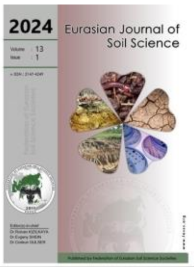
Eurasian Journal of Soil Science 2024, 13(1), 43 - 51

Eurasian Journal of Soil Science

Journal homepage : http://ejss.fesss.org



Improving the growth of *Glycyrrhiza Glabra* L. in saline soils using bioagent seed treatments

Botir Khaitov [a,*], Nauruzbay Tadjetdinov [b], Alisher Sayimbetov [b], Jamila Khaitbaeva [c], Obidjon Sindarov [c], Obid Khakberdiev [c], Tulkin Nematov [d]

[a] International Center for Biosaline Agriculture, Regional Office for Central Asia and South Caucasus, Tashkent, Uzbekistan
[b] Institute of Agriculture and Agrotechnologies of Karakalpakstan, Nukus, Karakalpakstan, Uzbekistan
[c] Tashkent Institute of Irrigation and Agricultural Mechanization Engineers National Research University, Department of Soil Science and Farming, Tashkent, Uzbekistan
[d] Tashkent State Agrarian University, Faculty of Agrobiology; Tashkent, Uzbekistan

Article Info
Received : 13.07.2023
Accepted : 06.11.2023
Available online : 14.11.2023

Author(s)
B.Khaitov *
N.Tadjetdinov
A.Sayimbetov
J.Khaitbaeva
O.Sindarov
O.Khakberdiev
T.Nematov

* Corresponding author

Abstract

Licorice (*Glycyrrhiza glabra* L.), known for its salt and drought tolerance, presents a potential solution for addressing soil salinity and desertification challenges in arid areas. Since the natural habitat of this plant is dwindling sharply in the Aral Sea regions due to negative human interventions, so it is vital to create production technologies with biological means. This study determined the agronomic characteristics of licorice when bioagents i.e. Geohumate, Aminomax and Caliphos were used as a seed treatment. Results showed that the application of these biostimulators significantly improved seed germination and plant growth compared to the control. Especially the effect was more pronounced with Geohumate as the seed germination increased by 36.4%, whereas the impacts of Aminomax and Caliphos were 17.5% and 12.4% higher, respectively as compared to the control group. Likewise, under the open-field condition, plant growth and development were greater with the bioagent applications. In regards the root biomass, the highest record with a 29.1% increase was achieved after the Geogumat treatment, while Aminomax and Caliphos applications exhibited 24.4 and 23.9% higher values, respectively as compared to the control values. The amounts of ash, glycyrrhizic acid, extractive compounds and flavonoids were increased by 26.5%, 22.0, 9.4% and 10.4%, respectively, compared to the respective control values due to the positive effect of the Geogumat treatment. Furthermore, the improved organic and chemical contents of soil were explained by the bioremediation functions of licorice plus bioagents efficiency. Using bioagents in licorice production could be a valuable approach for maintaining ecosystem function and stability in saline lands.

Keywords: Licorice (*Glycyrrhiza Glabra* L.), seed treatment, bio-agents, saline soil, seed germination, growth dynamics, root yield.

Introduction

The shrinking of the Aral Sea was accompanied by decertification, salination and land degradation, negatively impacting overall agricultural sustainability in this region. Over time, the increased use of fertilizers and pesticides exacerbated the situation, resulting in groundwater and soil pollution, leading to considerably falling crop productivity (Kushiev et al., 2021). These factors ultimately created a vicious cycle of environmental degradation, jeopardizing the prospect of agricultural production. The leading causes of further development of salinity in the area are the Aral Sea disaster and the arid climate associated with a high level of soluble salt in the irrigated land and underground water (Khaitov et al., 2020; Qureshi and Daba, 2020). Furthermore, these challenges were intensified with anthropogenic factors and climate change as the

: https://doi.org/10.18393/ejss.1390588
: http://ejss.fesss.org/10.18393/ejss.1390588
Publisher : Federation of Eurasian Soil Science Societies
e-ISSN : 2147-4249

main driving forces of ecological, environmental, and economic disaster. As a result, the area has experienced significant crop biodiversity reductions and overall ecosystem instability, decreasing crop productivity by 30-40%.

There are many degraded and abandoned lands in the Aral Sea region, whereas more than 90% of irrigated land is affected by salinity (Khaitov et al., 2022). Increased salinity levels in this region have restricted the growth of traditional crops. An urgent need is to restore salt-affected soils to their production potential while promoting environmentally sustainable development. The "*biosaline approach*" developed by the International Center for Biosaline Agriculture proposes modern techniques to rehabilitate abandoned salt-affected lands as a potential science-based solution. This approach is based on adaptable technology packages composed of salt-tolerant halophytes integrated with appropriate land and crop management systems.

Licorice (*Glycyrrhiza glabra*) is one of the existing native halophyte plants with salt and drought tolerance abilities in the Aral Sea regions. The plant is perennial and grows well in harsh environmental conditions because of its deep root system. It is used in several applications such as in medicine, cosmetics, manufacturing due to it's highly rich in nutritional profile. Therefore, this halophyte has a great economic value. Its natural distribution can be found in the deltas of the Amudarya river (on the territory of the Republic of Karakalpakstan and Khorezm province) and Syrdarya river and on the banks of small rivers in Fergana valley, Surkhandarya and Syrdarya provinces of Uzbekistan. Due to pharmacological properties i.e. glycyrrhizin and oleanane-type triterpene saponins in licorice roots, the demand for licorice grown and processed in Uzbekistan has steadily grown since 2000 (Khaitov et al., 2021; Mambetnazarov et al., 2021). Therefore, the over-exploitation has greatly decreased natural reserves of licorice in recent years. In fact, natural licorice habitats have decreased by 5.8-fold in Karakalpakstan during the last half century, from 38 thousand to 6.5 thousand hectares (Khaitov et al., 2021). These alarming records show this plant is in danger of extinction. Undoubtedly, the dwindling of the natural habitats of wild licorice creates ecological disasters, e.g., sandstorms, drought, air, soil and water pollution, soil salinization (Mambetnazarov et al., 2021).

Unfortunately, the local populace harvests wild licoricey roots, but its' cultivation is quite limited. Even though licorice is indigenous salt and drought-tolerant halophyte plant, it's not widely accepted by small and marginal farmers for subsistence farming systems. As a fragment of climate-resilient agriculture, improving licorice production has a great potential to rehabilitate abandoned saline lands. Licorice improves the physical and chemical properties of soil while enriching it with organic matters and restoring biological activities. These functions allow to provide the basis for sustainable reproduction of soil fertility and optimize environmental functions.

Very few research and crop improvement activities have been conducted on licorice so far. Development of licorice cultivation technologies with suitable seed treatment agents could also be used commercially. This research hypothesis that if licorice could grow under harsh conditions, biological agents might enhance crop productivity and soil quality, thereby rejuvenating the dryland cropping system. Although, studies exhibiting the role of bioagents to stimulate licorice growth, especially at the initial growth period and to alleviate salt stress are quite limited. Furthermore, using modern knowledge, innovation and technologies will bring added value by providing empowering opportunities.

Although, the region has suitable environmental conditions for the sustainable production of licorice, there was no research on using biostimulators for improving germination and growth under open-field conditions. Therefore, this research aims to determine the effectiveness of biological agents such as Geogumat, Aminomax, and Caliphos on the agronomic performance of licorice in saline areas.

Material and Methods

The study area

This study consisted of two series of licorice experiments under lab and open field conditions during 2018-2020 at the experimental station of the Institute of Agriculture and Agrotechnologies located in Nukus, Karakalpakstan (42.28°N 59.36°E), the north-west of Uzbekistan. Winter is severe in this area with absolute minimum air temperatures ranging from -10.3 up to 0.0°C intervals in December and January. In contrast, summer is long, dry and very hot, with an absolute maximum of 41.0-45.3°C (Figure 1). The desert region's harsh environment is characterized by high climatic fluctuation and recurrent periods of extreme drought. In this area, there are 270–280 days without frost overall, and the average annual evapotranspiration is up to 2000 mm. The annual rainfall ranges from 80 to 140 mm, although the most of it occurs from January to April, just before the start of the vegetative period. During the research period, 2018 was drier with only 83,0 mm of precipitation.

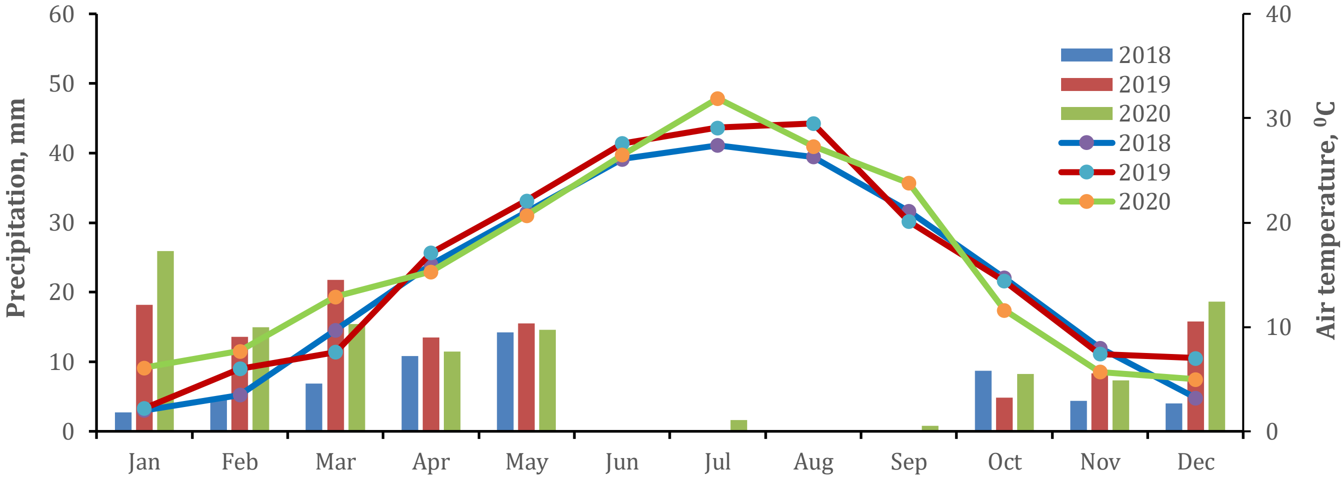


Figure 1. Climate records (2018-2020)

Soil properties

Meadow-alluvial soil in the experimental field had an overall bulk density of 1.4 g/cm^3, this amount has changed 1.35 g/cm^3 in 0-30 cm and 1.38 g/cm^3 in 0-100 cm soil horizons. The enhanced soil bulk density in the ploughing horizon shows that the macroaggregates tolerant to water leaching underwent dispargation. The humus content in these soils is very low, only containing 0.5-0.6% in 0-30 cm soil ploughing depth (Table 1). The soil ploughing depth had total N content 0.030-0.050 %, total phosphorous 0.160-0.175% and overall potassium 1.78-1.85%. The pH value of the soil was 7.4 (slightly alkaline) with moderate salinity EC 5.7 dSm^{-1}. The mineralization level of underground water was 2.0-3.0 g L^{-1}, but during the vegetation season this characteristic is likely to increase due to the location in 2-3 meter depth.

Table 1. Agrochemical characteristics of the soil affected by *Glycyrrhiza glabra* cultivation.

Treatments	Humus, %	N, %	P, %	K, %	NO_3, mg kg^{-1}	P_2O_5, mg kg^{-1}	K_2O, mg kg^{-1}
At the beginning of the experiment (2018)							
	0.610d	0.072c	0.142b	1.145a	13.2d	17.56a	174.7a
At the end of the experiment (2020)							
Control	0.632c	0.090b	0.125c	1.100b	14.0c	13.35c	145.5b
Geogumat	0.660a	0.107a	0.145a	1.000b	17.7a	14.07b	140.4c
Aminomax	0.641b	0.092b	0.135b	0.870c	14.3b	14.03b	140.1c
Caliphos	0.640b	0.092b	0.140b	0.800c	14.0c	14.00b	141.3c

Means marked with different letters (a to d) represent significant differences ($p<0.05$) according to the Tukey's LSD test.

Biofertilizers

Geogumat consisted of more than 20 microorganisms including Bacillus megaterium, Bacillus mucilaginosus, Basillus Subtilis and etc. It is liquid of 12% organic fertilizer and formed by microelements. There is Humic acid at least 32% and Fulfa and other organic acids consist of at least 25.0%. This biofertilizer positively impacts seed germination, root system development, and seedling growth, enhancing tolerance to environmental stresses and crop yield by 15-20%. In addition, it improves soil quality and productivity of mineral fertilizers.

Aminmax is organic fertilizer formed by 16% organic matters, 10% organic carbon, 10.2% overall free aminoacids, 10% humic and pulvo acids, 0.5% N, 1.5% K_2O, 0.6% MnO, 0.1% Mn, 0.1% Mo, 0.14% Zn. The level of pH is 4-6. It is used to rejuvenate soil microflora and thereby improve nutrients uptake by plants. It enhances seed germination and usually foliar treatment is useful for plant growth stimulation.

Caliphos is considered as liquid form of NPK. It consist of 1% N, 1.0% NO_3, 10.2% P_2O_5, 25% K_2O, 0,6% B, 0,1% Zn, pH is equal to 4-6. This bioagent is essential to increase nutrients for plant uptake, enhance vegetative and generative organs, thereby improving crop yield.

Greenhouse Experiment

Three bioagents i.e., Geogumat, Aminmax, Caliphos were compared against the control variable on licorice seed germination using a factorial experiment design with three replications in the greenhouse (25^{0}C/15^{0}C; 14h day:10h night periodicity) with relative humidity between 65% and 75%. Each Petri dish contained 100 seeds previously cleaned. For both sets of experiments, 10 min surface sterilization of licorice seeds was done with 0.1% mercuric chloride. Analysis of seed germination and survivability were revealed as per standard techniques (Uzpiti, 2007). Firstly, the germinated seeds were calculated starting 5 days 10 days after sowing and seedling viability was found at 20 days.

Three types of saline soils representing the most common types of salinity i.e., low 2.4±1.1 Na^+ mM/100 g soil, moderate 8.5±1.2 Na^+ mM/100 g soil, high 15.6±1.7 Na^+ mM/100 g soil were used for the pot experiments. Pot seedlings were irrigated with the same amount of water (~200 ml each every 3 days).

Field experiment practices and methods

Split-plot treatment structure in a randomised complete block design were used in three replications. The total land for this experiment constituted 0.288 hectares, including each plot area was 240 square meter: 4.8 m x 50 m (8 rows, each one had 0.6 m width and 50 m length), while the accounting area was 120 square meters. These field experiments were conducted according to the guidelines entitled "Methods of Field Experiments" (UzPITI, 2007). Fodder productivity, root mass and seed yield parameters were determined on 1 square meter area in each plot before recording an average value. Plant density was found at two stages: after seedling emergence and at the end of vegetation. Agronomic parameters such as plant height, weight, leaf and pod numbers were carried out on the 25 labelled plants in each plot.

The following observations were determined in the field experiments: number of leaves, plant height, biomass of plants, specific leaf weights (leaf dry weight, leaf: shoot dry ratio, shoot dry matter), leaf area and content of chlorophyll. A leaf area was measured using a LI-COR LI-30004 portable leaf area meter, and the total chlorophyll content was measured with a Minolta SPAD-502. The total chlorophyll content was measured every five days, beginning a week after germination until plant final harvest.

The chosen field was ploughed in 28-30 cm depth in 1-5 October 2018, following laser levelling activities. Then, the field was divided into small sections (0,03-0,05 ha) to carry out salt leaching process with 2500-3200 m^3/ha water in late October. At mid-November, 80% annual norms of phosphorous and potassium fertilizers for licorice cultivation were applied under the plough. Spring began with field tilling, harrowing and cultivating. Seed planting started in 22-24 of April when the land heated enough under sunshine. The seed planting aggregate SN-500 was fixed at norms of 10 kg/ha when the seeds were soaked for 36 hours with appropriate biostimulator.

The optimal rate of mineral fertilizer $N_{100}P_{140}K_{80}$ was provided according to the fertilizer standards. The field was irrigated after the seed planting process in order to improve germination and get vigorous seedlings. Following weeding and cultivation activities in June, the full fertilization norm of N and the remaining 20% portions of phosphorous and potassium fertilizers were applied before furrow irrigation. The furrow irrigation was applied five times at 800-1000 m3/ha norms each time, totalling 4000-5000 m^3/ha for the entire season.

Root mass was estimated at the end of every season by digging up to 1 meter with monometer method and drying at 70^0C for 72 hours in the drier equipment. While leaf area was determined by taking 20 samples on 1 cm^2 with special equipment. The leaf area of each sample was found with the following formula:

leaf area (cm^2) = x / y, where x is the weight (g) of the area covered by the leaf outline, and y is the weight of one cm^2 of the same graph paper. Then, the photosynthetic efficiency was determined by the ratio between plant biomass and leaf area per day during the vegetation period.

Plant extracts, i.e., ash, glycyrrhizic acid, extractive compounds and flavonoids were determined by spectrophotometry in the Metlertoledo laboratory complex.

Data analysis

All experiments were carried out in triplicates and values are expressed as means with standard deviations (±SD). Graphics were drawn using MS Office Excel 2007. Statistical analysis was conducted with a one-way ANOVA tool (CropStat program).

Results

Seed germination at different salinity

Data presented in Table 2 shows that the seed germination in all treatments increased progressively with increasing seed water soaking from 12 hours to 36 hours. The bioagent x water soaking interaction significantly impacted the germination of licorice seeds under lab conditions. Licorice seed reached to 85.0% germination at 20 days after a 36-hour water soaking period when seeds were treated with Geogumat. In this case, the treatment with Geogumat increased seed germination by 36.4%, while Aminomax and Caliphos enhanced this indicator by 17.5% and 12.4%, respectively, compared to the control variable.

Table 2. Seed germination % (lab experiment).

Treatments	Water soaking period of seeds	10 days after	15 days after	20 days after
Control	12 hours	10.1g	35.3e	39.1e
Geogumat		32.7d	61.4b	72.3b
Aminomax		25.6e	50.1d	60.2c
Caliphos		18.7f	50.3d	59.7c
Control	24 hours	30.4d	44.7e	50.8d
Geogumat		40.5b	64.6ab	75.9b
Aminomax		38.6c	60.4b	64.7c
Caliphos		36.2c	52.8c	54.4d
Control	36 hours	36.1c	48.4d	54.1d
Geogumat		46.7a	68.7a	85.0a
Aminomax		42.4b	62.5b	63.6c
Caliphos		40.6b	55.4c	60.8c

Means marked with different letters (a to f) represent significant differences ($p<0.05$) according to the Tukey's LSD test.

Similarly, as shown in Figure 2, licorice seeds germinated vigorously under less saline soil in the pot experiments. However, the seed treatment with Geogumat showed a significant ($p<0.05$) increase (83.5%) in seed germination, while this characteristic was 72.3% and 70.4% higher under Aminomax and Caliphos applications, respectively compared to the control variable. The increased concentration of soil salinity caused a considerable decrease in seed germination in all treatments. At the moderate soil salinity, the highest seed germination record was detected in the Geogumat seed application with a 74.1% increase, followed by Aminomax and Caliphos treatments with increments of 65.6% and 55.4%, respectively, while this indicator reached to 52.2% in the control variable. Under high saline soil conditions, licorice seeds did not germinate at all, regardless of the seed treatment methods.

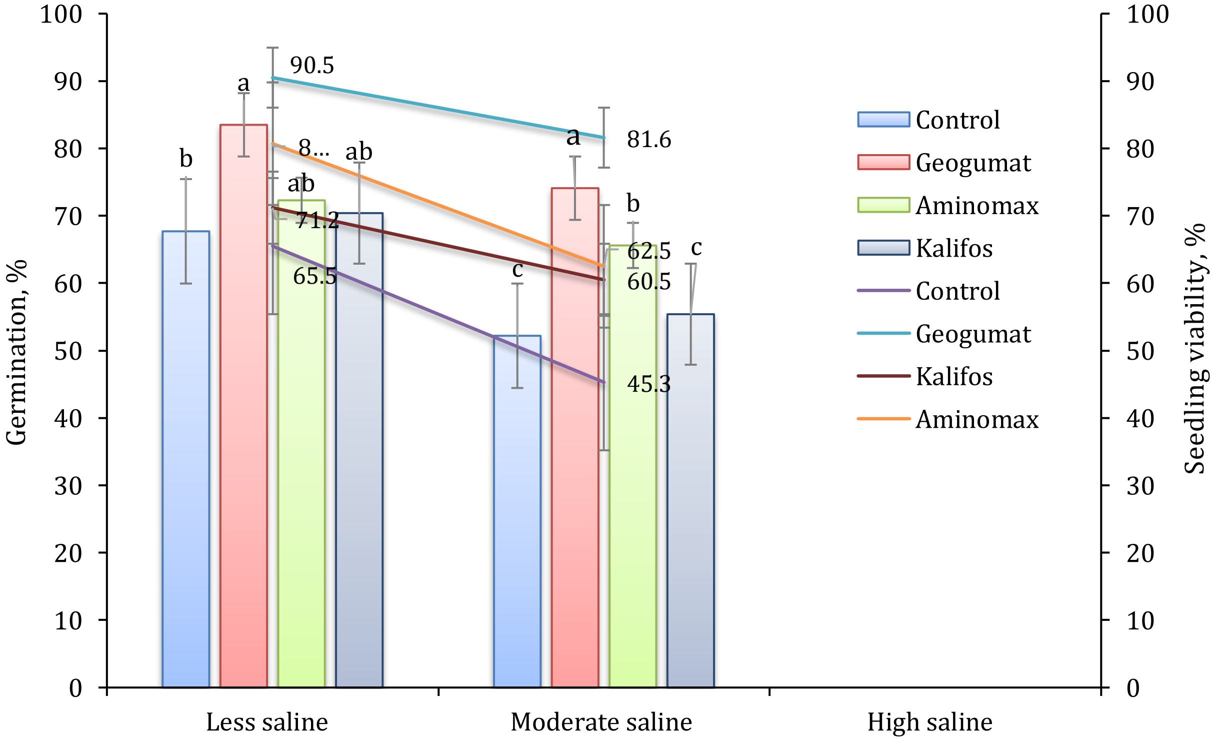


Figure 2. Seed germination of licorice under different soil salinity conditions (greenhouse experiment).

Analyses of seedlings viability exhibited the highest values by the Geogumat treatment from 90.5% in less saline soils and 81.6% in moderate saline soils, followed by the Aminomax (80.7% and 62.5%) and Caliphos seed treatments (71.2% and 60.5%) accordingly.

Overall, the bioagent application substantially alleviated the soil salinity effect by enhancing seed germination and seedling viability indicators. The effect was greater by Geogumat, followed by Aminomax and Caliphos applications promoting the studied parameters to a significant extent, whereas no significant difference was detected between the two latter applications.

Plant growth characteristics under open-field conditions

The positive effects of Geogumat, Aminomax and Caliphos to stimulate the germination, growth and development of licorice in the saline soils of Karakalpakstan have been identified in Table 3. The seed stimulation was more pronounced with Geogumat than the other bioagents, causing 76.6% germination. Whereas Aminomax and Caliphos treatments showed 70.3% and 70.4% seed germination, respectively. At the same time, this indicator in the control treatment was only 61.4%.

Table 3. Growth parameters of Glycyrrhiza glabra (at the end of vegetation period).

Treatments	2018				2019			2020		
	Germina tion (%)	Shoot height (cm)	Fruit branches	Plant density	Shoot height (cm)	Fruit branches	Plant density	Shoot height (cm)	Fruit branches	Plant density
Control	61.4c	86.6c	5.5d	158.0c	119.4d	5.8d	138.5c	118.9c	5.6d	121.1c
Geogumat	76.6a	103.7a	8.2a	171.8a	153.7a	8.8a	150.3a	132.5a	8.3a	131.4a
Aminomax	70.3b	100.8b	7.4b	165.5b	147.3b	8.0b	144.5b	130.4ab	7.5b	126.7b
Caliphos	70.4b	98.5b	6.3c	163.4	135.6c	7.1c	142.5b	127.2b	6.5c	125.5b

Means marked with different letters (a to d) represent significant differences (p<0.05) according to the Tukey's LSD test.

In the first year, considering shoot height of 86.6 cm tall and fruit branches 5.5 pieces in the control variable, whereas the Geogumat seed treatment enhanced the growth of shoot height and fruit branches by 19.7% and 49.1%, accordingly. Regardless of the bioagent applications, the plant gradually increased the shoot and root weights with time passage. The application of Aminomax and Caliphos stimulated the growth to a significant extent in both licorice shoots and roots, despite the inhibiting effect of salt stress.

As shown in Table 4, similar growth characteristics were detected in the following years of the experiment. However, in the third year, the plant started to allocate more photosynthetic materials to enhance root development, whereas shoot and leaf mass considerably declined compared to the second year. Seed treatment with Geogumat enhanced root biomass by 29.1% than that in the control, while Aminomax and Caliphos applications exhibited 24.4 and 23.9% higher values, respectively, indicating a positive effect in regards to plant development under soil salinity.

Table 4. Dry matter accumulation in licorice under the influence of the bioagents (2018-2020)

Treatments	Root, g	Leaf, g	Shoot, g	Total, g
		2018		
Control	14.1c	15.4c	38.5d	68d
Geogumat	21.5a	33.0a	45.5a	100a
Aminomax	20.3b	31.3b	42.3b	93.9b
Caliphos	20.0b	30.9b	40.9c	91.8c
		2019		
Control	37.5c	39.4d	87.5d	164.4d
Geogumat	42.9a	56.5a	110.7a	210.1a
Aminomax	40.5b	50.3b	105.1b	195.9b
Caliphos	40.0b	47.3c	100.8c	188.1c
		2020		
Control	40.2c	35.6c	80.1d	155.9d
Geogumat	51.9a	50.8a	100.7a	203.4a
Aminomax	50ab	46.7b	95.4b	192.1b
Caliphos	49.8b	45.1b	90.7c	185.6c

Means marked with different letters (a to d) represent significant differences (p<0.05) according to the Tukey's LSD test.

All three bioagents showed a positive effect on the plant measurements and root development, however, the highest achievements were recorded at the Geogumat application. Nevertheless, the overall contributions of the two bioagents i.e. Aminomax and Caliphos reached to a certain extent and in most cases, significantly differentiated against the control.

Yield characteristics and phytochemical compounds

As presented in Table 5, straw and root yield traits considerably enhanced with every passing year, even though the plant continued to grow. Considering total values, the highest indicators of the straw and root yields were observed at the Geogumat application, which exerted by 17.9% and 44.7% compared to the control. The effect of Aminomax and Caliphos treatments also reached a significant level in some growth parameters.

Photosynthetic efficiency in response to the bioagents application was positive, especially in the second and third experiment years. This parameter was 20.8%, 5.7% and 4.7% greater in Geogumat, Aminomax and Caliphos treatments, respectively than that in the control (2019). According to the observed parameters, the highest values were found at the Geogumat treatment, followed by Aminomax treatment and the lowest parameters were recorded at the Caliphos treatment.

The effects of Geogumat to induce phytohormone production was considerably higher compared to the non-treated control under salinated soils (Table 5), exhibiting the positive changes of the phytochemical compounds in the licorice roots in association with the bioagents treatments. Phytohormones were promoted in the Geogumat treated plants, most probably due to the microbial combinations contained in this bioagent. Therefore, the highest records were detected at the Geogumat application, increasing the amounts of ash, glycyrrhizic acid, extractive compounds and flavonoids by 26.5%, 22.0, 9.4% and 10.4%, respectively as compared to the respective control values. These characteristics similarly responded under the treatments of Aminomax, although all values reached a significant level as compared to the control. While phytohormone production tended to be lower in Caliphos treatment, and there was no significant difference between the untreated control in most indicators.

Table 5. Straw and root yields of *Glycyrrhiza glabra*.

Means marked with different letters (a to c) represent significant differences ($p<0.05$) according to the Tukey's LSD test.

Treatments	2018			2019			2020		
	Photosynthetic efficiency (g/m^2 per day)	Straw yield (Mg/ha)	Root yield (Mg/ha)	Photosynthetic efficiency (g/m^2 per day)	Straw yield (Mg/ha)	Root yield (Mg/ha)	Photosynthetic efficiency (g/m^2 per day)	Straw yield (Mg/ha)	Root yield (Mg/ha)
Control	9.8c	1.64c	1.1c	10.6c	4.31c	3.2c	10.8c	4.78c	4.4c
Geogumat	11.6a	2.02a	2.8a	12.8a	4.99a	4.1a	12.6a	5.65a	5.4a
Aminomax	10.4b	1.85b	2.3b	11.2b	4.72b	3.8b	11.4b	5.16b	5.0b
Caliphos	10.2b	1.83b	2.0b	11.1b	4.61b	3.7b	11.2b	4.97b	4.6b

Discussion

Seed germination and plant growth

Licorice with stress tolerance features can grow in extremely harsh environments and might be used to battle desertification in arid regions. In addition, the halophytic functions of licorice in conjunction with bioagents application could alleviate salinity stress more effectively, contributing to rejuvenate agroecosystems in the region. This study highlighted to improvement licorice productivity with bioagents in the harsh climatic area because of its high survivability and significance associated with acclimation to climate change. These resistance inducers can improve seed germination, plant growth, root development, and photosynthetic efficiency, increase biomass and alter specific abiotic stress tolerances to cope with the adverse consequence of salinity (Koch et al., 2010; Hao et al., 2019). Previous studies also showed that bioagent treatment improved seed germination of licorice seedlings under saline stress although Amin et al. (2014), Mogle and Maske (2012) reported a positive effect of bioagents against seed-borne diseases.

In the present study, the germination rate of licorice seeds was significantly enhanced with an increasing water-soaking period in conjunction with the bioagent treatments. A significant increase in plant characteristics was observed in the seed-treated licorice under salt stress because of the alleviation effect of the bioagent. This positive effect is dependent upon the bioagents functionality. Geogumat significantly stimulated seed germination of licorice in both greenhouse and open-field land conditions. The efficacy of the two bioagents, Aminomax and Caliphos, was lower than that of Geogumat in terms of germination, growth, development, root and biomass yield.

Root yield and phytohormone production

Bioagents are also known as stress-regulating organisms that help plants within the nutrient uptake, biotic and abiotic stress management (Omara et al., 2019; Bayadilova et al., 2022), improve soil health and plant growth promotion (Saleem et al., 2021; Hasna et al., 2022). Furthermore, biological organisms even promote phytohormones like auxin and cytokinin in some plants (Hafez et al., 2020), provoking metabolite accumulation and increasing enzyme activities (Irani and Todd, 2016). It needs to be emphasized that enhanced growth of licorice despite salt stress is due to the beneficial effect of the bioagents on assisting better nutrient supply (Johny et al., 2021).

In our study, the Geogumat application positively influenced in metabolic activity, which is reflected in facilitating the diversion of assimilates from vegetative growth to reproductive growth of licorice. The plants treated with the bioagents showed better phytohormone production performance than the control. In accordance with our result, a similar effect to overcome the adverse effects of salinity was achieved with the application of 2.8 ds/m SiO_2 for improved growth and yield of *Glycyrrhiza uralensis* (Cui et al., 2021). These researchers also pointed out the vital role of the synthesis and accumulation of metabolite production on salt tolerance, yield and quality increase of the plant.

Our results showed that considerably improved soil humus and nutrient status after the seed treatment with Geogumat played an essential role on the significantly increased growth and yield of *G. glabra*. In addition, this positive trend under open-field arid agriculture conditions might be due to the number of favourable assets, i.e. this plant lowers the saline groundwater, increases water-resistant aggregates, reduces bulk density and its roots penetrate to a depth of 3.5–4 m.

Soil health

The abundant literature indicated that licorice has a valuable bioremediation function for the reclamation of saline soils and restoration of irrigated cropping systems (Qadir et al., 2009; Gafurova and Juliev, 2021). After four years of cropping with licorice, wheat grain yield increased nearly 3-fold, as indicated in earlier studies of Kushiev et al. (2005). These authors also declared that because of setting up licorice plantations on abandoned land in the Hungry Steppes of Uzbekistan, the agrochemical, agrophysical and ameliorative properties of the soil were improved. In addition, improved soil indices i.e. biological functions, chemical compositions and soil physical structures due to licorice cultivation, might facilitate to enhance to the number of beneficial microbes in the root rhizosphere which in turn, promote the secretion of organic acids and lower the pH in the soil (Hosseini et al., 2022). It is well-known that beneficial microbes improve plant growth, nutrient acquisition, and synthesis of various metabolites, phytohormones and enzymes, promoting plant tolerance to biotic and abiotic stresses (Khaitov et al., 2019).

These results indicate that the bioagent application is crucial for licorice production in salt-affected regions. Thereby, the salt tolerance ability of licorice is essential in sustaining agricultural productivity to optimize environmental functions and food security in salt-ridden regions. licorice cultivation might be the most effective technique to mitigate the severe side effects of environmental challenges in the Aral Sea regions, including sandstorms, soil salinization, climate change and water scarcity (Kushiev et al., 2017). In accordance with the science-based information and applied knowledge, this practice might be one of the salinity management and climate-smart agriculture (CSA) strategies.

To our knowledge, the positive results obtained with the licorice seed - Geogumat treatment in the present study is the first report indicating this technique's efficacy in overcoming the negative effects of salinity. Hence, an alternative strategy of bioagent supplementation in licorice production can be considered as a practical approach to developing a highly value-added sustainable crop production system.

Conclusion

This study provides new insights regarding the efficacies of bioagents i.e. Geogumat, Aminomax and Caliphos on licorice seed germination, plant growth and phytohormone productivity under saline soils of the Aral Sea region. Geogumat was more effective than the other two bioagents, while increased the morphological and physiological parameters of licorice considerably compared to the control. The efficacies of Aminomax and Caliphos resulted in a statistically significant extent and exhibited salt alleviation function. Geogumat having facilitated the highest phytohormone extracts and photosynthesis makes the plant more resistant to this stress condition. Furthermore, the improved soil organic and chemical contents were explained by bioremediation functions of licorice plus the efficiencies of the bioagents.

Those positive statements in response to the Geogumat application as a seed treatment for licorice production can be recommended into agricultural production as a promising technology that may formulate a modern strategy to rejuvenate salt-affected lands.

References

Amin, M., Fitsum, S., Selvaraj, T., Mulugeta, N., 2014. Field management of anthracnose (Colletotrichum lindemuthianum) in common bean through fungicides and bioagents. *Advances in Crop Science and Technology* 2(2): 2-6.

Bayadilova, G., Zhylkibayev, A., Yessenbayeva, J., Yelibayeva, G., Kazkeyev, D., Karasseva, V.M. 2022. Effect of different organic wastes on biological properties of maize (Zea Mays Indendata) rhizosphere. *Eurasian Journal of Soil Science* 11(2): 141-150.

Cui, J., Zhang, E., Zhang, X., Wang, Q., 2021. Silicon alleviates salinity stress in licorice (Glycyrrhiza uralensis) by regulating carbon and nitrogen metabolism. *Scientific Reports* 11(1): 1-12.

Gafurova, L., Juliev, M., 2021. Soil Degradation Problems and Foreseen Solutions in Uzbekistan. In: Regenerative agriculture: what's missing? what do we still need to know? Dent, D., Boincean, B. (Eds.). Springer, Cham. pp. 59-67.

Hafez, Y.M., Attia, K.A., Kamel, S., Alamery, S.F., El-Gendy, S., Al-Doss A.A., Abdelaal, K.A., 2020. Bacillus subtilis as a bio-agent combined with nano molecules can control powdery mildew disease through histochemical and physiobiochemical changes in cucumber plants. *Physiological and Molecular Plant Pathology* 111:101489.

Hao, Z., Xie, W., Jiang, X., Wu, Z., Zhang, X., Chen, B. 2019. Arbuscular mycorrhizal fungus improves rhizobium–glycyrrhiza seedling symbiosis under drought stress. *Agronomy* 9(10): 572.

Hena, H., Khanam, M., Rahman, G.M., Afrad, M.S.I., Alam, M.S., 2022. Isolation and characterization of salt tolerant bacteria from saline soils of Bangladesh. *Eurasian Journal of Soil Science* 11(4): 284-294.

Hosseini, M.S., Ebrahimi, M., Abadía, J., Kadkhodaei, S., Amirian, R., 2022. Growth, phytochemical parameters and glycyrrhizin production in licorice (Glycyrrhiza glabra L.) grown in the field with saline water irrigation. *Industrial Crops and Products* 177: 114444.

Johny, L., Cahill D.M., Adholeya, A., 2021. AMF enhance secondary metabolite production in ashwagandha, licorice, and marigold in a fungi-host specific manner. *Rhizosphere* 17: 100314.

Irani, S., Todd, C.D., 2016. Ureide metabolism under abiotic stress in Arabidopsis thaliana. *Journal of Plant Physiology* 199: 87–95.

Khaitov, B., Karimov, A., Khaitbaeva, J., Sindarov, O., Karimov, A., Li, Y. 2022. Perspectives of Licorice Production in Harsh Environments of the Aral Sea Regions. *International Journal of Environmental Research and Public Health* 19(18): 11770.

Khaitov, B., Karimov, A., Toderich, K., Sultanova, Z., Mamadrahimov, A., Allanov, K., Islamov, S., 2020. Adaptation, grain yield and nutritional characteristics of quinoa (Chenopodium quinoa) genotypes in marginal environments of the Aral Sea basin. *Journal of Plant Nutrition* 44(9): 1365-1379.

Khaitov, B., Allanov, K., Islam K.R., Park, K.W. 2019. Bio-inoculant improves nitrogen-use efficiency and cotton yield in saline soils. *Journal of Plant Nutrition and Soil Science* 182(3): 393-400.

Khaitov, B., Urmonova, M., Karimov, A., Sulaymonov, B., Allanov, K., Israilov, I., Sottorov, O., 2021. Licorice (Glycyrrhiza glabra)—Growth and phytochemical compound secretion in degraded lands under drought stress. *Sustainability* 13(5): 2923.

Koch, E., Schmitt, A., Stephan, D., Kromphardt, C., Jahn, M., Krauthausen, H.J., Forsberg, G., Werner, S., Amein, T., Sandra, A.I., Tinivella, F., Gullino, M., Roberts, S., Wolf, J.V., Groot, S.P., 2010. Evaluation of non-chemical seed treatment methods for the control of Alternaria dauci and A. radicina on carrot seeds. *European Journal of Plant Pathology* 127(1): 99-112.

Kushiev, H., Noble, A.D., Abdullaev, I., Toshbekov, U., 2005. Remediation of abandoned saline soils using Glycyrrhiza glabra: A study from the Hungry Steppes of Central Asia. *International Journal of Agricultural Sustainability* 3(2): 102-113.

Kushiev, H.H., Kenjaev, A., Mirzabaev, A., Noble, A.D., Uzaydullaev, S., 2017. Economic aspects remediation of saline soils using licorice: the case of Mirzachul area in Uzbekistan. Proceedings of the International Scientific and Practical Conference World Science. Tashkent, Uzbekistan. pp. 48-56.

Kushiev, K., Ismailova, K.M., Rakhmonov, I., Kenjaev, A., 2021. The role of licorice for remediation of saline soils. *Open Journal of Science and Technology* 4(1): 10-20.

Mambetnazarov, A.B., Aybergenov, B.A., Kurbaniyazova, B.J., Jumatova, R.M., Turimbetov, M. S.M., Sabirova, G., Sabirov, G., 2021. To the development of optimal methods for licorice seeds growing (Glycyrrhiza glabra L.) in irrigated lands of the Republic of Karakalpakstan. IOP Conference Series: Earth and Environmental Science 937: 032102.

UzPITI, 2007. Methods of Field Experiments. Tashkent, Uzbekistan.

Mogle, U.P., Maske, S.R., 2012. Efficacy of bioagents and fungicides on seed mycoflora, germination and vigour index of cowpea. *Science Research Reporter* 2(3): 321-326.

Omara, R.I., El-Kot, G.A., Fadel, F.M., Abdelaal, K.A., Saleh, E.M., 2019. Efficacy of certain bioagents on patho-physiological characters of wheat plants under wheat leaf rust stress. *Physiological and Molecular Plant Pathology* 106: 102-108.

Qadir, M., Noble, A.D., Qureshi, A.S., Gupta, R.K., Yuldashev, T., Karimov, A., 2009. Salt-induced land and water degradation in the Aral Sea basin: A challenge to sustainable agriculture in Central Asia. *Natural Resources Forum* 33(2): 134-149.

Qureshi, A.S., Daba, A.W., 2020. Evaluating growth and yield parameters of five Quinoa (Chenopodium quinoa W.) genotypes under different salt stress conditions. *Journal of Agricultural Science* 12(3): 128-140.

Raza, A., Tabassum, J., Fakhar, A.Z., Sharif, R., Chen, H., Zhang, C., Varshney, R.K., 2022. Smart reprogramming of plants against salinity stress using modern biotechnological tools. *Critical Reviews in Biotechnology* 43(7): 1035-1062.

Saleem, S., Iqbal, A., Ahmed, F., Ahmad, M., 2021. Phytobeneficial and salt stress mitigating efficacy of IAA producing salt tolerant strains in Gossypium hirsutum. *Saudi Journal of Biological Sciences* 28(9): 5317-5324.