu, 2013).

One of the most promising microorganisms are potassium solubilizing bacteria (KSB) that take attention of scientist through their inoculation in soil which promote the plant growth and yield as a result of their effectiveness in analyzing potassium from insoluble and bounded form to an available element to plants (Zhang *et al.,* 2013). Biofertilizer reflect on maintaining the environment from the pollution caused by the excessive addition of mineral fertilizers. The mechanism of KSB on the transform of insoluble to soluble potassium might be referred to their ability on producing both organic acids such as oxalic acid, tartaric acid, gluconic acid, 2-ketogluconic acid, lactic acid, citric acid, malonic acid, fumaric acid and inorganic acid as well as protons (acidolysis mechanism) (Maurya *et al.,* 2014; Meena *et al.,* 2014b and Meena *et al.,* 2015a) which gave the chance to transform insoluble potassium to soluble element easily absorbed by the plant. Also, it was found that organic acids produced by KSB gave ammonia and hydrogen sulfide which can be oxidized in the soil and produce strong acids like nitric acid and sulfuric acid. An exchange process occurs among hydrogen, potassium, magnesium, calcium and manganese in the soil (Huang *et al.,* 2013). On the other hand, the decrease of soil pH could be referred to the effect of organic acid produced by KSB which can release potassium ions from mineral potassium through chelating silicon, aluminum, iron and calcium ions related with mineral. Also KSB play an important role in storing potassium in their biomass than transported it to plant (Jones *et al.,* 2003). KSB have the ability to form a biofilm around microbial cells for accelerating weathering process (Meena *et al.,* 2014a) and play an important role as protective layer around mineral-water-hyphal /root against ion losses, enhancing the corrosion of potassium rock and enhancing the release of potassium, silicon and aluminum (Man *et al.,* 2014).

One of the most promising KSB is *Bacillus mucilaginosus* which can release potassium from feldspar, aluminosilicate minerals and decompose it from organic matter and crop residues (Aleksandrov *et al.,* 1967). *Bacillus mucilaginosus* strain CS1 were isolated from the root zone of different crops grown under riches soil with potassium and silicate (Mikhailouskaya and Tcherhysh, 2005). These bacteria are existing either in rhizosphere or non-rhizosphere soil (Meena *et al.,* 2014b; Meena *et al*., 2015b and Zahedi, 2016).

Gamma rays are one of the most powerful electromagnetic ionizing rays. They had great ability of penetration more than alpha and beta rays (Kovács and Keresztes, 2002). Indeed, bacterial viability was connected to the induction of radiation to the oxidation of protein (Brown *et al.,* 2015). This appear the importance of aggregation low dose, particularly since lower dose permit species to counter through up-regulating repair mechanisms and led to an inducement of pivotal processes by microbial strains. Low doses of ionizing radiation in the form of gamma radiation, electrons beams or X-rays can enhance the activity of microorganisms (enhancement the enzymatic activity, degradation activity, production of economic products, etc.). Abo-State *et al.* (2013) demonstrated that when they exposed the isolated indigenous strains to different low doses of gamma irradiation, their ability to degrade different chloroaromatic polluting soil compounds at different concentrations increase.

Thus this experiment was carried out in order to evaluate the effect of most promising potassium solubilizing bacteria on the productivity of garlic before and after their exposure to the most appropriate dose of gamma radiation to activate potassium solubilization property for this strain under field conditions individually or with different recommended potassium levels.

Material and Methods

Microbiological studies

Isolation of potassium solubilizing bacteria (KSB) from agriculture wastes

Ten grams of each of the agriculture wastes (potato peals, corn cobs, banana peels, rice straw and bagasse) was diluted in 90 ml sterilized saline, then they were agitated 150 rpm in shaking incubator. The agriculture waste suspensions were then subjected to serial dilution from 10^{-1} to 10^{-5}.100 µl were spread over a petridish containing culture medium of Aleksandrov agar (1967) (composed of 1L medium: 10 g glucose, 0.5 g $MgSO_4.7H_2O$, 0.005 g $FeCl_3$, 0.1 g $CaCO_3$, 2 g $Ca_3(PO_4)_2$, 5 g insoluble potassium, aluminium silicate and 15 g bacto agar). The petridishes were placed in the incubator at 30^0C for 72 h.Six standard bacterial strains (*Enterobactereace cloaceae* MAM-4, *Bacillus mucilaginosus accession no.* HQ013329, *Pseudomonas chengduensis accession no.* KX257374, *Pseudomonas plecolossicida accession no.* KX257375) and (*Lactobacillus acidophilus* ATCC 4356, *Lactobacillus rhamnosus* ATCC 11981) which were collected in Bioburden and Toxin laboratory at Radiation Microbiology Department at National Center for Radiation Research and Technology (NCRRT), Atomic Authority, Cairo, Egypt and used for studying potassium solubilization.

Screening of bacterial isolates to configure potassium solubilizing zone

Potassium solubilization through bacterial isolates was studied on Aleksandrov medium plates by the spot test method. A loopful of 48 hours old growth of each isolated bacterial strain (10 µl of 10^5 $CFUml^{-1}$) was spotted on prepared plates. Thirteen bacterial cultures were spotted on each plate (seven bacterial isolates and six standard bacterial strains). Plates were incubated at 28 ± 2^0C for 3 days. Detection of potassium solubilization by different bacterial isolates was based on the ability of solubilizing zone configuration.

Index of potassium solubilization (IKS) was measured as follow

IKS = (diameter of clear zone – diameter of bacterial colony)/diameter of bacterial colony.

Each of single colony of the most promising bacteria was streaked on slant agar of Aleksandrov medium and used as stock isolate (Parmar and Sindhu, 2013).

Identification of the most promising bacterial isolate

The most promising bacterial isolate was identified biochemically according to the Bergey's Manual (Krieg and Holt, 1984), molecularly in Colors laboratory, Cairo, Egypt (Sambrook and Russel, 2001).

Effect of different low irradiation doses on the KSB

The isolated strain *Microbacterium keratanolyticum* SAB-2 and standard strain *Bacillus mucilaginosus* HQ013329 were separately exposed to 10 different doses (0.00, 0.01, 0.025, 0.05, 0.1, 0.2, 0.4, 0.6, 0.8 and 1.5 KGy) of gamma radiation. Irradiation process was achieved in (Indian cell - ^{60}Co) with dose rate of 1.249KGy/hr atNCRRT, Cairo, Egypt. Irradiated and unirradiated bacteria were screened for their ability to solubilize potassium element on modified Aleksandrov medium plates by the spot test method. Then the most promising strain (*Bacillus mucilaginosus*) was further exposed to 7 different doses (0.0, 2.0, 2.5, 3.0, 3.5, 4.0 and 5.0 KGy). Plates were incubated at 28±2°C for 3 days. Detection of potassium solubilization by both strains was based upon the ability of solubilization zone formation (Parmar and Sindhu, 2013).

Quantitative estimation of potassium release and pH value

A loopful of 48 hours of each grown bacterial culture was inoculated into 25 ml Aleksandrov medium broth in 100 ml capacity flask and inoculated in triplicate with tested isolates. Each one of the three samples including control (uninoculated Aleksandrov media), irradiated sample (irradiated *Bacillus mucilaginosus* inoculated in Aleksandrov medium) and un-irradiated sample (un-irradiated *Bacillus mucilaginosus* inoculated in Aleksandrov medium). All the inoculated flasks were incubated at 28±2°C for 10 days. The growth suspension was centrifuged at 7,000 g for 10 minutes in the Universal Centrifuge (230 V, 50/60 HZ, 1.9 A, associated with Cannic, Inc. U.S.A) to separate the supernatant from the cell growth and insoluble potassium. One ml of the supernatant was suspended with distilled water up to 5 ml total volume and mixed thoroughly. The solution containing soluble potassium was determined using Atomic Adsorption Spectrophotometer (AAS) analysis was carried out in the Regional Center for Food and Feed (RCFF), Agriculture Research Center located at Giza, Egypt. (Angraini *et al.*, 2016). The pH values were measured at intervals of zero, 6, 12, 30, 72 and 96 h with a pH meter (Hu *et al.*, 2006).

Application of potassium solubilizing bacteria

KSB were inoculated in sucrose minimal salts medium (composition of 1L medium: 8g NaCl, 0.2g potassium chloride, 1.15g disodium hydrogen phosphate, 0.2g potassium dihydrogen phosphate, 10g sucrose) and incubated on an orbital shaker at 150 rpm for 48 h at 28 ± 2^0C. The cells in cultured bacterial broth were collected by centrifugation for 15 min at 4^0C and washed with sterilized tap water, then the cells were adjusted to 10^8 cells/ml, based on optical density $O.D_{620}$= 0.08 and

30 ml of inoculum either irradiated or un-irradiated strain which were used in the agriculture trial (Han *et al.*, 2006).

Counting of KSB before and after soil inoculation used in the agriculture trial

Soil samples were serially diluted at three successive concentrations (10^5-10^7) and spread plated on and Aleksandrov medium and incubated at 28±2^0C for 3–5 days. Colonies were counted on the basis of potassium solubilization as indicated by clear halo around the bacterial colonies (Bashir *et al.*, 2017).

Agriculture studies

Agriculture studies were carried out during the two successive seasons of 2017/2018 and 2018/2019 in the experimental farm of the National Center for Radiation Research and Technology, Nasr City , Cairo , Egypt.

Soil samples were collected from 30 cm depth, air dried then were transferred to the Water and Environmental Research Institute to determine chemical and physical analyses of soil samples as presented in table 1.

Bulbs of garlic *cv.* Sids 40 were obtained from Horticultural Research Institute, Dokki, Giza, Egypt. Cloves of garlic were soaked in tap water for 24hours before planting, then cloves were cultivated on both sides of row,the distance between cloves was 10cm the area of the experimental plot was 9m^2 consisted of 3 rows, with 5 m of length and 0.6m of width. Planting date was in the 13th of October in both seasons. All agricultural management, disease and pest control programs were followed according to the recommendations of the Egyptian Ministry of Agriculture and Land reclamation.

Table 1: Chemical and physical analyses of the experimental soil of Nasr City, Cairo governorate during 2017/ 2018and 2018/2019 seasons.

	Experimental year	
Soil properties	**2017/2018**	**2018/2019**
pH(1:2.5)	7.84	7.88
EC dS/m	4.12	5.30
SP	40	41
Soluble anions (meq/l)		
$CO3^{--}$	-	-
$HCO3^-$	2.3	3.1
Cl^-	31.6	42.4
$SO4^{--}$	6.1	6.5
Soluble cations (meq/l)		
Ca^{++}	8.3	12.5
Mg^{++}	8	12
K^+	1	1.1
Na^+	22.7	26.4
Fine Sand (%)	18.7	20.5
Coarse sand (%)	10.5	14.4
Silt (%)	36.5	33.5
Clay (%)	34.3	31.6
Soil texture	Loamy clay	Loamy clay

Calcium super-phosphate (15% P_2O_5) at 300Kg/ feddan, was added one time during the soil preparation. Ammonium sulphate (20.5%N) at 250Kg/fed was applied as soil application in three portions, the first was added after four weeks from planting, the second one was carried out after one month from the first addition and the third portion was added after one month of the second one. The addition of potassium sulphate (48%) was conducted for three times as followed in ammonium sulphate and bacterial inoculation was added according to the following ratios:

1- Un-irradiated bacteria.

2- 100% potassium sulphate (150 Kg K_2SO_4 48%/ feddan).

3- 100% potassium sulphate (150 Kg K_2SO_4 48%/ feddan) +un-irradiated bacteria.

4- 75% potassium sulphate (112.5 Kg K_2SO_4 48%/ feddan) +un-irradiated bacteria.

5- 50% potassium sulphate (75 Kg K_2SO_4 48%/ feddan) +un-irradiated bacteria.

6- Irradiated bacteria

7- 100% potassium sulphate (150 Kg K_2SO_4 48%/ feddan) +irradiated bacteria

8- 75%potassium sulphate (112.5 Kg K_2SO_4 48%/ feddan) +irradiated bacteria

9- 50% potassium sulphate (75 Kg K_2SO_4 48%/ feddan) +irradiated bacteria

The bacterial inoculation was carried out three times with concentration of (10^{11}/L) for 3 times after one week of potassium sulphate addition.

All garlic vegetative characters were recorded at 120 days after planting date, while total yield were harvested at 200days after planting.

Vegetative characters

Random samples of three plants from each experimental plot were taken after 120 days from planting to determine: plant length (cm), leaf number per plant, neck diameter (cm), bulb diameter (cm), bulbing ratio, leaf dry weight (g), bulb dry weight (g) and plant dry weight (g).

Yield and its components

Total yield was determined for each experimental plot at harvest (200 days from planting). After curing period for 15 days under shaded place, plants of each experimental plot were weighted and total cured yield was calculated as ton per feddan (4200 m^2). Five bulbs were randomly taken from each experimental plot to determine the averages of bulb diameter (cm.), bulb weight (g). Weight loss after currying estimated according to the following formula:

Weight loss after currying % = [(Total yield at harvest time - Cured yield) x 100]/Total yield at harvest time.

Chemical constituents

Chlorophyll reading in leaves was measured using digital chlorophyll meter, Konika Minolta SPAD-502 (Minolta Company, Japan), total carbohydrates(g/100g) were determined calorimetrically in dry matter of the bulbs according to Dubois *et al.*(1956), total free amino acids (mg/g)in dry matter were determinate according to Jayaraman (1985), total nitrogen(%) was estimated according to Plummer (1971), phosphorus(%) was determined according to Jackson (1958) and potassium(%) according to Piper (1950) and crude protein(%) was calculated by multiplying total nitrogen by 6.25(A.O.A.C.,1990).

Storability

After curing, two kilograms of bulbs without stems were randomly taken from each experimental plot in both seasons and placed in net bags and stored at room temperature at (25±3°C) with common storage conditions. Bulb weight loss was determined every month till the end of storage period as follows:

Weight loss (%) = [(initial weight of storage bulb-weight at sampling date) x100]/initial weight of storage bulb.

Statistical analysis

Treatments were arranged in complete randomized block design (CRBD) with three replicates. The data were statistically analyzed using the procedure outlined by Snedecor and Cochran (1980). Also, data were tested for least significant differences (L.S.D.) to compare the averages of the determined parameters.

Results and Discussion

Seven bacterial isolates were isolated from five agriculture wastes (potato peals, corn cobs, banana peels, rice straw and bagasse) and six standard strains were obtained from Bioburden and Toxin laboratory at Radiation Microbiology Department at National Center for Radiation Research and Technology (NCRRT), Atomic Authority, Cairo, Egypt.

Totally thirteen bacterial cultures were studied for their ability to solubilize potassium from Aleksandrov media contained either soluble or insoluble potassium. Among the thirteen bacterial cultures, two bacterial cultures exhibited the higher potassium solubilization (KSB-2 isolate and standard strain *Bacillus mucilaginosus* HQ013329).

The index of potassium solubilization (IKS) of both bacterial strains KSB-2 and *Bacillus mucilaginosus* HQ013329 on Aleksandrov media containing either soluble or insoluble potassium were (8.8 and 10 mm) or (34.5 and 21.0 mm), respectively which represent higher selection ratio of potassium solubilization after incubation 7 days at 28±2^0C than other strains.

As presented in table 2, results show that the great ability of both cultures for solubilizing potassium either soluble or insoluble form was based on the nature of the matter from which they were isolated since that KSB-2 isolate was isolated from banana peels as agriculture waste while *Bacillus mucilaginosus* HQ013329 were an indigenous bacterial strain which isolated from chronic agriculture soil had a 41 years exposure history to contamination for deposition of pesticides and petroleum wastes (Abo-State *et al.*,2013).

Pirhadi *et al.* (2016) investigated the dissolution of insoluble potassium based on halo zone around the colonies of the isolates. Highest solubility index recorded in R-1 isolate (*Enterobacter*) in presence of both vermiculite and K_2HPO_4 followed by S-49 isolate (*Pseudomonas*). Most of the potassium solubilizing bacteria obtained from

Table 2: Screening of bacterial isolates of potassium solubilization zone formation (IKS: mm).

Isolate	IKS of soluble potassium	IKS of insoluble potassium	Isolate	IKS of soluble potassium	IKS of insoluble potassium
KSB-1	16.7	2.5	*Enterobactereace cloaceae* MAM-4	4.2	16.0
KSB-2	8.8	34.5	*Bacillus mucilaginosus* HQ013329	10.0	21.0
KSB-3	4.5	5.7	*Lactobacillus acidophilus* ATCC4356	-ve	11.2
KSB-4	8.1	4.2	*Lactobacillus rhamnosus* ATCC11981	-ve	20.0
KSB-5	4.4	8.2	*Pseudomonas chengduensis* KX257374	8.8	9.0
KSB-6	4.3	14.3	*Pseudomonas plecoglossicida* KX257375	11.4	9.0
KSB-7	12.2	6.1			

the plant rhizosphere and identified as *Bacillus* sp., *Pseudomonas* sp., *Bacillus mucilaginosus* (Zhang and Kong, 2014).

The phylogenetic tree represented in Fig. 1, show that the KSB-2 isolate was promising and was identified by 16SrRNA phylogenetic identification as *Microbacterium keratanolyticum* SAB-2.

The effect of gamma radiation on the ability of both promising strains to solubilize potassium was obtained by exposing *Microbacterium keratanolyticum* SAB-2 and *Bacillus mucilaginosus* HQ013329 to 9 different doses (0.01, 0.025, 0.05, 0.1, 0.2, 0.4, 0.6, 0.8, 1.5 KGy) of gamma radiation. Both un-irradiated *Microbacterium keratanolyticum* SAB-2 and *Bacillus mucilaginosus* HQ013329 strains served as control. The comparison between the IKS value of both strains on insoluble potassium was presented in Fig. 2. At low irradiation doses (0.01 and 0.025) *Microbacterium keratanolyticum* SAB-2 exhibited solubilizing ratio 18.5 mm and 19.5 mm, respectively which were near to that of control (20 mm). The increase of gamma radiation doses from 0.05 to 0.6 KGy increased the solubilizing ratio from 23 mm to 26 mm respectively, at 0.8 KGy the solubilizing ratio (20.5 mm) decrease nearly to the control again while at 1.5 KGy the solubilization ratio reach the lower value 17 mm. These results mean that low doses activate the vital processes of microbial strains and increase the potassium solubilization. These results are compatible with Brown *et al.* (2015) which appear the importance of aggregation low doses, particularly since lower dose permit species to counter through up-regulating repair mechanisms and led to an inducement of pivotal processes by microbial strains. On the contrary, *Bacillus mucilaginosus* HQ013329 showed gradual increase in solubilizing insoluble potassium when it was exposed to gamma doses from 0.01 to 1.5 KGy. These results show that all gamma radiation doses used, increased gradually the ability of *Bacillus mucilaginosus* HQ013329 for potassium solubilization. Ionizing radiation had the ability to change the tertiary structure of macromolecules, either by direct action or through the agency of reactive free radicals from water, leading to a rupture of hydrogen bonds, peptide bonds or other covalent linkages (Brown *et al.*, 2015).

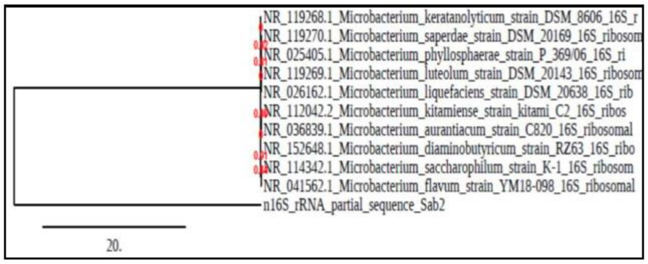

Fig. 1: Phylogenetic tree constructed by neighbor-joining al-gorithm based on the partial 16S rRNA gene sequences of the selected KSB-2, showing its position in relation to other members of *Microbacterium keratanolyticum* SAB-2.

Fig. 3 indicates that the most appropriate irradiation dose to increase the ability of *Bacillus mucilaginosus* HQ013329 to solubilize the insoluble potassium was 3.5 KGy, since it gave the highest IKS (38 mm). These results gave the highest ratio of potassium solubilization than the previous researches. Verma *et al.* (2016) investigated that out of 14 isolated bacterial isolates, 7 of them showed highest ratio which were (3.13, 3.50, 2.0, 3.22, 5.00, 4.13, 3.75 mm).

The standard strain *Bacillus mucilaginosus* HQ013329 was selected based on the highest dissolution index since it showed great K solubilization zone. As shown in Fig. 4, the un-irradiated *Bacillus mucilaginosus* HQ013329 showed large halo solubilization zone on Aleksandrov plates than those inoculated by irradiated one which was exposed to 3.5 KGy after 3 days of incubation. On the contrary Parmar and Sindhu (2013) found that 72.3% of 137 isolated strains didn't show

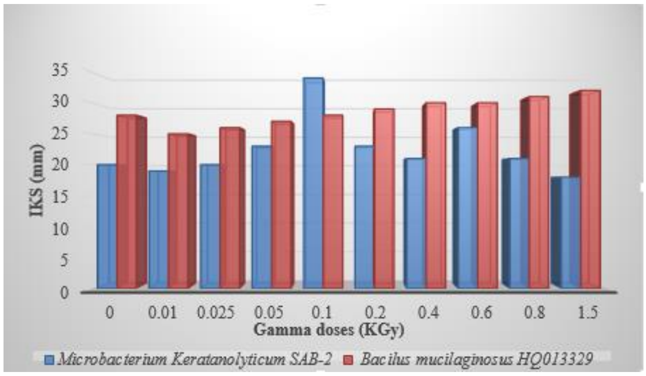

Fig. 2: Detection of the most promising KSB strain after ex-posing to different doses of gamma irradiation.

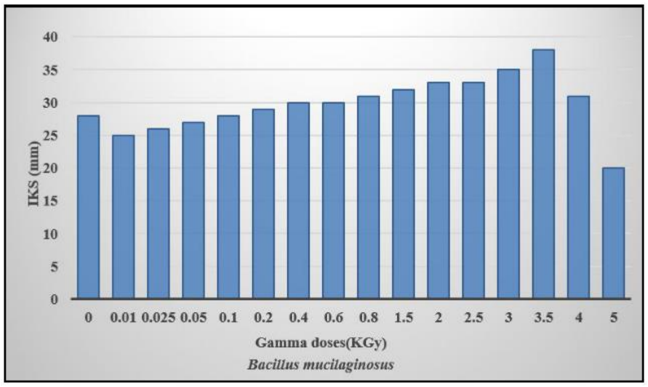

Fig. 3: Screening of the most appropriate dose of gamma radiation for *Bacillus mucilaginosus* HQ013329.

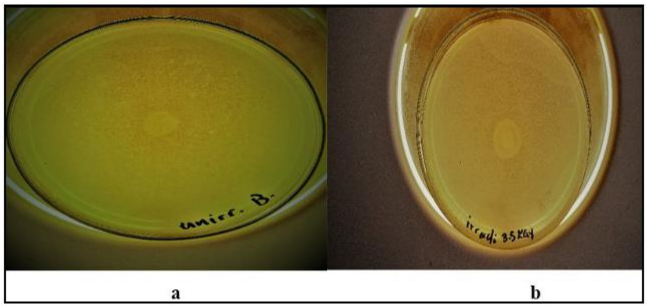

Fig. 4: Formation of solubilization zone on Aleksandrov me-dia by (a) un-irradiated *Bacillus mucilaginosus* HQ013329 and (b) irradiated *Bacillus mucilaginosus* HQ013329.

potassium solubilization while only three bacterial isolates showed significant potassium solubilzation zone.

The potassium solubilizing quantitative assessment value by the un-irradiated and irradiated selected strain *Bacillus mucilaginosus* HQ013329 showed different results. After 10 days of incubation, un-irradiated *Bacillus mucilaginosus* HQ013329 and irradiated *Bacillus mucilaginosus* HQ013329 solubilized the highest potassium concentration with value 29.01 mg/L and 28.15 mg/L, respectively. Our results are compatible with Prajapati, (2016) who found that KSB-7 isolate produced maximum amount of potassium (32.6 mg/L) followed by KSB-1 (31.2 mg/L) but they showed higher potassium solubilization quantitative estimation than Zhang and Kong (2014) who assessed the ability of all 27 KSB strains from the tobacco rhizosphere to solubilize potassium. They reported that all examined bacterial strains were able to solubilize K but not only to the same extent. The ability of KSB to solubilize K ranged from 0.59 mg/L to 4.4 mg/ L.

As shown in table 3, the pH value at zero time was 7.10 in both inoculated Aleksandrov media with either un-irradiated *Bacillus mucilaginosus* HQ013329 or irradiated *Bacillus mucilaginosus* HQ013329. The pH values released by both strains decreased, along the incubation period. In case of un-irradiated *Bacillus mucilaginosus* HQ013329 the decline in pH value was higher in comparison with that of irradiated *Bacillus mucilaginosus* HQ013329, since it started with 6.44 and at the end of the incubation period it ended with 4.93. In case of irradiated *Bacillus mucilaginosus* HQ013329, it began with 6.61 and ended with 5.55. Results of pH values confirmed that quantity of potassium released. The lowest pH decrease, the highest quantity of potassium released. Parmar and Sindhu (2013) found that most of bacterial strains prefer neutral pH for their growth. It was found that K solubilization was maximum when bacterial strains were grown in a medium with pH 7.0. Badr *et al.* (2006) studied potassium solubilization capacity of silicate solubilizing bacteria and found that it ranged from 490 mg/L to 758 mg/L at pH 6.5 to 8.0, with an increase in medium pH and a decrease of potassium solubilization.

Table 3: Effect of incubation time on pH values of un-irradiated and irradiated *Bacillus mucilaginosus* HQ013329.

	Time (hr)					
Strain	**zero**	**6**	**12**	**30**	**72**	**96**
Unirradiated *B. mucilaginosus*	7.10	6.44	5.77	5.77	5.24	4.93
Irradiated *B. mucilaginosus*	7.10	6.61	5.83	5.71	5.64	5.55

The presence of organic acids, in general, lowering the medium pH. Solubilization of the minerals is achieved through the production of metabolites containing organic acids as the active ingredients, increased the solubility of mineral. Some organic acids produced in the periplasm could easily be diffusible into adjacent environment and subsequently dissolve insoluble forms of minerals (Setiawati and Mutmainnah, 2016).

Fig. 5 show the count of viable potassium solubilizing bacterial cells in the soil during the two successive seasons before and after soil inoculation. The log viable count of uninoculated soil with *Bacillus mucilginosus* HQ013329 was 7.0 CFU/ml in both seasons. By adding un-irradiated *Bacillus mucilginosus* HQ013329 only, the log viable count reached 7.7 CFU/ml in both seasons and it was the same count that given by the addition 100% of potassium sulphate only and it means that potassium sulphate (chemical fertilizer) can be replaced by un-irradiated *Bacillus mucilginosus* HQ013329 (biofertilizer) since they gave the same results.

As for the interaction between un-irradiated *Bacillus mucilginosus* HQ013329 and 100% potassium sulphate, the log bacterial count increased to be (7.8 CFU/ml) in both seasons, which was similar to the interaction between *Bacillus mucilginosus* HQ013329 and 75% of potassium sulphate. On the other hand, it was observed that the

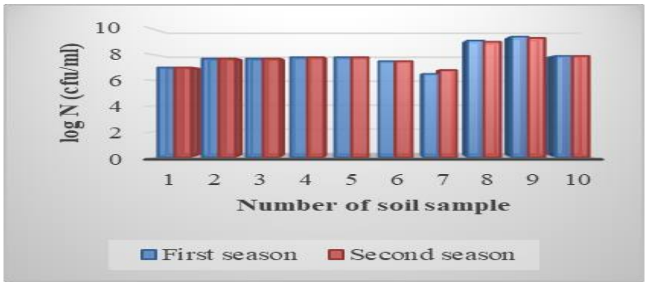

Fig. 5: Count of viable KSB from the soil before and after different treatments.

(1) control (uninoculated) soil, (2) Un-irradiated *Bacillus mucilaginosus* HQ013329 only, (3) 100% K only,(4)un-irradiated *Bacillus mucilaginosus* HQ013329 +100% K, (5) un-irradiated *Bacillus mucilaginosus* HQ013329 +75% K, (6) un-irradiated *Bacillus mucilaginosus* HQ013329 +50% K, (7) irradiated *Bacillus mucilaginosus* HQ013329 only, (8) irradiated *Bacillus mucilaginosus* HQ013329 +100% K, (9) irradiated *Bacillus mucilaginosus* HQ013329 +75% K, (10) irradiated *Bacillus mucilaginosus* HQ013329 +50% K.

addition of *Bacillus mucilaginosus* HQ013329 with 50% of potassium sulphate decreased the log bacterial count to (7.5, 7.4 CFU/ml) in both seasons.

The inoculated soil with irradiated *Bacillus mucilaginosus* HQ013329 only gave the lowest count (6.5 and 6.8 CFU/ml) compared to the control (uninoculated), which indicated that the inoculation with irradiated *Bacillus mucilaginosus* HQ013329 alone weakens the bacterial solubilizing potassium community in the soil. While, the addition of potassium sulphate with irradiated *Bacillus mucilaginosus* HQ013329 (100 and 75% of recommended doses) gave the highest count in all treatments (9.1 and 9.0 CFU/ml), (9.4 and9.3 CFU/ml) in both seasons respectively. Also, the addition of potassium sulphate (chemical fertilizer) in this case stimulate the action of irradiated *Bacillus mucilaginosus* HQ013329 and the addition of irradiated *Bacillus mucilaginosus* HQ013329 with 50 % of potassium sulphate retard the count and decreased it to (7.9 CFU/ml) in both seasons.

The inoculation with isolated indigenous KSB strains in the soil enhanced and maintained the efficiency of potassium solubilizing bacterial population and minimizing the sole use of chemical fertilizers by improving soil fertility, yield attributing characters and soil biota in agriculture to obtain good sustainable yield of various crops (Bahadur *et al.,* 2014).

Concerning agriculture experiment data presented in table 4 show that, the addition of 100% K_2SO_4, 100% K_2SO_4+ un-irradiated solubilizing potassium bacteria and 50% K_2SO_4+ irradiated solubilizing potassium bacteria scored the highest plant length during the two successive seasons. On the other hand, it was observed that un-irradiated solubilizing potassium bacteria, 100% K_2SO_4 and 100% K_2SO_4+ un-irradiated solubilizing potassium bacteria treatments gave the highest number of leaves in the first season only. As for neck and bulb diameter, data revealed that 100% K_2SO_4 and 100% K_2SO_4+ un-irradiated solubilizing potassium bacteria as well as 75% + un-irradiated solubilizing potassium bacteria gave higher values for both characters than other treatments in the first and the second seasons. These results agree with that obtained by Behairy *et al.* (2015) and Arisha *et al.*(2017) who found that plant height and leaf number per plant of garlic plants increase with the increment of potassium fertilizer levels. As for bacterial inoculation, similar result was obtained by (Khalil *et al.,* 2018 and Elkhatib *et al.,* 2019) who found that the inoculation with *Bacillus circulance* alone or combined with potassium fertilizer increase plant length, number of leaves of pepper and potato plants.

As shown in table 5, data revealed that the addition of 100% K_2SO_4 and 100% K_2SO_4+ un-irradiated

Table 4: Effect of potassium solubilizing bacteria inoculation, potassium sulphate levels and their interaction on plant length (cm), leaf number, neck and bulb diameter (cm) of garlic plants in 2017/2018 and 2018/2019 seasons.

Characters Treatments	**Plant length**		**Leaf number/ plant**		**Neck diameter**		**Bulb diameter**	
	First season	**Second season**	**First season**	**Second season**	**First season**	**Second season**	**First season**	**Second season**
T1	82.20	84.53	10.07	10.20	1.47	1.47	4.98	4.85
T2	88.43	90.17	10.27	10.40	1.57	1.67	5.14	5.31
T3	88.17	87.83	10.20	10.13	1.71	1.76	5.23	5.32
T4	84.29	87.25	9.93	9.40	1.61	1.67	5.11	5.30
T5	75.23	77.37	9.47	9.53	1.31	1.47	4.87	4.95
T6	76.25	81.43	9.67	9.93	1.27	1.45	4.36	4.71
T7	83.20	83.03	9.53	10.07	1.46	1.49	4.98	5.01
T8	88.27	84.07	9.93	9.73	1.56	1.51	5.11	5.23
T9	85.19	88.13	9.53	9.47	1.61	1.48	4.90	4.77
L.S.D. at 5%	3.44	5.21	0.51	N.S.	0.16	0.17	0.27	0.23

T1:un-irradiated solubilizing potassium bacteria; T2:100% K_2SO_4; T3: 100% K_2SO_4+ un-irradiated solubilizing potassium bacteria; T4: 75% K_2SO_4+ un-irradiated solubilizing potassium bacteria; T5: 50% K_2SO_4+ un-irradiated solubilizing potassium bacteria; T6: irradiated solubilizing potassium bacteria; T7: 100% K_2SO_4+ irradiated solubilizing potassium bacteria; T8: 75% K_2SO_4+irradiated solubilizing potassium bacteria; T9: 50% K_2SO_4+ irradiated solubilizing potassium bacteria.

solubilizing potassium bacteria as well as 75% K_2SO_4+ un-irradiated solubilizing potassium bacteria gave the highest leaf dry weight and plant dry weight in both seasons. On the other hand, it was noticed that the addition of 100% K_2SO_4+ un-irradiated solubilizing potassium bacteria and 75% K_2SO_4+ un-irradiated solubilizing potassium bacteria scored the highest bulb dry weight during the two successive seasons. As for bulbing ratio, results indicate that 100% K_2SO_4, 100% K_2SO_4+ un-irradiated solubilizing potassium bacteria and 75% K_2SO_4+ un-irradiated solubilizing potassium bacteria as well as 50% K_2SO_4+ irradiated solubilizing potassium bacteria led to the highest ratio in the first season only. These results agree with that obtained by Ahmed *et al.* (2009); El-Sayed and El-Morsy (2012) and Arisha *et al.* (2017) who found that the increase of potassium fertilizer increases bulbing ratio in the first season, leaves, bulbs and total plant dry weight. Regarding the effect of bacterial inoculation, same finding was obtained by Elkhatib *et al.*(2019) who declared that either the inoculation with *Bacillus circulance* alone or with potassium fertilization scored the highest dry weight of potato leaves and J'drszczyk *et al.* (2019) who found that the inoculation with *Bacillus subtilis* scored the highest dry matter content of garlic bulbs.

The promoting role of potassium on vegetative characters might be referred to its physiological function on regulating water and gas exchange, installation of protein, photosynthesis, carbohydrates transportation, the activity of different enzymes and plant metabolism which reflect on plant vegetative characters (Bednarz and Oosterhuis, 1999); Also, El-Shabasi (2001); Abdel-Fattah *et al.* (2002); El-Morsy *et al.* (2004); Ahmed *et al.*(2010) and Osman (2015) who reported that potassium application significantly affect vegetative growth of garlic plants.

As for bacterial inoculation and its role on vegetative growth, it could be summarized that potassium solubilizing bacteria excreted some organic acids like oxalic acid, tartaric acid, gluconic acid, 2-ketogluconic acid, lactic acid, citric acid, malonic acid, fumaric acid and inorganic acid as well as protons which transform potassium from insoluble form to soluble form and silicate minerals (Deka and Dutta, 2000). Also these microorganisms have the ability to produce amino acids, growth promoters like indole-3-acetic acid and gibberellic acid which enhance the growth and development of plants (Ponmurugan and Gopi, 2006).

As for total yield at harvest time, data in table 6 show that both 100% K_2SO_4 and 100% K_2SO_4+ un-irradiated solubilizing potassium bacteria led to the highest total yield at harvest time in both seasons. As for cured yield, bulb diameter and bulb weight, it was found that 100% K_2SO_4 and 100% K_2SO_4+ un-irradiated solubilizing potassium bacteria as well as 75% K_2SO_4+ un-irradiated solubilizing potassium bacteria gave the highest cured yield, bulb diameter and bulb weight during the two successive seasons. Regarding weight loss after curing, it was found that there was no significant differences among different treatments in both seasons. Same results were obtained

Table 5: Effect of potassium solubilizing bacteria inoculation, potassium sulphate levels and their interaction on bulbing ratio, leaf dry weight (g), bulb dry weight (g) and plant dry weight (g) of garlic plants in 2017/2018 and 2018/2019 seasons.

Characters Treatments	Bulbing ratio		Leaf dry weight		bulb dry weight		Plant dry weight	
	First season	Second season	First season	Second season	First season	Second season	First season	Second season
T1	0.29	0.31	14.29	14.59	10.11	11.02	24.41	25.61
T2	0.30	0.31	15.46	15.79	11.17	12.37	26.63	28.16
T3	0.33	0.33	15.66	15.92	11.92	12.59	27.58	28.51
T4	0.31	0.32	15.08	15.77	11.74	12.02	26.82	27.79
T5	0.27	0.30	13.45	13.75	10.65	11.69	24.09	25.44
T6	0.29	0.31	13.07	13.58	9.95	10.69	23.01	24.27
T7	0.30	0.30	13.47	14.39	10.47	12.01	23.95	26.41
T8	0.31	0.29	13.63	14.19	10.96	11.01	24.59	25.20
T9	0.33	0.31	13.46	14.65	10.04	11.13	23.50	25.77
L.S.D. at 5%	0.03	N.S.	0.99	1.20	0.65	0.76	1.43	1.46

T1:un-irradiated solubilizing potassium bacteria; T2:100% K_2SO_4; T3: 100% K_2SO_4+ un-irradiated solubilizing potassium bacteria; T4: 75% K_2SO_4+ un-irradiated solubilizing potassium bacteria; T5: 50% K_2SO_4+ un-irradiated solubilizing potassium bacteria; T6: irradiated solubilizing potassium bacteria; T7: 100% K_2SO_4+ irradiated solubilizing potassium bacteria; T8: 75% K_2SO_4+irradiated solubilizing potassium bacteria; T9: 50% K_2SO_4+ irradiated solubilizing potassium bacteria.

Table 6: Effect of potassium solubilizing bacteria inoculation, potassium sulphate levels and their interaction on total yield at harvest time (ton/fed.),total cured yield (ton/fed.) ,weight loss after curing(%), bulb diameter (cm) and bulb weight (g) of garlic plants in 2017/2018 and 2018/2019 seasons.

Characters Treatments	Total yield at harvest time		Total cured yield		Weight loss after curing		Bulb diameter		Bulb weight	
	First season	Second season	First season	Second season	First season	Second season	First season	Second season	First season	Second season
T1	7.355	7.802	4.630	4.990	36.97	35.57	5.75	5.92	62.83	65.04
T2	7.595	8.479	4.999	5.410	34.09	36.14	6.14	6.07	65.53	65.47
T3	7.554	8.391	4.882	5.290	35.38	36.85	5.82	5.85	63.78	65.15
T4	6.951	7.692	4.479	4.863	35.57	36.77	5.85	6.00	62.07	63.04
T5	6.519	6.534	4.238	4.187	35.01	35.97	5.93	5.37	60.52	62.10
T6	5.888	5.432	3.778	3.460	35.83	36.21	5.41	5.53	55.60	60.47
T7	6.354	7.654	4.258	4.840	33.06	36.77	5.55	5.68	57.25	61.08
T8	6.302	7.644	4.280	4.610	32.11	39.67	5.63	5.79	56.71	62.11
T9	5.930	7.120	3.734	4.480	36.98	36.90	5.68	5.61	59.27	60.63
L.S.D. at 5%	0.710	1.148	0.613	0.647	N.S.	N.S.	0.39	0.35	5.04	2.98

T1:un-irradiated solubilizing potassium bacteria; T2:100% K_2SO_4; T3: 100% K_2SO_4+ un-irradiated solubilizing potassium bacteria; T4: 75% K_2SO_4+ un-irradiated solubilizing potassium bacteria; T5: 50% K_2SO_4+ un-irradiated solubilizing potassium bacteria; T6: irradiated solubilizing potassium bacteria; T7: 100% K_2SO_4+ irradiated solubilizing potassium bacteria; T8: 75% K_2SO_4+irradiated solubilizing potassium bacteria; T9: 50% K_2SO_4+ irradiated solubilizing potassium bacteria.

by Behairy *etal.*(2015); Arisha *et al.* (2017) and Elkhatib *et al.*(2019) who concluded that the addition of potassium up to the optimum levels of recommended dose scored the highest bulb diameter, average bulb weight and total yield per feddan and tuber yield per plant as well as average tuber weight of potato plants.

Regarding bacterial inoculation similar result was found by Khalil *et al.* (2018) and Elkhatib *et al.*(2019) who stated that the inoculation with *Bacillus circulance* led to the highest total yield of pepper and potato tuber yield per plant and average tuber weight.

The effect of potassium on increasing yield and its components might be referred to its role on transporting the synthesized carbohydrates from plant leaves to bulb which affects yield quality. Typical findings were obtained by El Sayed *et al.* (2012) and Shafeek *et al.* (2016) who indicated that potassium fertilizers affect garlic bulb size and increase it. Also, these results agree with El-Shabasi (2001); Abdel-Fattah *et al*. (2002); El-Morsy (2004); Ahmed *et al.* (2010) and Osman (2015) ,they found that the application of potassium fertilizer significantly increased total yield and its components. The role of potassium on total yield and its component could be referred to its function in photosynthesis, regulation of opening and closure of stomata, transportation of carbohydrates synthesized in leaves to storage organs and diminishing dark respiration which reflect on increasing the amount of stored carbohydrates in bulb (Patil, 2011). As for microbial inoculation and its impact on yield, it could be concluded that potassium solubilizing bacteria have the ability on dissolving the mineral through the excretion of both organic and inorganic acids, producing some growth promoters like indole acetic acid, gibberellins and cytokiknins which play an important role in plant growth and development (Stancheva *et al.*, 1995).

As presented in table 7, data show that the addition of 100 % K_2SO_4 combined with the inoculation with un-irradiated solubilizing bacteria scored the highest chlorophyll reading in both seasons. A similar result was reached by Elhakim *et al.* (2016) who declared that potassium fertilizer combined with bacterial inoculation scored the highest photosynthetic pigment values of potato plants.

Regarding total carbohydrates concentration, data revealed that the addition of 100 and 75% of K_2SO_4 combined with the inoculation with un-irradiated solubilizing bacteria gave higher total carbohydrates content than other treatments in both seasons. These results might be referred to the effect of potassium on transporting carbohydrates synthesized in leaves to storage organs (Mengel, 1997). As for bacterial inoculation, it could be referred to the stimulant effect of bacteria on vegetative growth, photosynthesis process and mineral contents (Ahmed *et al.*, 2009).

Respecting total free amino acids concentration, data revealed that the addition of 100% and 75% of K_2SO_4 combined with un-irradiated potassium solubilizing bacteria as well as the addition of 75% of K_2SO_4 combined with irradiated potassium solubilizing bacteria

Table 7: Effect of potassium solubilizing bacteria inoculation, potassium sulphate levels and their interaction on chlorophyll reading (SPAD), total carbohydrates (g/100g dry weight), total free amino acids (mg/g dry weight) and crude protein (%) of garlic bulbs in 2017/2018 and 2018/2019 seasons.

Characters Treatments	Chlorophyll reading		Total carbohydrates		Total free amino acids		Crude protein	
	First season	Second season	First season	Second season	First season	Second season	First season	Second season
T1	81.27	82.37	26.92	23.08	12.96	14.20	12.23	15.74
T2	78.97	81.16	26.34	23.74	12.30	12.95	12.74	14.97
T3	83.78	87.60	32.39	29.51	15.87	15.96	13.09	13.30
T4	80.14	86.45	29.90	28.32	15.50	15.07	17.40	17.47
T5	78.68	77.22	29.00	25.24	10.19	11.06	16.14	16.43
T6	77.46	80.59	27.87	26.12	10.40	14.91	9.42	9.42
T7	81.14	78.37	25.23	25.41	11.31	12.38	14.87	13.78
T8	79.20	78.25	23.64	27.28	14.12	14.31	10.66	14.69
T9	76.50	76.49	29.05	25.52	10.54	10.51	13.01	17.47
L.S.D. at 5%	2.94	2.72	2.63	2.30	2.22	2.02	1.50	1.19

T1:un-irradiated solubilizing potassium bacteria; T2:100% K_2SO_4; T3: 100% K_2SO_4+ un-irradiated solubilizing potassium bacteria; T4: 75% K_2SO_4+ un-irradiated solubilizing potassium bacteria; T5: 50% K_2SO_4+ un-irradiated solubilizing potassium bacteria; T6: irradiated solubilizing potassium bacteria; T7: 100% K_2SO_4+ irradiated solubilizing potassium bacteria; T8: 75% K_2SO_4+irradiated solubilizing potassium bacteria; T9: 50% K_2SO_4+ irradiated solubilizing potassium bacteria.

scored the highest total free amino acids in both seasons.

As for crude protein percentage, data show that garlic plants fertilized with 75% of K_2SO_4 and 50% of K_2SO_4 combined with un-irradiated potassium solubilizing bacteria scored the highest percentage of crude protein in both seasons.

Regarding nitrogen, phosphorus and potassium percentage in bulbs, data in table 8 show that plants fertilized with 50 and 75% of K_2SO_4 +un-irradiated potassium solubilizing bacteria inoculation gave higher percentage of nitrogen than other treatments during the two successive seasons. As for phosphorus percentage, it was found that the addition of 100% of K_2SO_4 scored the highest phosphorus percentage in both seasons. Concerning potassium percentage, data revealed that there was no significant difference among different treatments in the first and the second seasons. Same result was obtained by (Han *et al.*, 2006) who found that eggplants inoculated with *Bacillus mucilaginosus* scored the highest content of nitrogen, phosphorus and potassium. The effect of *Bacillus mucilaginosus* on increasing nitrogen percentage in garlic bulbs might be referred to the effect of *Bradyrhizobium* sp. which has the ability to fixes atmospheric nitrogen (Zakhia and de Lajudie, 2001).

As for weight loss percentage of garlic bulbs during storage, results in table 9 show that there was an increase in weight loss percentage accompanied with the increase of storage period. On the other hand it was observed that bulbs of garlic fertilized with un-irradiated bacteria and 100% of K_2SO_4 + irradiated bacteria scored the lowest bulb weight loss percentage in the 1st month of storage period. In the 2nd month, it was observed that plants fertilized with 100% of K_2SO_4+un-irradiated bacteria gave lower bulb weight loss percentage than

Table 8: Effect of potassium solubilizing bacteria inoculation, potassium sulphate levels and their interaction on nitrogen, phosphorus and potassium percentage of garlic bulbs in 2017/2018 and 2018/2019 seasons.

Treat-ments	Nitrogen		Phosphorus		Potassium	
	First season	Second season	First season	Second season	First season	Second season
T1	1.96	2.52	0.27	0.28	1.08	1.15
T2	2.04	2.40	0.47	0.45	1.05	1.06
T3	2.10	2.13	0.46	0.39	1.06	1.08
T4	2.79	2.80	0.43	0.43	1.02	1.06
T5	2.58	2.63	0.40	0.40	1.16	1.08
T6	1.51	1.51	0.39	0.39	1.09	1.06
T7	2.38	2.21	0.41	0.32	1.12	1.03
T8	1.71	2.35	0.33	0.37	1.03	1.01
T9	2.08	2.80	0.32	0.35	1.04	1.01
L.S.D. at 5%	0.24	0.19	0.03	0.03	N.S.	N.S.

T1:un-irradiated solubilizing potassium bacteria; T2:100% K_2SO_4; T3: 100% K_2SO_4;+ un-irradiated solubilizing potassium bacteria; T4: 75% K_2SO_4;+ un-irradiated solubilizing potassium bacteria; T5: 50% K_2SO_4;+ un-irradiated solubilizing potassium bacteria; T6: irradiated solubilizing potassium bacteria; T7: 100% K_2SO_4;+ irradiated solubilizing potassium bacteria; T8: 75% K_2SO_4; +irradiated solubilizing potassium bacteria; T9: 50% K_2SO_4; + irradiated solubilizing potassium bacteria.

Table 9: Effect of potassium solubilizing bacteria inoculation, potassium sulphate levels and their interaction on weight loss percentage during storage of garlic bulbs in 2017/2018 and 2018/2019 seasons.

Treat-ments	First season							Second season						
	Storage period (month)							Storage period (month)						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
T1	0.91	2.92	3.61	3.88	6.21	9.60	13.80	0.92	2.54	3.19	4.70	5.79	8.60	15.06
T2	0.79	2.35	3.34	4.68	6.15	9.42	14.43	0.91	1.45	4.20	3.56	5.77	8.53	15.18
T3	0.75	1.58	3.50	5.86	7.35	8.78	14.53	0.63	1.57	4.04	4.43	6.95	9.71	14.53
T4	0.67	2.13	3.55	4.64	6.35	8.46	13.18	0.84	2.15	3.37	4.51	6.46	8.36	12.83
T5	0.73	2.09	3.20	4.11	6.45	8.70	14.48	0.61	1.73	2.83	4.29	6.57	10.18	14.54
T6	0.49	1.84	3.36	4.82	7.73	10.84	17.54	0.44	2.48	3.71	4.45	6.97	12.16	17.27
T7	0.51	1.75	3.07	4.16	6.62	9.68	14.57	0.84	2.43	3.58	4.40	5.75	8.74	13.92
T8	0.67	2.33	3.90	4.89	6.37	9.58	16.68	0.48	1.19	3.55	4.85	5.51	8.45	14.33
T9	0.52	2.29	3.79	5.81	7.63	10.59	17.42	0.63	1.94	3.15	4.07	5.59	8.27	14.53
L.S.D. at 5%	0.17	0.51	0.59	1.26	0.77	0.86	1.85	0.22	0.41	0.53	1.14	1.06	1.04	1.76

T1:un-irradiated solubilizing potassium bacteria; T2:100% K_2SO_4; T3: 100% K_2SO_4; + un-irradiated solubilizing potassium bacteria; T4: 75% K_2SO_4; + un-irradiated solubilizing potassium bacteria; T5: 50% K_2SO_4; + un-irradiated solubilizing potassium bacteria; T6: irradiated solubilizing potassium bacteria; T7: 100% K_2SO_4; + irradiated solubilizing potassium bacteria; T8: 75% K_2SO_4; +irradiated solubilizing potassium bacteria; T9: 50% K_2SO_4; + irradiated solubilizing potassium bacteria.

other treatments. The 3rd month of storage period showed that, the addition of 50% of K_2SO_4+un-irradiated bacteria led to lower bulb weight loss percentage than other fertilizer levels. Bulbs resulted from plants treated with un-irradiated bacteria, 50% of K_2SO_4+ un-irradiated bacteria and 100 of % K_2SO_4+irradiated bacteria in the first season and bulbs resulted from plants fertilized with 100% of K_2SO_4 in the second one show a lower increase in weight loss percentage than other treatments in the 4th month of storage period.

During the 5th month of storage period, it was found that the fertilization with un-irradiated bacteria and 100% of K_2SO_4 as well as 75% of K_2SO_4+ irradiated bacteria scored lower bulb weight loss percentage than other treatments. During the last two months (the 6th and the 7th), results show that bulbs obtained from plants fertilized with 75% of K_2SO_4 and un-irradiated bacteria scored the lowest weight loss percentage in both seasons. These results may be due to the role of potassium on enzymes promotion activity and enhancing the translocation of assimilates and protein. These results agree with that obtained by (Ahmed *et al.,* 2009) who found that the addition of K_2SO_4 enhance the storage ability of garlic bulbs and decrease their weight loss percentage.

Conclusion

Un-irradiated *Bacillus mucilaginosus* HQ013329 can be used as soil inoculum to promote garlic plant growth characters and avoid environmental pollution hazards caused by heavy application of potassium fertilizers. The combination between un-irradiated *Bacillus mucilaginosus* HQ013329 with 100% and 75% of recommended rate of potassium sulphate enhance bulb yield and its component such as bulb weight and storage ability of garlic and maintain bulbs during storage period.

References

A.O.A.C. (1990). Official methods of analysis of the association of official analytical chemists 15th Ed. Published by the association of official analytical chemists, INC suite 400, 2200 Wilson Boulevard. Arlington, Virginia. 22201 USA.

Abdel-Fattah, A.E., A.T.M. Kasim and Z.S. El-Shal (2002). Effect of some sources and levels of potassium fertilizer on growth, yield and bulb quality of garlic (*Allium Sativum,* L.). *Annals of Agriculture Science Moshtohor.,* **40(3):** 1727-1738.

Abo-State, M.A.M., Y.E. Saleh, O.M. Gomaa and O.A.A. Khalil (2013). Isolation and identification of chloroaromatic degrading bacterial strain isolated from indigenous microbial communities of petroleum contaminated soils. *World Applied Sciences Journal,* **21(9):** 1341-1355.

Agusti, K.T. (1990). Therapeutic and medicinal values of onions and garlic. In J.L. Brewster and H.D. Rabinowitvh eds). *Onions and Allied Crops,* **3:** CRC Press, Inc. 99-104.

Ahmed, M.E.M., A. Derbala and N. Abd El-Kader (2009). Effect of irrigation frequency and potassium source on the productivity, quality and storability of garlic. *Misr Journal of Agriculture Engendering,* **26(3):** 1245- 1262.

Ahmed, M.E.M., A.A. El-Aidy, E.A. Radwan and T.S. Abd-Bary (2010). Response of garlic plants to humic acid and different application methods of potassium fertilizer. *Menoufia Journal of Agriculture Research,* **35(6):** 2159-2175.

Aleksandrov, V.G., R.N. Blagodyr and I.P. Iiiev (1967). Liberation of phosphoric acid from apatite by silicate bacteria. *Mikrobiyol Zh*. (Kiev)., **29:** 111-114.

Angraini, E., N.R. Mubarik and R. Widyastuti (2016). Study of potassium bacteria from limestone mining area in Palimanan, Cirebon Quarry. *Malaysian Journal of Microbiology,* **12:** 62-68.

Arisha, H.M.E., K. Sabren, A. Ibraheim and N.M. El-Sarkassy (2017). Response of garlic (*Allium sativum* L.) yield, volatile oil and nitrate content to foliar and soil application of potassium fertilizer under sandy soil conditions. *Middle East Journal of Applied Science,* **7(1):** 44-56.

Badr, M.A., A.M. Shafei and S.H. Sharaf El-Deen (2006). The dissolution of K and phosphorus bearing minerals by silicate dissolving bacteria and their effect on sorghum growth. *Research Journal of Agriculture and Biological Sciences*, **2:** 5-11.

Bahadur, I., V.S. Meena and S. Kumar (2014). Importance and application of potassic biofertilizer in indian agriculture. *International Research Journal of Biological Sciences,* **3(12):** 80-85.

Barakat, M.A., A.S. Osman, W.M. Semida and M.A. Gyushi (2019). Integrated use of potassium and soil mulching on growth and productivity of garlic (*Allium sativum* L.) under deficit irrigation. *International Letters of Natural Sciences*.**76:**1-12.

Bashir, Z., M.Y. Zargar, Z.A. Baba and F.A. Mohiddin (2017). Effect of potassium and phosphorus solubilizing bacteria on growth parameters of chilli (*Capsicum annuum* L.) under Kashmir climatic conditions. *International Journal of Chemical Studies,* **5(5):** 692-695.

Bednarz, C.W. and D.M. Oosterhuis (1999). Physiological changes associated with potassium deficiency in cotton. *Journal of Plant Nutrition*, **22:** 303-313.

Behairy, A.G., A.R. Mahmoud, M.R. Shafeek, A.H. Ali and M.M. Hafez (2015). Growth, yield and bulb quality of onion plants (*Allium cepa* L.) as affected by foliar and soil application of potassium. *Middle East Journal of Agriculture Research*, **4(1):** 60-66.

Brown, A.R., C. Boothman, S.M. Pimblott and J.R. Lloyd (2015). The impact of gamma radiation on sediment microbial processes. *Applied and Environmental Microbiology,* **81:** 12.

Deka, N.C. and T.C. Dutta (2000). Effect of potassium on yield and economics of potato cultivation in an acidic soil of Assam. *Journal of Potassium Research*, **16:** 77-99.

Dubois, M., F. Smith, K.A. Gilles, J.K. Hammilton and P.A. Robers (1956). Colorimetric method to determination of sugars and related substances. *Annals of Chemistry,* **28(3):** 350-356.

Elhakim, S.A.Z., S.D. El-Mesirry and M.M. Yousry (2016). Impact of potassium fertilization rates and *Bacillus circulans* on the growth, yield and color of processed potato (*Solanum tuberosum* L.) tubers chips. *Alexandria Science Exchange Journal,* **37(4):** 594-605.

Elkhatib, H.A., M.G. Saed, A.M. Ramadan and F.M. Ahmed (2019). Impact of potassium fertilizer rates and potassium solubilizing bacteria inoculation on the growth, yield and quality of potato (*Solanum tuberosum* L.). *Alexandria Science Exchange Journal,* **40(1):** 127-141.

El-Morsy, A.H.A., Z.S. El-Shal and S.M.H. Sarg (2004). Effect of potassium application methods and some micronutrients on growth, yield and storability of garlic. *Journal of Agricultural Science Mansoura University*, **29(4):** 2013-2023.

El-Sayed, H.E.A. and A.H.A. El-Morsy (2012). Response of productivity and storability of garlic (*Allium sativum* L.) to some potassium levels and foliar spray with mepiquat chloride (PIX). *International Research Journal of Agricultural Science and Soil Science*, **2(7):** 298-305.

El-Shabasi, M.S.S. (2001). Effect of potassium and boron fertilizers on growth, yield, bulb quality and bulb storage ability on garlic. The Fifth Arabian Horticulture Conference, Ismailia, Egypt, March. 35-48.

FAO (2018). Statistical Yearbook. Food and Agriculture Organization (FAO), Rome, Italy.

Gallegos-Cedillo, V.M., M. Urrestarazu and J.E. Álvaro (2016). Influence of salinity on transport of nitrates and potassium by means of the xylem sap content between roots and shoots in young tomato plants. *Journal of Soil Science and Plant Nutrition,* **16(4):** 991-998.

Han, H.S., Supanjani and K.D. Lee (2006). Effect of co-inoculation with phosphate and potassium solubilizing bacteria on mineral uptake and growth of pepper and cucumber. *Plant Soil Environment*, **3:** 130-136.

Hu, X.F., J. Chen and J.F. Guo (2006). Two phosphate and potassium solubilizing bacteria isolated from Tiannu Mountain, Zhejiang, China. *World Journal of Microbiology and Biotechnology,* **22:** 983-990.

Huang, Z., L. He, X. Sheng and Z. He (2013). Weathering of potash feldspar by *Bacillus* sp. L11. *Acta Microbioligica Sinica*, **53:** 1172-1178.

Hussain, Z., R.A. Khattak, M. Irshad, Q. Mahmood and P. An (2016). Effect of saline irrigation water on the leach ability of salts, growth and chemical composition of wheat (*Triticum aestivum* L.) in saline-sodic soil supplemented with phosphorus and potassium. *Journal of Soil Science and Plant Nutrition*, **16:** 604-620.

Jackson, N.L. (1958). Soil chemical analysis. Constable. Ltd. Co., Londodn.498.

Jahangir, A.A., R.K. Mondal, K. Nada, R.S. Afroze and M. Begum (2005). Response of plant spacing and different levels of nitrogen and potassium fertilizer on growth, yield and oil content of garlic. *Bangladesh Journal of Scientific and Industrial Research*, **40(1/2):** 63-68.

Jayaraman, J. (1985). Postharvest biological control. Wiley Eastern Limited New Delhi.

J'dszczyk, E., A. Kope, P. Buck, A.M. Ambroszczyk and B. Skowera (2019). The enhancing effect of plants growth bio stimulants in garlic cultivation on the chemical composition and level of bioactive compounds in the garlic leaves, stems and bulbs. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, **47(1):** 81-91.

Jones, D.L., P.G. Dennis, A.G. Owen and P.A.W. Van Hees (2003). Organic acid behavior in soils–misconceptions and knowledge gaps. *Plant soil*, **248:** 31-41.

Khalil, H.M.A., D.M.R. Abo-Basha and F.H.A. El-Agyzy (2018). Effect of *Bacillus circulans* bacteria on availability of potassium from different sources on the productivity and quality of pepper under saline soil conditions. *Middle East Journal of Agriulture Research,* **7(2):** 339-351.

Kovács, E. and A. Keresztes (2002). Effect of gamma and UV-B/ C radiation on plant cells. *Micron*., **33(2):** 199-210.

Krieg, N.R. and J.C. Holt (1984). Bergey's Manual of Systematic Bacteriology, *1st edition*, (1), Williams and Wilkins,Baltimore.

Mahfooz, S.H., S.S. Abbasi, K. Waqar and J. Ahmed (2016). Effect of potassium and phosphorus on the physical and biochemical characteristics of local garlic under the agroclimatic conditions of Rawalakot, Azad Jammu and Kashmir. *Science, Technology and Development,* **35(4):** 185-191.

Man, L.Y., X.Y. Cao and D.S. Sun (2014). Effect of potassium-solubilizing bacteria-mineral contact mode on decomposition behavior of potassium-rich shale. *The Chinese Journal of Nonferrous Metals*, **24:** 48-52.

Maurya, B.R., V.S. Meena and O.P. Meena (2014). Influence of Inceptisol and Alfisol's potassium solubilizing bacteria (KSB) isolates on release of K from Waste mica. *Vegetos,* **27:** 181-187.

Meena, V.S., B.R. Maurya and J.P. Verma (2014a). Does a rhizospheric microorganism enhance K^+ availability in agricultural soils? *Microbiological Research*, **169:** 337-347.

Meena, V.S., B.R. Maurya and I. Bahadur (2014b). Potassium solubilization by bacterial strain in waste mica. *Bangladesh Journal of Botany*, **43(2):** 235–237.

Meena, R.S., V.S. Meena, S.K. Meena and J.P. Verma (2015a). Towards the plant stress mitigate the agricultural productivity. *Journal of Cleaner Production*, **102:** 552– 553.

Meena, V.S., B.R. Maurya, J.P. Verma, A. Aeron, A. Kumar, K. Kim and V.K. Bajpai (2015b). Potassium solubilizing rhizobacteria (KSR): Isolation, identification and K-release dynamics from waste mica. *Ecological engineering*, **81:** 340-347.

Mengel, K. (1997). Impact of potassium on crop yield and quality with regard to economic and ecological aspects. In: proceedings of the IPI regional workshop on: Food security in the WANA Region, The Essential Need for balanced fertilization, held on Bornova, Izmir, Turkey, International Potash Institute. Bern, Switzerland. 157-174.

Mikhailouskaya, N. and A. Tcherhysh (2005). K-mobilizing bacteria and their effect on wheat yield. *Latvian Journal of Agronomy*, **8:** 154–557.

Osman, Y.M.M. (2015). Effect of some foliar application on yield, quality and storability of garlic. Ph.D. Thesis, Faculty of Agriculture. Ain Shams University, Egypt.1-116.

Parmar, P. and S.S. Sindhu (2013). Potassium Solubilization by Rhizosphere Bacteria: Influence of nutritional and environmental conditions. *Journal of Microbiology Research*, **3(1):** 25-31.

Patil, R.B. (2011). Role of potassium humate on growth and yield of soybean and black gram. *International Journal of Pharma and Bio Sciences,* **2(1):** 242-246.

Piper, C.S. (1950). Soil and plant analysis. International science. Pulb, New York. 368.

Pirhadi, M., N. Enayatizamir, H. Motamedi and K. Sorkheh (2016). Screening of salt tolerant sugarcane endophytic bacteria with potassium and zinc for their solubilizing and antifungal activity. *Bioscience Biotechnology Research Communications*, **9(3):** 530-538.

Plummer, D.T. (1971). An introduction to practical biochem. Published by MC Graw Hill Book company (U.K.) limilted.

Ponmurugan, P. and C. Gopi (2006). In vitro production of growth regulators and phosphate activity by phosphate solubilizing bacteria. *African Journal of. Biotechnology,* **5:** 348-350.

Prajapati, K. (2016). Impact of potassium solubilizing bacteria on growth and yield of Mungebean Vigna radiata. *Indian Journal of Applied Research,* **6:** 390-392.

Sambrook, J. and D.W. Russel (2001). Molecular Cloning: A Laboratory Manual 3 rd Ed. cold Spring Harbor Laboratory Press. Cold spring Harbor. NY.

Sattar, A., M. Naveeda, M. Alia, Z.A. Zahra, S.M. Nadeemb, M. Yaseena, V.S. Meenac, M. Farooqd, R. Singhe, M. Rahmanf and H.N. Meena (2018). Perspectives of potassium solubilizing microbes in sustainable food production system: A review. *Applied Soil Ecology*, **133:** 146-159.

Setiawati, T.C. and L. Mutmainnah (2016). Solubilization of potassium containing mineral by microorganisms from sugarcane rhizosphere. *Agriculture and Agricultural Science Procedia*, **9:** 108–117.

Shafeek, M.R., A.H. Ali, A.R. Mahmoud and M.M. Hafez (2016). The influence of foliar and soil fertilization of potassium on growth, yield and quality of garlic plants (*Allium sativum* L.). *International Journal of Pharm.Tech. Research*, **9(9):** 390 -397.

Snedecor, G.W. and W.G. Cochran (1980). Statistical Method. 7thEd. Iowa State Univ. Press, Ames Iowa, USA.

Stancheva, I., I. Dimitrov, N. Kaloyanova, N. Dinev and N. Poushkarov (1995). Improvement of the nitrogen uptake and nitrogen content in maize (*Zea mays*) by inoculation with *Azospirillum brasilense*. *Agrochimica*, **39:** 299-306.

Verma, A., Y. Patidar and A. Vaishampayan (2016). Isolation and purification of potassium solubilizing bacteria from different regions of India and its effect on crop's yield. *Indian Journal of Microbiology Research*, **3(4):** 483-488.

Xiao, Y., X. Wang, W. Chen and Q. Huang (2017). Isolation and identification of three potassium-solubilizing bacteria from rape rhizospheric soil and their effects on ryegrass. *Geomicrobiology Journal*, 1-8.

Yang, B.M., L.X. Yao, G. L. Li, Z.H. He and C.M. Zhou (2015). Dynamic changes of nutrition in litchi foliar and effects of potassium-nitrogen fertilization ratio. *Journal of Soil Science and Plant Nutrition*, **15:** 98-110.

Zahedi, H. (2016). Growth-promoting effect of potassium-solubilizing microorganisms. Potassium Solubilizing Microorganisms for Sustainable Agriculture. *Springer, India*. 31-42.

Zakhia, F. and P. de Lajudie (2001). Taxonomy of rhizobia. *Agronomie*, **21:** 569-576.

Zhang, A., G. Zhao, T. Gao, W. Wang, J. Li, S. Zhang and B. Zhu (2013). Solubilization of insoluble potassium and phosphate by *Paenibacillus kribensis* CX-7: a soil microorganism with biological control potential. *African Journal of Microbiology Research,* **7:** 41-47.

Zhang, C. and F. Kong (2014). Isolation and identification of potassium-solubilizing bacteria from tobacco rhizospheric soil and their effect on tobacco plants. *Applied Soil Ecology*, **82:** 18–25.