BMC Plant Biology

RESEARCH

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Sweet corn (*Zea mays* L.) seed performance enhanced under drought stress by chitosan and minerals coating

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Abstract

Sweet corn (*Zea mays* L.) var. Saccharata is a tropical and semitropical annual cereal with low germination, poor vigor, and weak seedling establishment in the soil. In order to enhance the physical properties of sweet corn and examine the effects of seed coating on the morphological, biochemical, and physiological characteristics of sweet corn seedlings under drought stress conditions, we conducted a factorial experiment in greenhouse conditions. Seed coating was carried out using a mixture of vermiculite (V), kaolin (K), and perlite (P) in a ratio of 3:1.5:2. The main factors of the greenhouse experiment comprised three levels of coating treatment (chitosan 0.5% + V10K2.5P5 (gr), NaAlg 1% + V10K2.5P5 (gr), and non-coated seeds as a control) along with drought stress at four levels (0, -0.3, -0.6, and -0.9 bar). In greenhouse conditions, the growth indexes of sweet corn seedlings were studied under increasing levels of drought stress. The results showed that as drought stress levels increased, certain growth indicators such as seedling emergence and seedling emergence rate, soluble protein, chlorophyll total content, nitrogen, and phosphorus content decreased. On the other hand, mean emergence, proline, potassium, soluble sugars, malondialdehyde, and hydrogen peroxide were increased. The study found that the highest seedling emergence percentage occurred in the coating treatment of chitosan 0.5% + V10K2.5P5 (gr) at all levels of drought stress. Overall, seed coating with the Chitosan 0.5% + V10K2.5P5 (gr) treatment improved the performance of sweet corn seeds and reduced the negative effects of drought stress by increasing seedling emergence and establishment.

Keywords Biochemical indices, Chitosan, Filler compound, Osmotic potential, Seedling growth, Sweet corn

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Introduction

Sweet corn (*Zea mays* L.) var. Saccharata is a tropical and semitropical cereal. It was obtained through a genetic mutation in the gene locus of Su (sugary) on chromosome number four of common maize [1, 2]. This highly significant vegetable is rich in minerals, vitamins, phytonutrients, and dietary fiber, making it an optimal choice for fostering optimal health. It has a high water content (72.7%) and total solids content (27.3%), which further enhance its nutritional value. The solid part of sweet corn contains hydrocarbons (81%), proteins (13%), lipids (3.5%), and other beneficial elements (2.5%). These nutritional elements are crucial for human nutrition. However, its cultivation is limited due to problems such as poor germination, slow growth, and poor seedling establishment in the soil [2, 3].

Certain seed properties have been identified as factors contributing to the low germination and weak growth of sweet corn seedlings. These factors include cracking of the seed coat during maturation, decreased ratios of embryo and endosperm, membrane damage caused by rapid water absorption during germination, reduced starch reserves, and kernel infection by fungal pathogens [4].

Seed coating is a technique developed in the late 1930s and early 1940s. It is more than just altering seed size and shape; it is a powerful solution to the cultivation challenges of sweet corn. This technique involves adding effective materials to seeds, serving various purposes such as enhancing germination and plant establishment, facilitating seeding operations, increasing root development, ensuring uniform seed distribution, preventing pest damage and diseases, and controlling weeds. Using suitable elements like microorganisms, pesticides, and fertilizers in seed coating can regulate aspects of development, moisture absorption, and pest control. With seed coating, we can confidently overcome the hurdles that limit the cultivation of sweet corn [5, 6].

There are three main categories of seed coating: seed pelleting, film coating, and seed encrusting. Pelleting involves coating seeds with inert materials such as vermiculite, perlite, calcium peroxide, talc, bentonite, and sand. This process allows for precise metering and improves plantability by altering the shape, size, and weight of the seeds. It transforms thin seeds into larger, spherical seeds and creates a uniform surface on wrinkled seeds, making it easier to handle them in the field. Chitosan is a hydrophilic polysaccharide obtained from chitin through deacetylation. It is used in seed coating to preserve seeds during storage and to promote seedling growth. Additionally, chitosan has bactericidal properties. Alginate, another hydrophilic polysaccharide derived from brown algae, is commonly used for seed coating due to its biocompatibility, non-toxic nature, and ability to degrade quickly [5–8].

The use of coating materials such as Perlite with Kaolin and Vermiculite in Chenopodium (*Chenopodium Quinoa*) seeds resulted in improved shape and strength of the coated seeds. Two specific coating treatments, V12K3P6 (Vermiculite 12 times the weight of the seed, Kaolin 3 times the weight of the seed, and Perlite 6 times the weight of the seed) and V10K2.5P5 (Vermiculite 10 times the weight of the seed, Kaolin 2.5 times the weight of the seed, and Perlite 5 times the weight of the seed), were identified as the most effective treatments for chenopodium seed coating, leading to higher germination rates compared to other coating treatments [9]. The coating treatment also had a positive impact on various traits of corn seeds, including germination percentage, root and shoot length, germination uniformity coefficient, and α-amylase enzyme activity, outperforming non-coated seeds in these aspects [10].

Environmental stresses limit the use of maximum water, soil, and plant potential for maximum production. Most of these issues are related to drought stress. Drought has become a significant concern for agricultural production in arid and semi-arid regions [11]. Although each stress factor has its specific effect on plants, all types of stress can generally lead to an increase in reactive oxygen species (ROS). ROS can harm biological systems in stressful conditions by causing oxidative damage to lipids, proteins, DNA, and carbohydrates. Additionally, ROS can damage cellular membranes, ultimately resulting in cell death [12]. In a study, Bazrgar et al. [13] found that increased drought stress intensity led to an increase in the soluble sugar, proline, and malondialdehyde (MDA) content of corn cultivars, while the soluble protein content decreased. Another study [14] showed that hydrogen peroxide content, MDA, and the activity of antioxidant enzymes in quinoa increased with drought stress levels [15].

The physical shape of sweet corn causes problems in mechanized cultivation systems. The wrinkled seed of sweet corn gets stuck in the vents of the machinery, preventing it from reaching the desired depth in the soil. This ultimately results in uneven plant growth in the fields [16]. As a result, farmers often encounter difficulties when using seed-sowing instruments. However, these issues can be addressed by rounding and smoothing the sweet corn seeds through a coating process and improving mechanized cultivation with seed-sowing instruments. This is important because low seed vigor can also result in reduced green coverage of the farm [17].

Given the low vigor and germination rates of sweet corn seeds under stress conditions, as well as their

wrinkled physical shape, there is a critical need for further research. Notably, there has been no previous research on coating wrinkled sweet corn seeds with mineral and biological materials. Therefore, the objective of this research, in which your expertise and insights are invaluable, is to enhance mechanized cultivation and improve the ability of sweet corn plants to establish themselves in greenhouses, particularly under drought-stress conditions [18, 19].

The results of the current study show that coating sweet corn seeds can improve germination and seedling growth. Treating the seeds with chitosan 0.5% and NaAlg 1% helps the seedlings tolerate drought stress by enhancing germination and seedling growth and affecting the plant's defense system. Coating the seeds with chitosan 0.5% + V10K2.5P5 (gr) + AG 0.4% in greenhouse conditions improves seedling emergence percentage, rate, and vegetative growth of sweet corn and reduces the negative effects of drought stress.

Materials and methods

Experimental design

This study was conducted in five separate experiments in the laboratory of the Department of Agronomy and Plant Breeding, Yasouj University, Kohgiluyeh and Boyer-Ahmad Province, Iran in 2018 (Table 1). The aim was to select the optimal coating compounds based on the seed's external shape, seed coating germinability, and stability.

A critical experiment was carried out using the results of the four optimal coating compounds from the previous experiments. It studied sweet corn seedlings' morphological and physiological indices in the Department of Agronomy and Plant Breeding, Yasouj University greenhouse in 2019. The sweet corn seeds were obtained from Seminis Company (Origin of France), whose characteristics are shown in Table 2.

All four experiments were determined as factorial based on a completely randomized design with four replications. The first and second experiments were conducted to determine the best chitosan and sodium alginate (NaAlg) levels under optimal conditions and drought stress. In the first experiment, chitosan was used in six levels, including (control (without chitosan + distilled water), zero (without chitosan + acetic acid 0.3%), 0.25, 0.5, 0.75, and 1%), and in the second experiment, NaAlg in three levels (zero (distilled water) 1 and 2%) along with non-treated seeds (control).

In both experiments, drought stress was applied in osmotic potentials of 0, -0.3, -0.6, and -0.9 MPa. The third and fourth experiments were conducted under laboratory conditions to coat sweet corn seeds with chitosan and sodium alginate treatments and plant substrates like vermiculite, kaolin, and perlite. In the third experiment, the chitosan was in three levels (0, 0.5, and 0.75%), and in the fourth experiment, NaAlg was in two levels (0 and 1%). In both experiments, Arabic gum (0 and 0.4%) and V10K2.5P5 (gr) coating composition (10, 2.5, 5, and tenfold to seed weight, respectively, in vermiculite (V), kaolin (K), and perlite (P)) and non-coating treatment. A standard germination test was done after considering the treatments in each experiment.

Table 2 Seed traits of sweet corn (Hybrid challenger)

Year of seed production	Seed physical purity (%)	Seed initial germination (%)	Seed viability (%)
2017	99	93	98

Table 1 The characteristics of the performed experiments in the present research

Laboratory	Experiment *No*	Treatments
	(First)	Chitosan at six levels (Control (without chitosan + distilled water), 0 (without chitosan + acetic acid 0.3%), 0.25, 0.5, 0.75, and 1%), & osmotic potential at four levels (0, -0.3, -0.6 and -0.9 MPa)
	(Second)	NaAlg at four levels (0 (distilled water), 1%, and 2%) along with non-primed seeds (control) and osmotic potential at four levels (0, -0.3, -0.6 and -0.9 MPa)
	(Third)	1) Coating (V10K2.5P5 (gr)) and non-coating & 2) Arabic gum (AG) at two levels (0 and 4%) & 3) Chitosan at three levels (0, 0.5 and 75%)
	(Fourth)	1) Coating (V10K2.5P5 (gr) and non-coating: 2) Arabic gum (AG) at two levels (0 and 4%) & 3) NaAlg at two levels (0 and 1%)
Greenhouse	(Five)	First factor: Coating treatment at three levels: 1) Uncoated (Control) 2) Chitosan 0.5% + V10K2.5P5 + AG 0.4% 3) NaAlg 1% + V10K2.5P5 + AG 0.4% Second factor: Osmotic potential at four levels: (0, -0.3, -0.6 and -0.9 MPa)

Twenty-five seeds were sown on top of a two-layer filter paper in 12 cm Petri dishes and were in seed germinators at 25 ± 1 °C for 7 days [20]. Counting germinated seeds was done on the first day of a given time. During counting, those seeds were considered germinated, and their root length was over 2 mm. Germination percentage (GP) was calculated based on the following relationship:

$$GP = n/N \times 100 \quad (1)$$

Where, *n* is the total number of germinated seeds, and *N* is the number of seeds [21].

The fourth experiment were conducted in laboratory conditions to select the most effective combined seed coating treatment. The treatment with the highest germination percentage was chosen for each subsequent greenhouse experiment. The main experiment was conducted to study the effect of coating treatments on morphological and physiological indices of sweet corn seedlings under drought stress in the greenhouse. This experiment was factorial based on the completely randomized design (CRD) in three replications. The experiment factors consisted of three coating treatments (chitosan 0.5% + V10K2.5P5(gr) + Arabic gum 0.4% and NaAlg 1% + V10K2.5P5(gr) + Arabic gum 0.4%) and non-coating seeds as a control, and drought stress in four levels of 0 (distilled water), -0.3, -0.6 and -0.9 MPa (Fig. 1). And a schematic of the seed coating process is shown in Fig. 2.

Plastic pots were provided for the greenhouse experiment with 1 kg, and each pot filled with soil and sand was mixed with a 2:1 ratio. Seeds should be coated for the greenhouse experiment. They were poured into a coating

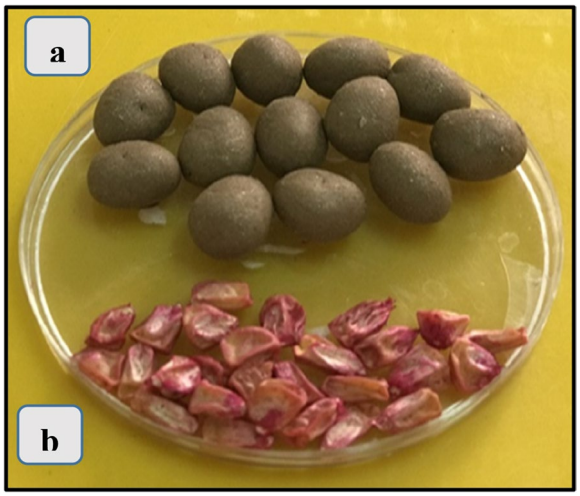

Fig. 1 Coated (Chitosan 0.5% + V10K2.5P5 (gr) + Arabic Gum 0.4%) sweet corn (**a**) and uncoated sweet corn (**b**)

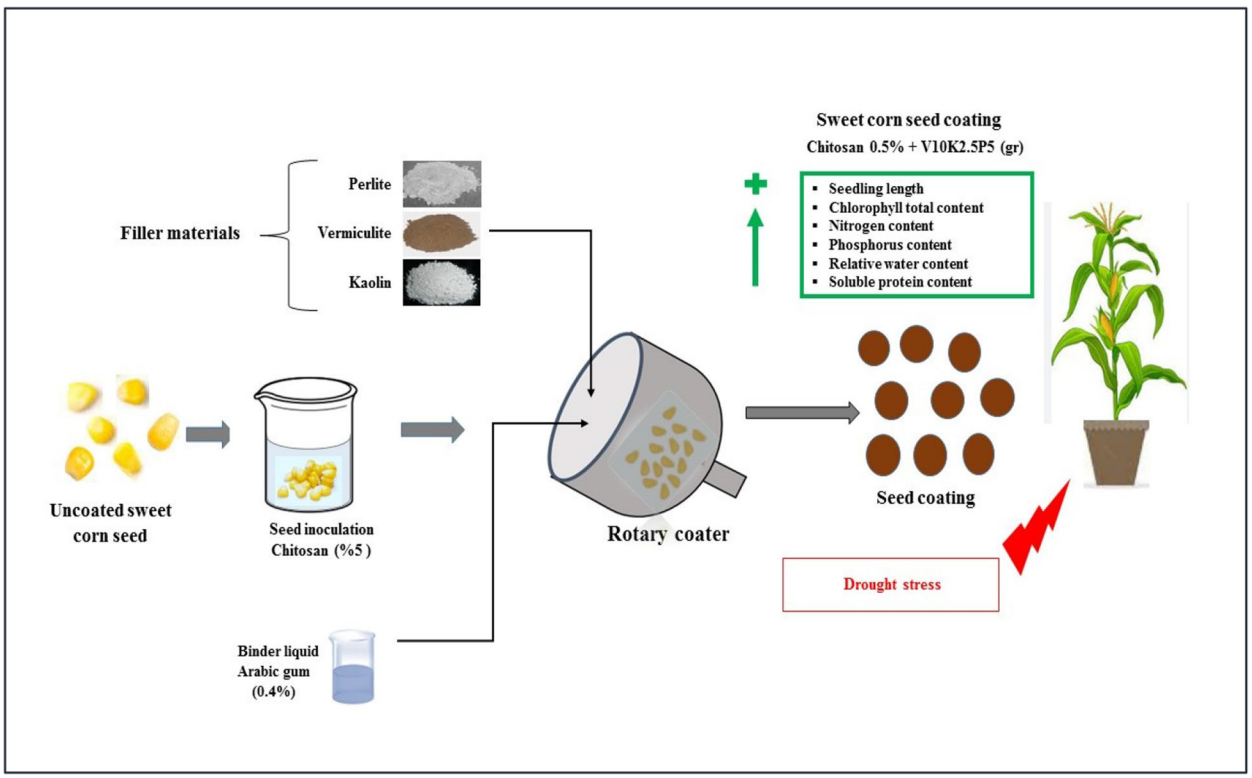

Fig. 2 A schematic representation of the sweet corn seed coating process

machine, and viscous substances (chitosan, sodium alginate, and Arabic gum) were used to attach coating compound V10K2.5P5 (gr) to seeds. After that, in each pot, 20 coated seeds were sown at a depth of 2.5–3 cm. Seedlings grow in greenhouse conditions at 25 °C. Watering was done every five days. To avoid the build-up of osmotic solutions in the pots. As a precaution, the pots were washed once before the third round of watering. Drought stress was applied using a solution of polyethylene glycol (Merck, Schuchardt OHG, Hohenbrunn, Germany). Michel and Kaufmann's [22] method formula was used for the calculation of PEG needed to make each osmotic potential:

$$\psi S = -\left(1.8 \times 10^{-2}\right) C - \left(1.8 \times 10^{-4}\right) C^2 + \left(2.67 \times 10^{-4}\right) CT + \left(8.39 \times 10^{-7}\right) C^2 T \quad (2)$$

Where *ΨS* is osmotic pressure in terms of the bar, *C* is the concentration of PEG-6000 in g/kg H_2O, and *T* is the temperature in terms of the degrees Celsius.

Traits measurement

Biochemical and physiological indices

Leaf proline content was measured using the Paquin and Lechasseur [23] method. The proline concentration of samples was obtained using different concentrations of l-proline in a standard curve and absorption at 515 nm with a UV spectrophotometer (Shimadzu 54a, Japan). The results were calculated and presented by measuring proline content based on μmol.g^{-1} of leaf fresh weight.

Soluble sugar content was measured using the Irigoyen et al. [24] method by anthrone, sulfuric acid, and glucose standards. Standards' absorption was measured with the absorption of the soluble sugar content of samples using a UV-spectrophotometer at 650 nm. The amount of soluble sugar in the samples was calculated based on mmol. g^{-1} of leaf fresh weight.

Soluble protein content was measured using the Bradford [25] method. Samples were absorbed in 595 nm using a UV Spectrophotometer. The amount of leaf protein content was calculated based on μg g^{-1} of leaf fresh weight using the Bovine Serum Albumin (BSA) standard curve.

Using Arnon's method [26], 0.5 g of finely cut fresh leaves were ground with 10 ml of 80% acetone to calculate the total chlorophyll content. The leaves were then centrifuged at 30,000 rpm for 15 min. The supernatant was transferred and repeated until the residue became colorless. The solution's absorbance was measured at 645 and 663 nm against the blank (acetone solvent).

The leaf's relative water content (RWC) was determined by the method described by [27]. To RWC, the fresh weight of leaves collected from control and stress-applied samples were measured. Then, the samples were put into jars filled with distilled water for 6 h at room temperature for hydration. The turgid weight of hydrated leaf tissues was measured, and they were dried in an oven at 70 °C for 24 h. Then, samples were weighed to record dry weight.

Lipid peroxidation indices

Malondialdehyde (MDA) was measured as the final product of membrane lipid peroxidation using the Heath and Pack [28] method. Samples' MDA content was calculated by measuring the absorption at 532 and 600 nm and using an extinction coefficient of 155 mM^{-1} cm^{-1}.

To extract hydrogen peroxide (H_2O_2) content, 0.2 g of leaf samples were homogenized with 2 ml Trichloro acetic acid 1% and centrifuged at 15,000 rpm for 15 min at 4 °C using a centrifuge device (Sigma 2-16KC). The resulting extract was used to measure hydrogen peroxide. The light absorption of each sample was read at 390 nm using a spectrophotometer. The hydrogen peroxide contents were determined using the H_2O_2 standard [29].

Elements content

Nitrogen content in leaves was measured using the Eaton et al. [30] method. At first, plant leaves were inside the oven at 78 for about 48 h to dry. Plant samples were digested in stages using sulfuric acid, salicylic acid, and hydrogen peroxide on the heater at 180 °C. Thus, nitrogen element absorption was read using a UV Spectrophotometer at 660 nm. Sample absorption, standard solution density, and nitrogen density based on mg/lit were obtained using a regression line. Nitrogen content based on mg.g^{-1} of leaf dry weight was obtained using sample absorption regression line and standard solution concentration.

To measure potassium and phosphorus elements, the plant sample (leaf) was initially changed into a grey inside an electric kiln at 550 °C; then it was digested with 2N hydrochloric acid. The potassium content was measured using a flame emission photometer (PFP7-England) based on mg.g^{-1} of leaf dry weight [31].

The colorimetric method (yellow, molybdate, vanadate) measured phosphorus content with a UV spectrophotometer at 420 nm based on mg.g^{-1} of leaf dry weight [32].

Growth and morphological indices

After 21 days of growth in the greenhouse, root, and shoot length was measured by a ruler, and samples

were placed inside an oven device at 75 °C for about 48 h to measure the dry weight of the root and shoot. Then, they were weighed by a precision scale of 0.001 g. Root volume trait measurement was done in a way that the roots of each pot were located inside a graduated cylinder with a determined water ratio and root volume based on cm^2 from coming water up.

Seedling emergence percentage (SEP), seedling emergence rate (SER), and mean emergence time (MET) were calculated using equations as described below:

$$SEP = n/N \times 100 \quad (3)$$

Where, *n* is the total number of grown seedlings after 21 days, and N is the number of planted seeds.

$$SER = \sum ni/Di \quad (4)$$

Where, *ni* is the number of seedlings grown, and *Di* is the number of the corresponding growing days [33].

Statistical analysis

All analyses were performed based on a factorial experiment in a completely randomized design with three replicates. Statistical analysis was performed using SAS (version 9.4, SAS Institute, Cary, NC) software. Arc SinX was used to convert germination and seedling emergence percentages. The data was analyzed using two-way ANOVA, and mean comparison was performed by Duncan's multiple range test ($p \leq 0.05$). Graphs were created using Excel 2013.

Results

Laboratory experiments

The first experiment showed that 0.5% chitosan had the highest germination percentage in all levels of osmotic potential. The highest germination percentage (77.94%) was observed in 0 MPa and 0.5% chitosan, which was not significantly different from the 0.75% chitosan treatment (Fig. 3). The second experiment showed that in all levels of osmotic potential, NaAlg 1% treatment had the highest germination percentage (Fig. 4).

The third experiment revealed that the highest germination percentage (76.01%) was related to Chitosan 0.5% + Coating V10K2.5P5 (gr) + Arabic Gum 0.4% compound among the coating treatments of the third experiment (Fig. 5). Also, The fourth experiment demonstrated that in the results obtained from the fourth experiment, the highest germination percentage (75.05%) was related to treatment NaAlg 1% + Coating compound V10K2.5P5 (gr) + Arabic Gum 0.4% (Fig. 6).

The greenhouse experiment

Growth and morphological indices

Seedling emergence percentage Results showed that increasing osmotic potential caused a decrease in the emergence percentage of sweet corn seedlings. It also indicated that coating treatments significantly improved seedling emergence percentage in all osmotic potential levels than non-coating seeds. The highest seedling emergence percentage (70.11%) was related to the coating treatment of Chitosan 0.5% + V10K2.5P5 (gr) + AG 0.4% in 0 MPa which had an 11.8% difference with the uncoated treatment under the same conditions and the

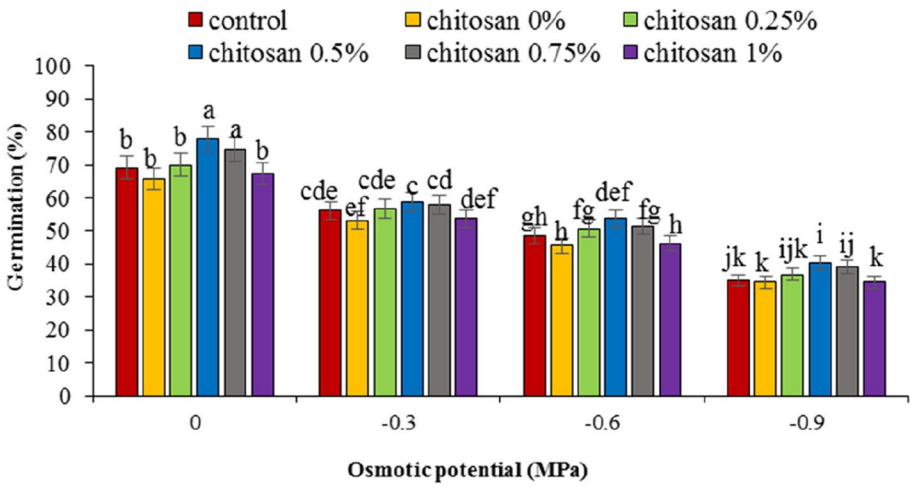

Fig. 3 Germination percentage of sweet corn affected by chitosan at different levels of the osmotic potential. According to Duncan's multiple range test, means with the same letter are not significantly different at the 5% level

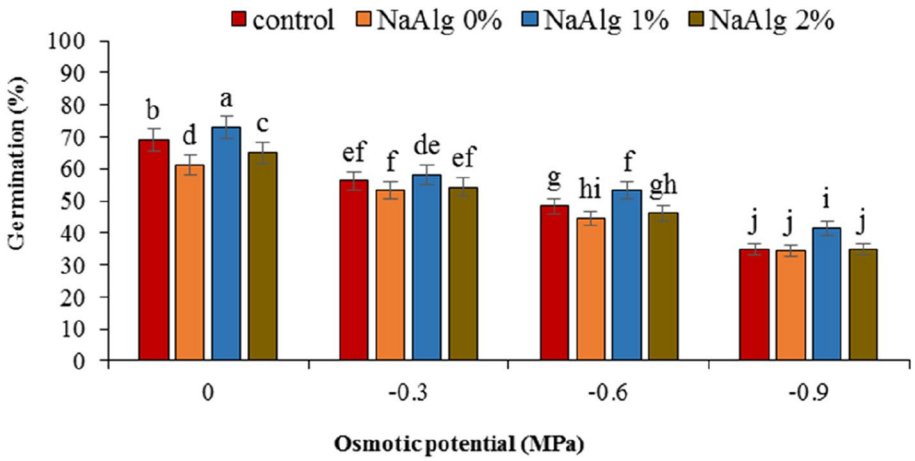

Fig. 4 The germination percentage of sweet corn is affected by sodium alginate (NaAlg) at different levels of the osmotic potential. According to Duncan's multiple range test, means with the same letter are not significantly different at the 5% level

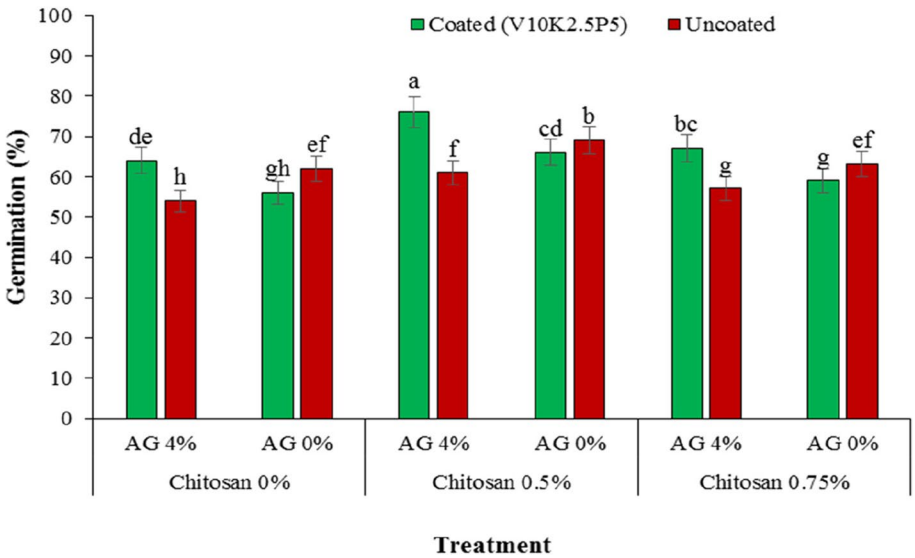

Fig. 5 Germination percentage of sweet corn affected by arabic gum (AG) and coating treatment (V10K2.5P5 (gr)) at different levels of chitosan. According to Duncan's multiple range test, means with the same letter are not significantly different at the 5% level

lowest seedling emergence percentage (41.15%) obtained from non-coating treatment in -0.9 MPa level of drought stress (Fig. 7-A).

Seedling emergence rate According to the results of Fig. 7B, the seedling emergence rate decreased with increasing osmotic potential levels. Coating treatments improved this index than non-coating seeds. The highest seedling emergence rate (3.70 seedlings d^{-1}) was observed in 0 MPa and coating treatment Chitosan 0.5% + V10K2.5P5 (gr) + AG 0.4% that had no significant difference with coating treatment NaAlg 1% + V10K2.5P5 (gr) + AG 0.4% and it almost causes threefold increase in seedling emergence rate than its lowest ratio (0.78 seedlings d^{-1}) in -0.9 MPa and non-coating seeds.

Root length, shoot length and root/length ratio The results revealed that the highest root length (231.93 mm) allocated to coating treatment chitosan 0.5% + V10K2.5P5 (gr) + AG 0.4% and 0 MPa caused an 81% increase in root length than the lowest root length (127.53 mm) in non-coating seeds and -0.9 MPa level (Table 3). According to a comparison of data means, the length of the shoot decreased with drought stress intensity. Data

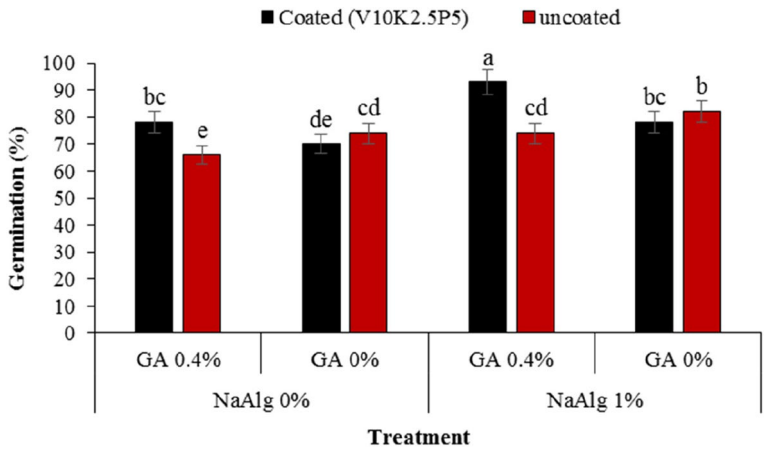

Fig. 6 Germination percentage of sweet corn affected by Arabic gum (AG) and coating treatment (V10K2.5P5 (gr)) at different levels of sodium alginate (NaAlg). According to Duncan's multiple range test, means with the same letter are not significantly different at the 5% level

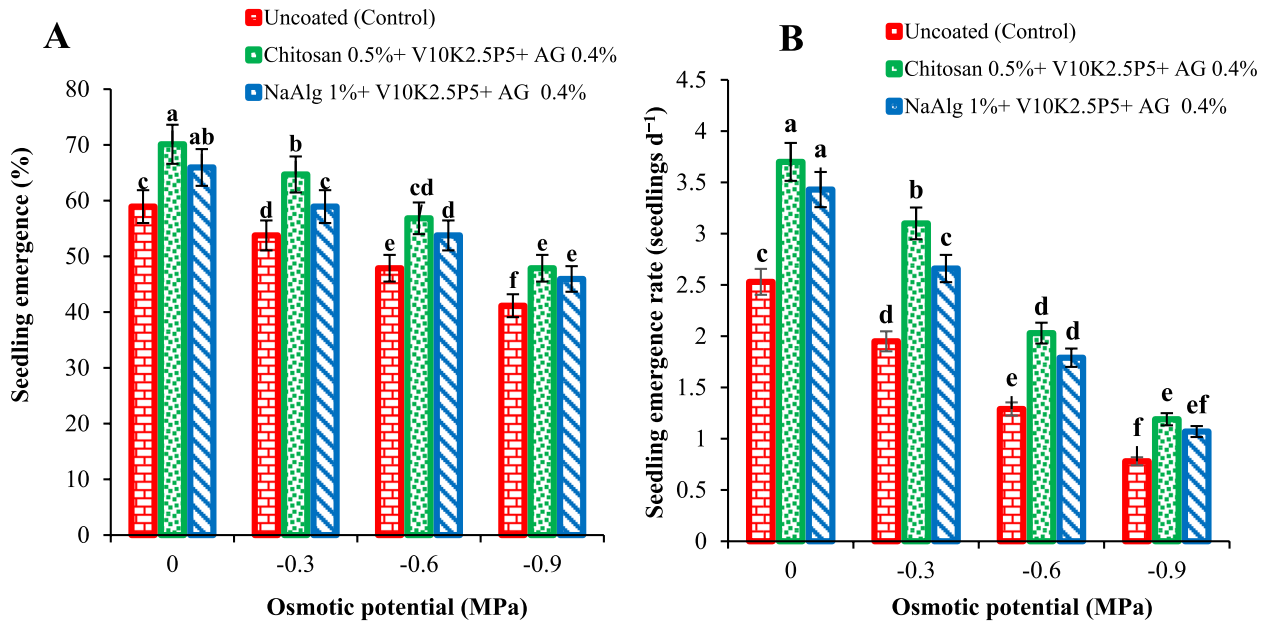

Fig. 7 Mean comparison of coating treatment and osmotic potential on seedling emergence percentage (**A**) and seedling emergence rate (**B**) of sweet corn. Arabic Gum (AG), Sodium alginate (NaAlg). According to Duncan's multiple range test, means with the same letter are not significantly different at the 5% level

showed that coating treatments increased shoot length in drought stress levels. Osmotic potential 0 MPa and coating treatment chitosan 0.5% + V10K2.5P5(gr) + AG 0.4% allocated the highest shoot length (297.46 mm) to themselves, which had a 46% difference with the lowest shoot length (159.86 mm) in non-coating seeds and a -0.9 MPa level. The highest Root/Length ratio (0.904) was raleted to NaAlg 1% + V10K2.5P5 + AG 0.4% in -0.3 MPa and the lowest (0.779) was observed in Chitosan 0.5% + V10K2.5P5 + AG 0.4% at 0 MPa (Table 3).

Root dry weight, shoot dry weight, and root volume Results showed that in all levels of osmotic potential (0, -0.3, -0.6, and -0.9 MPa), the highest root dry weight was related to coating treatment chitosan 0.5% + V10K2.5P5(gr) + AG 0.4%. Data showed that an increase in drought stress intensity caused a decrease in root dry weight. The highest root dry weight (61.40 mg) was observed in 0 MPa and coating treatment Chitosan 0.5% + V10K2.5P5 (gr) + AG 0.4% that had a

Table 3 Mean comparison of coating treatment and osmotic potential on some growth and morphological indices of sweet corn. Arabic Gum (AG), Sodium alginate (NaAlg), Root Length (RL), Shoot Length (ShL), Root Dry Weight (RDW), Shoot Dry Weight (SDW), Root Volume (RV)

Osmotic potential (MPa)	Coating treatment	RL (mm)	ShL (mm)	R/Sh ratio	RDW (mg)	SDW (mg)	RV (cm^3)
0	Uncoated (Control)	196.66 e ±3.71	227.46 d ±2.77	0.864 bc ±0.010	44.26 f ±0.17	116.13 c ±0.29	2.66 cd ±0.16
	Chitosan 0.5% + $V_{10}K_{2.5}P_5$ + AG 0.4%	231.93 a ±1.97	297.46 a ±2.21	0.779 g ±0.012	61.40 a ±0.30	131.60 a ±1.90	3.83 a ±0.16
	NaAlg 1% + $V_{10}K_{2.5}P_5$ + AG 0.4%	225.66 b ±0.98	286.00 b ±0.50	0.789 g ±0.002	59.66 b ±0.37	127.33 b ±0.63	3.50 ab ±0.28
-0.3	Uncoated	169.53 g ±0.63	205.20 f ±1.40	0.826 de ±0.006	38.33 g ±0.24	98.46 f ±0.64	2.16 de ±0.17
	Chitosan 0.5% + $V_{10}K_{2.5}P_5$ + AG 0.4%	208.46 d ±0.99	238.73 c ±1.93	0.873 b ±0.011	52.40 c ±0.23	113.20 d ±0.64	3.16 bc ±0.16
	NaAlg 1% + $V_{10}K_{2.5}P_5$ + AG 0.4%	213.33 c ±1.33	235.86 c ±1.04	0.904 a ±0.003	51.33 d ±0.29	110.46 e ±0.63	2.50 d ±0.28
-0.6	Uncoated	152.93 i ±0.66	181.00 i ±1.52	0.845 cd ±0.005	35.66 h ±0.24	76.26 i ±0.35	1.83 of ±0.16
	Chitosan 0.5% + $V_{10}K_{2.5}P_5$ + AG 0.4%	183.20 f ±1.90	209.86 e ±0.59	0.872 b ±0.006	49.53 e ±0.24	89.33 g ±0.40	2.16 de ±0.17
	NaAlg 1% + $V_{10}K_{2.5}P_5$ + AG 0.4%	164.00 h ±1.52	199.86 g ±0.94	0.820 de ±0.004	48.93 e ±0.48	86.60 h ±0.52	2.16 de ±0.16
-0.9	Uncoated	127.53 j ±1.27	159.86 j ±0.86	0.797 fg ±0.002	32.53 i ±0.35	64.73 k ±0.40	1.50 f ±0.05
	Chitosan 0.5% + $V_{10}K_{2.5}P_5$ + AG 0.4%	162.13 h ±1.07	191.40 h ±1.50	0.847 cd ±0.005	38.06 g ±0.17	76.06 i ±0.52	1.66 of ±0.16
	NaAlg 1% + $V_{10}K_{2.5}P_5$ + AG 0.4%	148.86 i ±1.48	182.13 i ±1.61	0.817 ef ±0.009	37.46 g ±0.40	72.26 j ±0.24	1.66 of ±0.16

According to Duncan's multiple range test, means with the same letter are not significantly different at the 5% level

47% difference with the lowest root dry weight ratio (32.53 mg) in non-coating-seeds and -0.9 MPa level (Table 3).

Like root dry weight, shoot dry weight decreased with increased osmotic potential levels. The usefulness of coating treatments caused an improvement in this index compared to non-coating seeds. Coating treatment Chitosan 0.5% + V10K2.5P5(gr) + AG 0.4% in 0 MPa had the highest dry weight of shoot with a mean (131.60 mg) that had a 50% difference with the lowest shoot dry weight ratio (64.73 mg) in non-coating seeds and -0.9 MPa level (Table 3). The results of osmotic potential interaction and coating treatment for root volume trait showed that coating treatments caused this trait improvement in all levels of osmotic potential. The highest root volume (3.83 cm^3) was observed in coating treatment chitosan 0.5% + V10K2.5P5 (gr) + AG 0.4% and 0 MPa. The lowest ratio of this trait (1.50 cm^3) was in non-coating seeds and -0.9 MPa level (Table 3).

Proline content

Table 4 showed that proline content increased with increased osmotic potential levels. Coating treatment significantly increased proline content in optimal conditions and drought stress. The highest proline content, with a mean of 4.22 µmol g^{-1} FW, was observed in -0.9 MPa and coating treatment chitosan 0.5% + V10K2.5P5 (gr) + AG 0.4%, which had a difference of 64%. The lowest proline content, with a mean of 1.50 µmol g^{-1} FW, was observed in non-coating seeds and at the 0 MPa level.

Soluble sugar content

Investigation of means showed that soluble sugar content increased with an increase in osmotic potential levels, and coating treatments caused its growth compared to non-coating seeds. In -0.9 MPa and coating treatments, chitosan 0.5% + V10K2.5P5 (gr) + AG 0.4%, the highest ratio of soluble sugars (34.31 mg g^{-1} FW) was obtained. It caused a 78% increase in soluble sugar content compared to the lowest ratio of this index (19.17 mg g^{-1} FW) in non-coating seeds and 0 MPa level (Table 4).

Soluble protein content

Results showed that increasing osmotic potential levels caused a decrease in soluble protein content, and coating treatment led to improvement of this index compared

Table 4 Mean comparison of coating treatment and osmotic potential on some biochemical and physiological indices of sweet corn. Arabic gum (AG) and sodium alginate (NaAlg)

Osmotic potential (MPa)	Coating treatment	Proline content (μmol.g^{-1} FW)	Soluble sugar content (mg.g^{-1} FW)	Soluble protein content (mg.g^{-1} FW)	Total chlorophyll content (mg.g^{-1} FW)	Relative water content (%)
0	Uncoated (Control)	1.50 l ±0.015	19.17 k ±0.050	16.69 d ±0.064	1.19 f ±0.002	80.97 b ±0.448
	Chitosan 0.5% + $V_{10}K_{2.5}P_5$ + AG 0.4%	1.76 j ±0.026	24.23 i ±0.073	20.14 a ±0.050	2.06 a ±0.005	83.81 a ±0.917
	NaAlg 1% + $V_{10}K_{2.5}P_5$ + AG 0.4%	1.68 k ±0.019	22.13 j ±0.133	18.61 b ±0.043	1.98 b ±0.007	81.99 ab ±0.395
-0.3	Uncoated	1.84 i ±0.011	24.66 h ±0.213	14.45 f ±0.057	0.93 h ±0.006	73.21 d ±0.353
	Chitosan 0.5% + $V_{10}K_{2.5}P_5$ + AG 0.4%	2.19 g ±0.011	26.39 f ±0.096	18.10 c ±0.043	1.80 c ±0.005	76.51 c ±0.267
	NaAlg 1% + $V_{10}K_{2.5}P_5$ + AG 0.4%	2.06 h ±0.015	26.14 f ±0.032	15.90 e ±0.100	1.70 d ±0.003	74.56 cd ±0.846
-0.6	Uncoated	2.39 f ±0.022	25.79 g ±0.043	11.49 i ±0.096	0.70 j ±0.001	62.56 g ±1.312
	Chitosan 0.5% + $V_{10}K_{2.5}P_5$ + AG 0.4%	2.94 c ±0.023	31.16 c ±0.066	14.24 g ±0.058	1.21 e ±0.004	68.40 e ±0.195
	NaAlg 1% + $V_{10}K_{2.5}P_5$ + AG 0.4%	2.62 e ±0.019	30.79 d ±0.030	12.81 h ±0.057	1.13 g ±0.005	65.09 f ±0.346
-0.9	Uncoated	2.81 d ±0.039	30.19 e ±0.171	9.20 l ±0.114	0.58 k ±0.002	51.72 i ±0.169
	Chitosan 0.5% + $V_{10}K_{2.5}P_5$ + AG 0.4%	4.22 a ±0.015	34.31 a ±0.024	10.93 j ±0.063	0.92 h ±0.008	56.19 h ±1.191
	NaAlg 1% + $V_{10}K_{2.5}P_5$ + AG 0.4%	3.68 b ±0.015	33.91 b ±0.018	10.32 k ±0.053	0.87 i ±0.003	53.20 i ±0.202

According to Duncan's multiple range test, means with the same letter are not significantly different at the 5% level

to non-coating seeds. In 0 MPa and coating treatment, Chitosan 0.5% + V10K2.5P + (gr) + AG 0.4%, the highest content of soluble protein (20.14 mg g^{-1} FW), was observed to almost cause an increase 1.1 fold soluble protein content than the lowest of its ratio (9.20 mg g^{-1} FW) in -0.9 MPa and non-coating seeds (Table 4).

Total chlorophyll content

Results of the mean comparison showed that with increasing osmotic potential levels, total chlorophyll content decreased, but coating treatments caused improvement in these indices in osmotic potential levels. The highest total chlorophyll ratio (2.06 mg g^{-1} FW) was related to 0 MPa and coating treatment Chitosan 0.5% + V10K2.5P5 (gr) + AG 0.4% with the lowest total chlorophyll content (0.58 mg g^{-1} FW) had 71% difference in non-coating seeds and -0.9 MPa (Table 4).

Relative water content (RWC)

Mean Comparison of the interaction of osmotic potential and coating treatment for RWC index showed that an increase in osmotic potential led to an RWC decrease, and coating treatment application at all osmotic potential levels improved RWC than non-coating seeds. The highest RWC (83.81%) was observed at 0 MPa and coating treatment Chitosan 0.5% + V10K2.5P5 (gr) + AG 0.4%. The lowest RWC (51.72%) was observed in -0.9 MPa and in non-coating seeds that had no significant difference with coating treatment NaAlg 1% + V10K2.5P5 (gr) + AG 0.4% and -0.9 MPa level (Table 4).

Lipid peroxidation indices

Malondialdehyde (MDA) content

According to the results, an increase in osmotic potential increased MDA content. Coating treatments decreased MDA content compared to non-coating seeds. The highest MDA content (0.0024 mM g^{-1} FW) was observed in non-coating seeds and 0 MPa. The lowest MDA content (0.0018 mM g^{-1} FW) was observed in 0 MPa and coating treatment Chitosan 0.5% + V10K2.5P5 (gr) + AG 0.4%, which had no significant difference with coating treatment NaAlg 1% + V10K2.5P5 + AG 0.4% in -0.3 MPa level (Table 5).

Hydrogen peroxide content (H_2O_2)

The results showed that with increasing osmotic potential levels, H_2O_2 content increased. Application of coating treatments reduced this trait compared

Table 5 Mean comparison of coating treatment and osmotic potential on lipid peroxidation indices of sweet corn. Arabic Gum (AG), Sodium alginate (NaAlg), Malondialdehyde (MDA), and Hydrogen peroxide (H_2O_2). According to Duncan's multiple range test, means with the same letter are not significantly different at the 5% level

Osmotic potential (MPa)	Coating treatment	MDA content (mM g^{-1} FW)	H_2O_2 content (mM g^{-1} FW)
0	Uncoated (Control)	0.0021 c ±0.0000284	3.43 g ±0.059
	Chitosan 0.5% + $V_{10}K_{2.5}P_5$ + AG 0.4%	0.0018 e ±0.0000215	2.53 i ±0.033
	NaAlg 1% + $V_{10}K_{2.5}P_5$ + AG 0.4%	0.0019 de ±0.0000106	2.64 i ±0.028
-0.3	Uncoated	0.0021 c ±0.0000215	3.88 f ±0.034
	Chitosan 0.5% + $V_{10}K_{2.5}P_5$ + AG 0.4%	0.0018 e ±0.0000860	3.21 h ±0.030
	NaAlg 1% + $V_{10}K_{2.5}P_5$ + AG 0.4%	0.0018 e ±0.0000211	3.32 gh ±0.023
-0.6	Uncoated	0.0022 b ±0.0000215	4.73 c ±0.057
	Chitosan 0.5% + $V_{10}K_{2.5}P_5$ + AG 0.4%	0.0019 de ±0.0000108	4.03 e ±0.042
	NaAlg 1% + $V_{10}K_{2.5}P_5$ + AG 0.4%	0.0020 cd ±0.0000705	4.35 d ±0.022
-0.9	Uncoated	0.0024 a ±0.0000108	5.04 a ±0.069
	Chitosan 0.5% + $V_{10}K_{2.5}P_5$ + AG 0.4%	0.0019 de ±0.0000538	4.68 c ±0.014
	NaAlg 1% + $V_{10}K_{2.5}P_5$ + AG 0.4%	0.0019 de ±0.0000013	4.86 b ±0.030

According to Duncan's multiple range test, means with the same letter are not significantly different at the 5% level

to non-coating seeds. The highest content of H_2O_2 (5.04 mM g^{-1} FW) was observed in non-coating seeds and -0.9 MPa. The lowest H_2O_2 content (2.53 mM g^{-1} FW) was observed at 0 MPa and coating treatment Chitosan 0.5% + V10K2.5P5(gr) + AG 0.4%, which had no significant difference with coating treatment NaAlg 1% + V10K2.5P5 + AG 0.4% at the 0 MPa level (Table 5).

Elements content

Nitrogen content

Results of the mean comparison showed that nitrogen content decreased with increasing osmotic potential levels. Coating treatments significantly improved nitrogen content in all levels of osmotic potential. The highest nitrogen content (47.14 mg.g^{-1} FW) was in 0 MPa and coating treatment Chitosan 0.5% + V10K2.5P5(gr) + AG 0.4%, which significantly differed from the lowest nitrogen content (17.27 mg.g^{-1} FW) in non-coating seeds and -0.9 MPa level (Table 6).

Potassium content

With increasing in drought stress intensity, potassium content increased. The rate of potassium content changes under coating treatments was that the highest potassium content (17.93 mg g^{-1} FW) in -0.9 MPa and coating treatment Chitosan 0.5% + V10K2.5P5(gr) + AG 0.4% that had no significant difference with coating treatment NaAlg 1% + V10K2.5P5 (gr) + AG 0.4% in -0.9 MPa. The lowest potassium content (9.80 mg.g^{-1} FW) was observed in non-coating seeds and at 0 MPa level (Table 6).

Phosphorus content

Results showed that phosphorus content decreased with an increase in osmotic potential levels. In all levels of osmotic potential, coating treatments improved phosphorus content. The highest content of phosphorus (8.97 mg.g^{-1} FW) obtained from coating treatment Chitosan 0.5% + V10K2.5P5 + AG 0.4% and 0 MPa that had no significant difference with coating treatment NaAlg 1% + V10K2.5P5 (gr) + AG 0.4% and 0 MPa and causes almost an increase about 1.1 fold phosphorus content than lowest amount (4.15 mg.g^{-1} FW) in non-coating seeds and 0 MPa level (Table 6). A negative correlation was observed between GP and MDA, H_2O_2, Proline, Soluble sugar, and K, whereas GP (seedling) was positively correlated with GR, P, N, and Protein (Pro) and Chl total content (Fig. 8).

Table 6 Mean comparison of coating treatment and osmotic potential on some elements content of sweet corn. Arabic Gum (AG) and Sodium alginate (NaAlg). According too Duncan's multiple range test, means with the same letter are not significantly different at the 5% level

Osmotic potential (MPa)	Coating treatment	Nitrogen content (mg. g^{-1} FW)	Potassium content (mg. g^{-1} FW)	Phosphorus content (mg.g^{-1} FW)
0	Uncoated (Control)	33.08 e ±0.088	9.80 e ±0.223	7.96 d ±0.087
	Chitosan 0.5% + $V_{10}K_{2.5}P_5$ + AG 0.4%	47.14 a ±0.113	11.60 d ±0.270	8.97 a ±0.021
	NaAlg 1% + $V_{10}K_{2.5}P_5$ + AG 0.4%	46.67 b ±0.133	11.29 d ±0.160	8.93 a ±0.024
-0.3	Uncoated	25.95 g ±0.123	11.73 d ±0.322	6.67 f ±0.010
	Chitosan 0.5% + $V_{10}K_{2.5}P_5$ + AG 0.4%	41.70 c ±0.073	14.02 c ±0.164	8.25 b ±0.018
	NaAlg 1% + $V_{10}K_{2.5}P_5$ + AG 0.4%	40.42 d ±0.293	13.90 c ±0.223	8.12 c ±0.022
-0.6	Uncoated	21.61 h ±0.159	13.96 c ±0.320	5.30 g ±0.014
	Chitosan 0.5% + $V_{10}K_{2.5}P_5$ + AG 0.4%	33.18 e ±0.127	15.95 b ±0.164	6.78 e ±0.018
	NaAlg 1% + $V_{10}K_{2.5}P_5$ + AG 0.4%	31.96 f ±0.093	15.26 b ±0.215	6.63 f ±0.025
-0.9	Uncoated	17.27 i ±0.142	15.45 b ±0.284	4.15 j ±0.029
	Chitosan 0.5% + $V_{10}K_{2.5}P_5$ + AG 0.4%	25.83 g ±0.088	17.93 a ±0.162	4.72 h ±0.021
	NaAlg 1% + $V_{10}K_{2.5}P_5$ + AG 0.4%	25.67 g ±0.070	17.25 a ±0.270	4.62 i ±0.022

According to Duncan's multiple range test, means with the same letter are not significantly different at the 5% level

Discussion

Laboratory experiments

The growth and development of plants were significantly impacted by drought, leading to a noticeable decline in biomass accumulation and crop growth rate [34]. The results of our study's experiments demonstrated that drought stress reduced the seedling indices of sweet corn, which is consistent with the findings of Manu et al.'s study [35]. Drought stress affects germination through creating low osmotic potential preventing water uptake by the seed, affecting the movement and transfer of seed resources, or directly impacting the organic structure and protein synthesis in the embryo. If water uptake by the seed is impaired, the metabolic activities during germination inside the seed will slow down. Consequently, the time of root emergence increases, and the germination rate decreases [36].

Seed coating with absorbent materials is a seed enhancement method that can play an essential role in plant growth under drought stress. Our laboratory's first experiment showed that among different concentrations of chitosan, 0.5% chitosan had the highest germination at all levels of osmotic potential. Chitosan has a superficial viscous quality that creates a permeable membrane on the seed, increasing water absorption and preventing seed moisture loss. It also enhances germination and plant growth by regulating cellular osmotic pressure [37], which aligns with the first experiment's results.

The results from the second laboratory experiment showed that NaAlg1% treatment resulted in the best germination across all levels of osmotic potential when compared to different concentrations of NaAlg compound. Sodium alginate is a hydrophilic polysaccharide with the ability to retain moisture. It can enhance the drought resistance and salinity tolerance of germinating seeds [38]. Sodium alginate has high permeability, does not repel water, and swells when in contact with water for a prolonged period. These characteristics allow the seed to effectively absorb water, thereby promoting germination and high emergence rates [39].

In the third and fourth experiments, using a 4% AG binder with 5% chitosan and 1% NaAlg was found to be the most effective treatment in terms of germination percentage. In these two experiments (3rd and 4th), the V10K2.5P5 (gr) treatment was used as a seed coating. Vermiculite, which has the ability to expand and

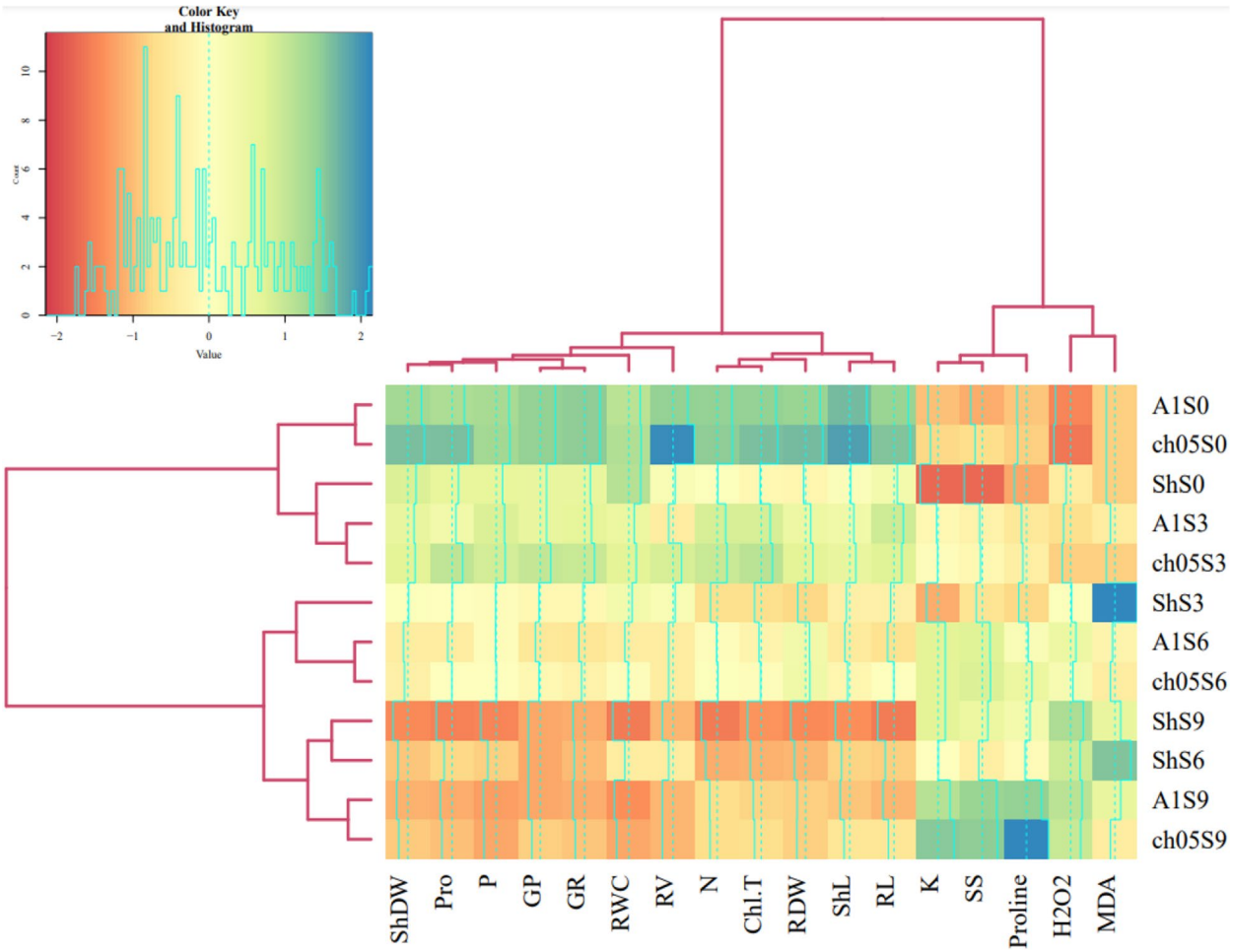

Fig. 8 Correlation between various seedling emergence and biochemical indices of Sweet corn under osmotic potential

retain more water around the seed compared to perlite, was used in the seed coating. When a higher percentage of vermiculite is used, it provides greater water-holding capacity in its layers, allowing the seed to emerge more quickly [7, 40, 41].

Greenhouse conditions

In this study, drought stress affected the growth of sweet corn plants. Water deficit resulted in decreased seedling emergence percentage and rate, root and shoot fresh weight, shoot length, and root and shoot dry weight of the plant. However, treatment with chitosan improved these growth indices. The germination and seedling process involves events that begin with water uptake and end with the elongation of the embryonic axis and root emergence. Water is essential for initiating metabolism and embryo development, and the activity of biochemical reactions during germination is directly related to moisture availability [42]. In a study by Piri et al. [43], it was reported that the coating treatment V3K1.5P2 (3, 1.5, and 2 times the seed weight, respectively, of vermiculite (V), kaolin (K), and perlite (P)) resulted in an increase in emergence percentage, root and shoot length, fresh weight, and dry weight of cumin compared to other coating treatments in the experiment. The higher seedling growth indices in the coating treatments may be attributed to increased water uptake and protection by vermiculite during germination. In another study, Hosseini et al. [5] discovered that using the K10P20 + *Trichoderma harzianum* (T36) fungi treatment as the best treatment could enhance the initial vegetative growth of anise seedlings under optimal and drought stress conditions.

Our experiment demonstrated that drought stress led to a reduction in leaf-soluble protein, catalase enzyme activity, and total chlorophyll content in sweet corn plants. It also resulted in an increase in proline, soluble sugars, and MDA content. These findings are consistent with a study on linseed plants conducted by Movahhedi-Dehnavi et al. [44]. In a study of the Ajwain plant (*Carum copticum* L.), it was found that increasing the

chitosan ratio to 200 ppm elevated the levels of proline, soluble sugars, and MDA content [45]. Plants employ various methods to resist environmental stresses. Under stress conditions, cells reduce their osmotic potential by accumulating compatible osmolytes such as proline and soluble sugars, and eliminate free oxygen produced by environmental stresses to protect macromolecules [46]. Our study showed that applying chitosan as a coating treatment has helped the plant by increasing proline content (Table 2) in plant organs, thereby enhancing resistance and reducing damage resulting from stresses [47]. Additionally, it caused ultrastructural changes in cellular organelles, including the tonoplast and enzymes involved in sugar metabolism. This matching mechanism is in line with maintaining osmotic potential under chitosan treatment.

The process of protein synthesis is essential for regulating plant metabolism and helping plants respond to stress. When plants experience drought stress, it leads to an increase in enzymes that break down proteins, a decrease in protein synthesis, and an accumulation of free amino acids like proline, which reduces protein content. However, in our study, we found that treating seeds with coatings resulted in higher levels of soluble protein compared to untreated seeds. It appears that these coating treatments increased soluble proteins by enhancing amino acid synthesis, thereby reducing the damaging effects of drought stress. Our experimental findings align with a previous study that showed a decrease in soluble protein content in cumin leaves as drought stress levels increased. Interestingly, coating seeds with various materials like vermiculite, perlite, and kaolin, as well as using fungi and bacteria, improved the soluble protein content.

Plant cells can cope with oxidative stress by activating the antioxidant defense system [48]. H_2O_2 is harmful to cells and needs to be swiftly converted into water and oxygen by the antioxidant defense system. Without any protection, ROS can harm cell membranes, protein structures, and DNA by peroxidizing unsaturated fatty acids, breaking down lipid membranes, and releasing various aldehydes, including MDA, leading to a decrease in photosynthesis activity [49]. The study indicates that coating treatments for non-coated seeds result in lower levels of H_2O_2 and MDA. This is because coating treatments can enhance the physiological responses in seeds under drought-stress conditions, significantly boosting their resistance to environmental stresses. Consequently, coated seeds release fewer radicals and experience reduced damage to macromolecules, nucleic acids, and oxidative reactions that produce toxic substances compared to non-coated seeds when faced with stressful conditions.

Moharramnejad et al. [50] conducted a study on the impact of drought stress on maize and found that the stress led to a significant decrease in total chlorophyll. They observed a reduction of about 40% compared to the control treatment. The increase in reactive oxygen species (ROS) accumulation in chloroplasts, caused by the activity of the Rubisco enzyme and inhibition of ATP synthesis, was identified as the reason for the destruction of chlorophyll. In our study, we found that coating treatments resulted in an increase in total chlorophyll content and improved photosynthesis compared to non-coated seeds. This is consistent with the findings of Dzung et al. [51], who noted that the use of chitosan led to an increase in chlorophyll a and b content as well as carotenoids in coffee leaves. The application of chitosan in coating treatments was found to influence chloroplast gene expression in leaves, leading to changes in chloroplast size and development, ultimately stimulating plant growth.

The Relative Water Content (RWC) is a crucial measure of a plant's water status, indicating the balance between water uptake by roots and water loss through transpiration. Drought stress, which leads to reduced RWC and total water potential, can stunt plant growth. This study focuses on the osmotic regulation mechanism, particularly proline accumulation in sweet corn seedlings, which helps to maintain and increase RWC in plants. Our findings are consistent with previous research [52] that observed a decrease in leaf RWC as drought stress increased, affecting sweet corn yield. Attaran Dowom et al. [53] noted that chitosan treatments increased leaf RWC in *Salvia abrotanoides* under drought stress compared to the control group. Coating treatments for seeds are also likely to improve water uptake and reserves by enhancing the root system's efficiency, while reducing transpiration, thereby maintaining RWC under stress conditions. Increased RWC supports photosynthesis, cell division, and leaf development, ultimately leading to higher production of photosynthetic substances and increased plant growth [54].

The decrease in nitrate accumulation in plants under environmental stress is attributed to a reduction in nitrogen metabolism, resulting from a decrease in the activity of the nitrate reductase enzyme in the leaves and a reduction in water uptake by the plant. Nitrogen plays a crucial role in producing compatible solutes like proline and betaine in plants under stress [55]. Only about 1% of the water absorbed by the roots is used for plant consumption, while the rest is emitted as vapor from the plant. Therefore, improving the plant's Relative Water Content (RWC) enhances its growth and increases the uptake of elements, especially under dehydrating conditions. The study indicated that seedlings from coated seeds had higher elemental content than non-coated ones. Coating

treatments that increased the RWC of sweet corn leaves compared to non-coated seeds resulted in an uptake of elements by the plant's roots in the soil. Additionally, it was shown that the potassium content of corn leaves (*Zea mays* L.) increased with an increasing level of drought stress [56]. The increase in potassium uptake under drought stress can be attributed to the active uptake mechanism of this ion by the plant, which enhances its resistance to high stress. This increase in potassium uptake has a positive effect on photosynthesis, growth, leaf area index, ATP and NADPH synthesis, transfer rate of photosynthetic material, protein synthesis, regulation of stomatal opening and closing, and decrease in transpiration. Furthermore, an increase in water uptake by the plant, a crucial issue during drought stress, is facilitated by the rise in potassium uptake [57].

The research has shown that drought stress reduces the uptake of phosphorus by maize, which aligns with the results of our experiment. Phosphorus is mainly absorbed by diffusion processes at the plant's root level. When there is a lack of water in the soil, the drainage of the pores reduces the necessary level for diffusion, resulting in a decrease in its rate. Consequently, less phosphorus is transported to the root surface, leading to a decrease in phosphorus content in plant tissues [58]. It appears that the use of chitosan in the coating treatment has a positive impact on improving root and shoot growth, which can directly influence the uptake of these elements [59]. In this study, seed coating with biological substances and inorganic materials improved various physiological and biochemical indicators, such as phosphorus, nitrogen, soluble protein (Pro), and total chlorophyll content. This treatment also enhanced the morphological characteristics of sweet corn seedlings under both optimal and drought stress conditions (Fig. 8).

Conclusions

The findings of this study show that coating sweet corn seeds can improve germination and seedling growth. Treating the seeds with chitosan 0.5% and NaAlg 1% can enhance the seedlings' ability to withstand drought stress by improving germination and growth and by directly affecting the plant's antioxidant defense system. Coating the seeds with chitosan 0.5% + V10K2.5P5 (gr) + AG 0.4% in a greenhouse can improve seedling emergence percentage and rate, as well as the vegetative growth of sweet corn, while also lessening the negative effects of drought stress. However, it's important to note that the effectiveness of chitosan coating can vary depending on the plant species and environmental conditions. Chitosan has the potential to enhance germination and plant defenses, but its effects vary across different plant types and environments. For instance, the extent to which chitosan activates plant defenses and promotes seedling development varies significantly. This variability suggests that its use may require customization for specific crops and environments. Therefore, future research on chitosan seed coatings should focus on improving formulations to enhance their effectiveness across a broader range of crops and environments. This could involve exploring combinations with other biostimulants or protective chemicals to enhance plant resistance and growth. Additionally, integrating chitosan with nanotechnology, such as chitosan nanoparticles, could improve distribution and effectiveness, potentially leading to more consistent results in various agricultural settings.

Acknowledgements
The authors thank their colleagues in the Laboratory of Agronomy at the Agricultural Faculty of Yasouj University.

Authors' contributions
R. B.: investigation, writing-original draft. A. M.: conceptualization; research supervision; for-mal analysis; methodology; data curation. R. P.: writing-original draft, visualization. B. D., B. F.-N. and M. G.: Writing-review and editing. All authors have read and agreed to the published version of the manuscript.

Funding
This research received no specific grant from public, commercial, or not-for-profit funding agencies.

Data availability
All data generated or analyzed during this study are included in this article. Further enquiries can be directed to the corresponding author.

Declarations

Ethics approval and consent to participate
This manuscript is an original research and has not been published or submitted in other journals.

Consent for publication
All authors listed have read the complete manuscript and have approved submission of the paper.

Competing interests
The authors declare no competing interests.

Received: 11 August 2024 Accepted: 14 October 2024
Published online: 22 October 2024

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