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Mitigating of Salinity Stress and Amelioration Productivity of Potato (*Solanum Tuberosum* L.) Using Soil Conditioners and Foliar Application of Osmoprotectants

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ABSTRACT

Potato yield and tuber quality, as well as enzymatic activity and their responses to soil amendments and osmoprotectants were evaluated under saline condition (soil EC= 5.2 dSm^{-1}). A field experiment was conducted using potato (*Solanum tuberosum* L. cv. Spunta) cultivated in the Experimental Farm, Horticulture Research Department, Faculty of Agriculture, Damietta University, New Damietta, Egypt during 2015 and 2016 summer growing seasons. A split-plot design was used with soil conditioners SC (farmyard manure FYM, humic acid HA, sulfur S, and gypsum GYP) as main plots, proline Pro, essential oils EOs, silicon dioxide SiO_2, and ascorbic acid AsA as biomedulators BMs and antioxidants or osmoprotectants randomly distributed within sub-plots. Each treatment was repeated three times. The combined interaction of SC and BMs had significant effects on growth, yield and yield components, quality, and catalase CAT activity. Tuber decline in quality was observed by saline stress as dry matter and specific gravity. Pro and polyphenol oxidase PPO contents in tuber were increased in salinity stressed plants. Application potato plants with FYM at 30 $ton.fed^{-1}$ as a soil conditioner with a foliar spray with Pro (10 mM) exhibited significant positive effects on all mentioned studied parameters in the two seasons of study. Application of FYM>GYP>HA>S (sole soil application) recorded the highest significant values of growth, yield, as well as nutraceutical properties and enzymatic activity studied parameters over the control. All applied BMs also preserved tuber yield, grading (30:60 and over 60 mm), and quality. Foliar spray with Pro (10 mM) had increased values of all studied parameters over two seasons of the study compared with EOs, AsA, and SiO_2. It was concluded that treatment with combined application of FYM and Pro could be a practical approach to avert yield decreases in salinity-stress potato and that treatment maintains plant growth, tuber yield, quality, and antioxidant defense system.

Keywords: Potato, salinity, soil conditions, foliar application, biomedulators.

Introduction

Globally, potato (S*olanum tuberosum* L.) is the 3rd most significant food crop after rice and wheat in terms of production and consumption (Muthoni and Kabira, 2016). Potato is a major crop in Egypt and contributes immensely to human nutrition and food security (Devaux *et al*., 2014). In Egypt, potato occupies about 405,845 fed., producing about 4.9 million tons with an average of 11.8 ton/fed (Assad *et al*., 2018). Amidst various abiotic stresses, salinity is considered as one of the essential abiotic stresses that plant confrontation. Salt affected soil is a vital abiotic constraint in crop production (Khan *et al*., 2012). Increasing soil salinization of good arable farming is predicted to have destructive universal effects resulting in 30% cultivated-land losses within the next twenty-five years, and up to 50% by the year 2050 (Luo *et al*., 2017). Salts affect adversely on soil fertility and subsequently plant growth and productivity including soil health due to osmotic pressure (Türkan and Demiral, 2009). According to an estimate by FAOSTAT (2018), over 6% of the arable world's cultivated land is salt-affected. Moreover, 45 million hectares (~20%) out of 230 million hectares of irrigated land are affected with salinity.

Salinity shows many adverse effects including osmotic stress, ion toxicity, osmotic inhibition of water uptake and nutrient-acquisition and deficiency, molecular bases for higher Na^+: K^+ ratio, decline stomatal conductance, increased cell-turgor loss, physiological and biochemical changes, and increased reactive oxygen species ROS-caused oxidative stress (Munns and Tester, 2008; Nazar *et al*., 2011). Many investigators have been attempting to find the approaches to mitigate salt stress or to overcome

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salt injury in numerous plants, in the last decades. Application of exogenous protectants such as antioxidants, phytohormones, biomedulators, and trace elements came of interest in recent times (Noreen *et al.,* 2013; Hasanuzzaman *et al.,* 2019). Moreover, intelligent and selective use of organic amendments like FYM, humic substances, have demonstrated effective in soil properties value and modifying on soil fertility. The application of organic substances raises humification, increases aggregate stability resulting in better aeration, enzyme production, and microbial activity (Asghari and Fard, 2016). Moreover, organic matter has chelating properties that binding mineral ions like potassium, calcium, and magnesium in the form of colloids (humus with clay), facilitating stable aggregates of soil particles for the required porosity to afford plant growth. Soil microbial and enzyme activities are important signals of soil health as a result of the addition of organic compounds (Asghari and Fard, 2016). Humic acid (HA) is a major component of humic compounds, which are the principle of organic constituents of soil. The application of organic compounds as humic substances to saline soils can increase Na^+ leaching and reduce both ESP (exchangeable sodium percentage) and soil salinity (Suddarth *et al.,* 2019). The plants can increase in the concentration of Ca^{2+} when they are challenged with salinity stress and often can improve the inhibitory effects on growth. Calcium sulfate ($CaSO_4$) plays a major role in for Na^+ efflux from cells, preserve the various functional and structural integrity of membranes, stabilize cell wall structures, regulate ion selectivity and transport, and control ion-exchange conduct as well as on metabolic activities in the cytosol and cell wall enzyme activities (Marschner, 1995). Preserving a sufficient supply of calcium in saline soil is a vital factor in controlling the severity of specific ion toxicity, especially in crops that are susceptible to sodium and chloride damage (Tuna *et al*., 2007). Sulfur (S) has an essential role in the alleviation of salinity stress. Sulfur assimilates acting as signaling molecules with beneficial effects for cellular communication with the environment besides providing structural components of essential molecules. Sulfur increases salinity resistance by up-regulating specific gene for stress tolerance proteins. Another mechanism for salinity is modulating physiological processes, i.e. acts of the K^+ channel AKT and regulation of enzyme activities (Khan *et al.,* 2011).

Silicon (Si) is the second most abundant macro-element in the soil that helps plants tolerate environmental stress and improve soil conditions. Silicon can mediate salinity stress tolerance by a variety of mechanisms including reducing Na^+ uptake and decreased the permeability of the plasma membrane of cells (Gong *et al.,* 2006). Plants demonstrate a variety of adaptive mechanisms to neutralize salinity stress. Medicinal plant species have been used by the ancestors around the world since ancient times. Due to sustainable development for economic and environmental products, there is a need for consumers to orient towards more healthy food products that reduce chemical compounds. In the last decade, the development of new strategies of integrated pest management (IPM) to promote sound structures and healthy plants, reduces environmental risk, improve crop productivity and sustainable quality are requested by producers. For this scope, the foliar application with essential oils (E.Os) is suggested as a potential natural antioxidant in open field potato cropping systems. Medicinal plants have various bioactive compounds (secondary metabolites) like alkaloids, terpenes, tannins, flavonoids, steroids, glycosides, saponins, etc. These compounds play a principle role in preserving the plants from different stress factors like salinity and drought. Moreover, secondary metabolites that act as active components display a wide range of antimicrobial activity (Rojas *et al*., 2000; Kotagiri *et al*., 2018). Plants explain a variety of adaptive mechanisms to face various environmental stresses. Since one of the primary responses under salt stress is an osmotic adjustment, appreciate solutes such as proline (Pro) and ascorbic acid (AsA) are very common to be accumulated during salt stress and play an essential role in osmoregulation in the plants (Szabados and Savouré, 2010; Agami, 2014). Moreover, osmoprotectants, AsA, and Pro also showed their roles in removing of oxidative stress by triggering the antioxidant defense and glyoxalase system (Agami, 2014; Patade *et al*., 2014).

Therefore, we investigated the protective effects of these soil conditioners, biomedulators, and osmoprotectants on the growth, yield, quality, and antioxidant defense in potatoes grown under salinity stress.

Materials and Methods

1. Plant materials and experimental conditions

The experiment was managed with potato cv. Spunta at the Experimental Farm of Horticulture Research Department, Faculty of Agriculture, Damietta University, New Damietta, Egypt (latitude

31°25/ N, longitude 31° 48/ E and altitude +8 m above sea level), during two summer seasons of 2015 and 2016. Imported potato half seed tubers from the Netherlands (weighing 30-40 g each), "Elite E" were planted at hills 25 cm apart in the middle of the ridges by hand workers. Planting took place on 8 and 10 January, for both seasons, respectively. The soil was sandy clay loamy, with 0.045% organic matter, 0.175% total N, pH 8.20, and EC 5.2 dSm^{-1} (average two seasons). Extractable soil P and K levels in the plots this 2-yr trial were in the range of 0.12 to 0.89 ppm for P and 40 to 44 ppm for K, respectively. Experimental unit was 11.25 m^2; consisted of 3 ridges; 5 m long; 75 cm wide. Nitrogen (ammonium nitrate 33.5% N), phosphorus (mono-superphosphate 15.5% P_2O_5) and potassium (potassium sulfate 48% K_2O) were applied in the rates of 150 + 75 + 96 kg fed^{-1}, respectively. The other agricultural practices were carried out according to the recommendation of the Ministry of Agriculture. The local climate is Mediterranean type, warm and dry during the summer season. The temperature range varied between a minimum average of 12.5° C at night and a maximum average of 37.3° C at a day in summer (average two seasons of study). The source of this data is obtained in Agric. Res. Center, Central Management of Agriculture Guideline, Bulletin of agricultural meteorological data.

2. The experimental arrangement, Treatments

The field experimental unit was laid out in a split-plot system in a randomized complete blocks design with three replicates. Four soil amendments (farmyard manure FYM, gypsum GYP, sulfur S, and humic acid HA) were assigned to the main plots. The sub-plots were devoted to four foliar applications with osmoprotectants or biomedulators (essential oils EOs, ascorbic acid AsA, SiO_2, and proline Pro). The FYM and GYP are considered as soil conditioners or effective procedures that decrease salinity stress.

3. Soil conditioners

Farmyard manure was taken from a dairy farm near Mansoura. Chemical analyses of the organic manures were determined by using standard methods described by Official Methods of Analysis AOAC (2019). Farmyard manure was applied to the soil and left two weeks before planting at the rate of 30 ton/fed. Farmyard manure was a fine-textured, with 23.3% organic matter, N 1.4%, C/N ratio 18.6, and pH 6.9. Extractable P and K levels were 0.18 and 0.86 mg/kg, respectively. Gypsum ($CaSO_4.2H_2O$) was added to the soil at the rate 6 ton/fed. Gypsum requirements (GR) were calculated to minimize the initial Exchangeable Sodium Percentage (ESP) from 24.5 to 10% for 30-cm soil surface according to USDA (1954). Gypsum was obtained from Heliopolis for Mining Co., Egypt. Broadcast application of powdered gypsum to the soil surface before 1^{st} irrigation, was used. Elemental sulfur (soil amendment) was added to the soil plots at 150 kg S/fed before planting. The elemental sulfur was thoroughly mixed with soil at the depth (0-25 cm) during soil preparation processes. Soluble humic acid (Agro BioChemicals Co., India) as potassium-humate (80% humic acid, 11-13% K_2O) was purchased from Shams Chemicals, Dakahlia group, Egypt. Humic acid was mixed with moist pure sand at rate of 80 g/m^2 equivalent to 336 kg/fed. The mixture was broadcast and mixed well in plots before 1^{st} irrigation.

4. Biomedulators/osmoregulators

Essential oils, 200 g from leaves of thyme (*Thymus vulgaris*; containing thymol 40%, carvacrol 15%), and peppermint (*Mentha piperita* L.; containing menthol 31%; menthone 20%) were utilized for oil extraction by hydro-distillation for 2–3 hours according to Charles and Simon (1990). Spraying and drenching potato plants at a rate of 5 ml oils L^{-1} water with 2 ml tween 80 (as emulsion materials) were used. Essential oils were added beside potato plants with 100 ml at the same time of spraying treatments. The treatments were done three times at 45, 60, and 75 DAP. Nanoparticles of SiO_2 (particle size = 50 nm) with an identical surface area ranged from 200–600 m^2 g^{-1} were purchased from the Nanotechnology Unit, Beni-Sueif University, Egypt. Suspensions of SiO_2-NPs in the concentration of 1.5 mg L^{-1} were prepared with deionized water and dispersed with a sonicator (JL360, Shanghai, China) for 30 min. The nanoparticle suspensions were centrifuged (3000 xg for 1 h) and filtered (0.7 µm glass filter) prior to being added to potatoes (Gowayed *et al*., 2017). Plants were sprayed with SiO_2 solution three times 45, 60, and 75 DAP. Proline (Pyrrolidine-2-carboxylic acid), $C_5H_9NO_2$, MW: 115.13 $g.mol^{-1}$, was purchased from Sigma Aldrich Co. Proline was applied at a rate 10 mM with 0.1% Tween 20. Pro. applied three times at 45, 60, and 75 DAP. Ascorbic acid (AsA) was sprayed on potatoes at a rate of 200 mg L^{-1} after 45, 60, and 75 days from planting DAP; stock solution (1000 mg L^{-1}) of pure

AsA (1.0 g L^{-1}) was prepared and then from this stock solution. Two drops of Tween 40 were added to each solution as a surfactant agent. The plants were sprayed with solutions at the early morning hours by using a manual sprayer and the volume of the spray solution has to cover the plant foliage completely till drip (Dolatabadian *et al*., 2009). AsA was purchased from Al-Gomhoria Company for Medicines and Medical Supplies, Egypt.

5. Measurements

Ninety DAP, plants (n=9) were randomly chosen from each treatment and the growth parameters were recorded. Plant length was measured as the main stem length started from the surface of the soil to the plant apex. Foliage fresh weight; the all foliage above ground (leaves + stems) was weighed in each treatment. Foliage dry weight; the leaves and stems of the plant were oven-dried till constant weight at 70 ˚C. Leaves area LA per plant was calculated according to the formula described by Koller (1972). Total leaves area = (Area of the disks (cm^2) x Dry weight of leaves per plant (g)) / Dry weight of disks (g). (1)

At harvest time, 105 days after planting the tuber yield were estimated. The total tuber yield per feddan (ton) was recorded. Tubers from each plot were size-graded to three classes according to tuber diameter, less than 30 mm, from 30 to 60 mm, and over 60 mm, then each grade was weighed separately and converted into ton per feddan.

A representative sample of 10 to 15 healthy tubers from each plot was selected from the largest sizes to obtain quality data. Dry matter content in tubers; tubers were dried separately in a forced-air oven at 70 ˚C to constant weight (for 72 hr.) and their dry weight was recorded (AOAC, 2019). The specific gravity of tubers was estimated according to Schippers (1968) as follows: Specific gravity (SG) = Tuber weight in the air (5 kg) / (Tuber weight in air - Tuber weight in water). (2)

Proline content in fresh tuber was determined by ninhydrin assay at A520 nm according to the method of Bates *et al.* (1973). Catalase (CAT) activity was assayed according to the method of Garcìa-Limones *et al.* (2002). Polyphenol oxidase (PPO) activity was determined according to the method of Cao *et al.* (2009).

Statistical analysis

Data were analyzed using AVOVA technique and the differences between individual pairs of treatment means were compared using Duncan Multiple Range Test at 5% according to Snedecor and Cochran (1982).

Result and Discussion

1. Effect of soil conditioners and osmoprotectants foliar application and their interactions on vegetative growth characters of potato plants.

The interaction effect between soil conditioners SC and biomedulators BMs had significant effects on plant length, plant foliage fresh and dry weights, and leaves area per plant, in both seasons (Table 1). Under salinity stress, the growth attributes of potato were decreased. Control plants had lower plant height, fresh and dry biomass weights, and produced a lower number of leaves (not shown) which were of lower leaves area compared with those treated with SC x BMs (Table 1).

When osmoprotectants/biomedulators were kept constant, soil conditioners had significant effects on biomass parameters in both seasons (Table 1). Application of FYM 30 ton.fed^{-1} recorded the highest significant values of growth studied parameters in comparison to other treatments and control. This is true in two seasons of study. Foliar application with proline Pro 10mM gave the same trend on all vegetative growth parameters compared to other treatments (Tables 1). This is because plant tolerance or adaption to salinity stress involves several mechanisms including osmotic stress, specific ion toxicity, and nutrient deficiencies, thereby affecting a range of physiological and biochemical processes involved in cell turgor and metabolism (Munns and Tester, 2008; Iqbal *et al*., 2012).

The results of the present study indicate that it is advantageous to apply FYM as it increases potato growth by way of improving soil physical properties. FYM also supplies macro and micronutrients and maintains healthy positive nutrient balance besides being a source of organic matter; and further, it emphasizes the need for integrated and balanced nutrient management in potato in sandy loam clayey moderate saline soils. This is in accordance with results obtained by Ahamad *et al*. (2014)

Table 1: Vegetative growth parameters of potato plants as affected by soil amendments and foliar application with osmoprotectants and their interactions in 2015 and 2016 seasons.

No.	Treatments A (Soil amendments)	Treatments B (Foliar application)	Plant length (cm) 2015	Plant length (cm) 2016	Foliage fresh weight per plant (g) 2015	Foliage fresh weight per plant (g) 2016	Foliage dry weight per plant (g) 2015	Foliage dry weight per plant (g) 2016	Leaves area per plant (cm^2) 2015	Leaves area per plant (cm^2) 2016
1	**Control**	**Control**	38.00 r	35.00 q	284.580 u	241.287 v	17.792 o	13.655 n	3120.00 m	3100.33 p
2		**Essential oils**	41.90 op	39.00 no	299.900 s	296.800 rs	20.121 ijk	17.053 ghi	3494.00 k	3521.33 l-o
3		**Ascorbic acid**	40.50 pq	37.70 op	297.150 t	295.110 st	19.483 kl	16.389 h-k	3420.00 kl	3417.33 m-p
4		**SiO_2**	40.10 q	36.50 p	296.100 t	294.050 tu	18.784 mn	15.652 kl	3221.67 lm	3254.67 nop
5		**Proline**	42.40 no	40.00 mn	300.820 s	297.720 r	21.153 ef	18.180 c-f	3640.67 jk	3654.33 j-m
Mean			**40.58 E**	**37.64 E**	**295.710 E**	**284 993 E**	**19.467 D**	**16.186 E**	**3379.27 E**	**3389.60 E**
6	**Farmyard manure (FYM)**	**Control**	45.65 l	43.85 k	331.830 p	335.400 o	19.878 i-l	17.029 ghi	3984.00 hi	3950.33 g-j
7		**Essential oils**	57.80 ab	54.36 b	438.350 b	437.560 a	22.552 bc	19.325 b	5118.67 b	5068.33 b
8		**Ascorbic acid**	56.66 bc	53.33 bc	436.390 bc	433.290 b	21.770 de	18.862 bcd	5059.00 bc	5001.00 b
9		**SiO_2**	55.60 cd	52.15 cd	434.400 cd	431.300 c	21.034 fg	17.790 efg	4794.00 d	4629.33 cd
10		**Proline**	58.99 a	56.23 a	440.920 a	437.820 a	23.663 a	20.328 a	5420.67 a	5474.67 a
Mean			**54.94 A**	**51.98 A**	**416.378 A**	**415.074 A**	**21.779 A**	**18.667 A**	**4875.27 A**	**4824.73 A**
11	**Gypsum (GYP)**	**Control**	39.80 q	41.68 l	326.600 t	323.500 p	19.393 lm	16.054 i-l	3771.00 ij	3768.00 i-l
12		**Essential oils**	53.50 ef	50.36 e	430.650 ef	427.570 e	21.247 ef	18.874 bcd	4813.67 cd	4331.67 def
13		**Ascorbic acid**	53.00 f	49.84 ef	428.770 fg	425.670 f	20.863 fgh	18.003 d-g	4281.67 efg	4121.00 fgh
14		**SiO_2**	52.90 f	46.87 h	427.740 g	424.640 f	20.333 hij	17.110 ghi	3790.33 ij	4009.67 f-i
15		**Proline**	54.58 de	51.69 d	432.540 de	429.440 d	22.770 b	19.572 ab	5076.67 b	4837.67 bc
Mean			**50.76 B**	**48.09 B**	**409.026 B**	**406.164 B**	**20.921 B**	**17.922 B**	**4346.67 B**	**4213.60 B**
16	**Sulfur (S)**	**Control**	44.78 lm	36.51 p	295.870 q	293.000 u	18.505 n	14.566 mn	3196.33 lm	3228.33 op
17		**Essential oils**	48.60 jk	45.95 ij	360.250 m	357.170 l	21.059 fg	17.847 d-g	4176.67 fgh	4050.33 f-i
18		**Ascorbic acid**	47.30 k	45.07 hi	350.320 n	347.220 m	20.450 ghi	16.989 g-j	4000.00 hi	3863.67 g-k
19		**SiO_2**	45.80 l	43.90 jk	340.420 o	337.320 n	19.739 jkl	15.969 jkl	3990.00 hi	3582.00 k-n
20		**Proline**	49.50 ij	47.07 hi	370.200 l	367.127 k	21.466 def	18.551 c-e	4488.67 e	4188.67 efg
Mean			**47.20 D**	**43.70 D**	**343.412 D**	**340.367 D**	**20.244 C**	**16.784 D**	**3970.33 D**	**3782.60 D**
21	**Humic acid (HA)**	**Control**	43.65 mn	40.55 lm	310.720 r	307.740 q	18.845 mn	15.248 lm	3660.00 jk	3390.33 m-p
22		**Essential oils**	52.10 fg	48.67 fg	400.990 i	397.890 h	20.856 fgh	18.186 c-f	4404.67 ef	4115.33 f-i
23		**Ascorbic acid**	51.30 gh	47.90 gh	390.100 j	387.000 i	20.416 ghi	17.425 fgh	4150.00 gh	4015.33 f-i
24		**SiO_2**	50.10 hi	46.70 hi	380.130 k	377.080 j	19.495 kl	16.640 h-k	4034.33 ghi	3834.00 h-l
25		**Proline**	52.50 fg	49.73 ef	410.980 h	407.880 g	22.060 cd	19.178 bc	4965.00 bcd	4490.67 de
Mean			**49.93 C**	**46.71 C**	**378.594 C**	**375.518 C**	**20.335 C**	**17.335 C**	**4242.80 C**	**3969.13 C**
			#	#	#	#	#	#	#	#
Control			**42.38 E**	**39.52 E**	**309.920 E**	**300.185 E**	**18.883 E**	**15.310 E**	**3546.27 E**	**3487.47 D**
Essential oils			**50.78 B**	**47.67 B**	**386.028 B**	**383.398 B**	**21.167 B**	**18.257 B**	**4401.53 B**	**4217.40 B**
Ascorbic acid			**49.67 C**	**46.77 C**	**380.336 C**	**377.446 C**	**20.596 C**	**18.534 C**	**4182.13 C**	**4086.67 B**
SiO_2			**48.98 D**	**45.22 D**	**375.978 D**	**373.090 D**	**19.877 D**	**16.632 D**	**3966.07 D**	**3861.93 C**
Proline			**51.59 A**	**48.94 A**	**391.092 A**	**387.997 A**	**22.223 A**	**19.162 A**	**4718.33 A**	**4529.20 A**

Means of each column for every separate factor and interaction followed with the same letters are not significantly different according to Duncan multiple range test at the probability of 0.05 levels.

and Zewide *et al*. (2016). Moreover, exogenous EOs and Pro applied singly, improved the scavenging of reactive oxygen species ROS and ion chelating, forming a critical part of abiotic stress responses in plant cells. Generally, Pro application generated better results followed by EOs application, to get better the harmful effects of salt stress. Exogenously-applied antioxidants have been observed to improve the injurious effects of salinity on plant growth and metabolic processes (Rady and Hemida, 2016; Sammour *et al*., 2018).

2. Effect of soil conditioners and osmoprotectants foliar application and their interactions on tuber yield and yield components of potato plants.

Amendments with FYM (30 ton.fed^{-1}) as well as foliar application with Pro (10 mM) and FYM x EOs had significant effects of total tuber yield and yield components (30: 60 mm and over 60 mm) of potato, in comparison with other treatments, in both seasons (Table 2). The third treatment regarding tuber yield and yield components of medium and large tubers was GYP x Pro. However, under-saline soil potatoes without application of any treatments had increased value of tuber weight >30 mm. The highest tuber yield (15.390 and 12.385 ton.fed-1, in both seasons, respectively) was obtained under the treatment received GYP x Pro. The second treatment regarding the increase in tuber yield (14.370 and 11.597 ton.fed^{-1}) was GYP x EOs with significant differences between 1st and 2nd treatments, respectively. The percentage increases over the control reached to 79.37, 129.82 % and 67.48, 115.20% for both superiority treatments, in both seasons, respectively. On the other hand, the lowest tuber yield (8.580 and 5.389 ton.fed^{-1}) was recorded under the control treatment, in both seasons (Table 2).

When osmoprotectants were kept constant, soil amendments had a significant effect on biomass parameters in both seasons. Application of FYM@30 ton.fed^{-1} to potato plants recorded the highest significant values of growth studied parameters in comparison to other treatments and control. This is true in two seasons of study. Foliar application with proline Pro@10 mM gave the same trend on all vegetative growth parameters compared to other treatments (Table 1). The results of the present study indicate that it is advantageous to apply FYM as it increases potato growth by way of improving soil physical properties. FYM also supplies macro and micronutrients and maintains healthy positive nutrient balanced besides being a source of organic matter; and further, it emphasizes the need for integrated and balance nutrient management in potato in sandy loam clayey moderate saline soils. This is in accordance with those obtained by Zewide *et al*. (2018).

Based on the results, FYM and Pro applied singly "nearly the same trend" increased yield by 33.17, 47.91%, and 33.11, 47.73% higher, in both seasons, respectively, as compared to control. This result is in close agreement with the findings of Baniuniene and Zekaite (2008); Zewide *et al.* (2018); Yousry *et al*. (2015), and Ezzat *et al*. (2019). The total tuber yield increase was due to primarily the increase in tuber size in larger grades and a decrease of the small grade. Salinity may affect potato crop through a two-phase physiological challenge, one is osmotic stress and the other is ion toxicity (Munns and Tester, 2008). Osmotic stress minimizes the growth of plants due to decreased water potential (Munns and Tester, 2008), whereas sodium ions (Na^+) congest to a toxic concentration that reduces potassium ions (K^+) absorption. These challenges cause the disorder of a variety of physiological processes and enzyme activity in the plant (Fricke *et al.,* 2004). The production of reactive oxygen species (ROS) is prevalent during metabolism and all plants can overcome with them. However, a considerable increase in ROS production can lead to a fundamental damage of cells, lipid, DNA, RNA, and proteins (Mittler, 2002; Prasad *et al.,* 2015). Proline, an important appropriate osmolyte in plants, could maintain cell turgor and function in osmotic adjustment to enhance plant tolerance to osmotic stress. The level of accumulated Pro is mainly correlated with the degree of salt tolerance according to the studies of both plant physiology and genetics (Murmu *et al*., 2017).

3. Effect of soil conditioners and osmoprotectants foliar application and their interactions on tuber quality and enzymatic activity of potato.

The interaction treatments between biomedulators (Pro, EOs, AsA, and SiO_2) and soil conditioners, i.e., FYM, S, HA, and GYP had significant effects on tuber quality parameters (Table 3). Tuber DM and specific gravity of potato tuber in both seasons, increased significantly with the integrated application of FYM (30 ton.fed^{-1}) and Pro (10 mM), in comparison to other treatments (Table 3). The quality of potato tubers that subjected to salinity stress was negatively affected (Table 3). These are consistent with those obtained by Ghosh *et al*., 2001 and Oliveira *et al*., 2016. They found that

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Table 2: Tuber yield and yield components of potato plants as affected by soil amendments and foliar application with osmoprotectants and their interactions in 2015 and 2016 seasons.

No.	Treatments: A (Soil amendments)	Treatments: B (Foliar application)	Tuber grading (ton/fed.): Tuber weight < 30 mm 2015	Tuber weight < 30 mm 2016	Tuber weight 30: 60 mm 2015	Tuber weight 30: 60 mm 2016	Tuber weight > 60 mm 2015	Tuber weight > 60 mm 2016	Total tuber yield (ton/fed.) 2015	Total tuber yield (ton/fed.) 2016
1	**Control**	**Control**	3.623 a	3.522 a	10.879 m	9.678 p	8.957 m	9.367 o	8.580 q	5.389 q
2		**Essential oils**	2.309 def	2.084 e-h	15.723 jk	14.285 lm	11.402 jk	11.848 lm	10.863 lmn	8.012 mno
3		**Ascorbic acid**	2.479 cd	2.477 c	14.857 kl	13.450 mn	10.773 kl	10.896 mn	10.323 mn	7.317 op
4		**SiO_2**	2.577 bc	2.940 b	13.843 l	12.592 n	9.922 lm	10.134 no	9.212 pq	6.753 p
5		**Proline**	1.394 jkl	1.598 jk	16.680 ij	15.402 jkl	12.144 ij	12.979 jk	12.260 ijk	8.842 jkl
Mean			**2.477 A**	**2.524A**	**14.395 D**	**13.081 E**	**10.639 E**	**11.0445 E**	**10.248 E**	**7.263 E**
6	**Farmyard manure (FYM)**	**Control**	1.418 jk	1.345 kl	18.329 fg	16.132 j	13.014 hi	13.401 jk	11.494 jkl	8.778 j-m
7		**Essential oils**	1.221 lm	1.138 l	21.781 ab	22.757 b	17.549 b	17.334 ab	14.370 bc	11.597 bc
8		**Ascorbic acid**	1.280 klm	1.218 l	20.986 bc	21.541 c	16.573 bc	16.568 bcd	13.624 cde	10.839 cde
9		**SiO_2**	1.337 kl	1.265 l	20.022 cde	20.401 cde	15.545 cd	15.780 c-f	13.360 d-g	10.117 efg
10		**Proline**	1.146 m	1.083 l	22.572 a	24.035 a	18.847 a	18.049 a	15.390 a	12.385 a
Mean			**1.280 E**	**1.210 E**	**20.738 A**	**20.973 A**	**16.306 A**	**16.226 A**	**13.647 A**	**10.743 A**
11	**Gypsum (GYP)**	**Control**	1.769 h	1.822 g-j	17.216 hi	16.001 jk	11.678 jk	13.324 jk	11.361 klm	7.109 p
12		**Essential oils**	1.544 ij	1.607 jk	21.012 ab	20.607 cde	16.587 bc	16.653 bc	13.481 c-f	10.876 cde
13		**Ascorbic acid**	1.626 hi	1.739 ij	20.397 cd	19.827 def	15.806 cd	15.856 cde	13.234 d-h	10.676 de
14		**SiO_2**	1.689 hi	1.770 hij	19.259 ef	19.112 fgh	14.911 def	14.957 e-h	12.180 ijk	9.641 f-i
15		**Proline**	1.230 klm	1.149 l	21.759 ab	21.504 c	17.346 b	17.414 ab	14.578 ab	11.943 ab
Mean			**1.571 D**	**1.617 D**	**19.928 B**	**19.410 B**	**15.265 B**	**15.641 B**	**12.967 B**	**10.049 B**
16	**Sulfur (S)**	**Control**	2.698 b	2.464 cd	14.031 l	10.787 o	9.981 lm	10.743 n	10.588 mno	7.872 no
17		**Essential oils**	2.199 fg	2.180 c-f	19.132 ef	18.522 ghi	13.850 fgh	14.568 ghi	12.794 e-i	9.783 fgh
18		**Ascorbic acid**	2.313 def	2.267 cde	17.937 gh	17.468 i	13.113 ghi	13.737 f-i	12.382 hij	8.953 i-l
19		**SiO_2**	2.428cdf	2.348 cde	16.818 i	15.760 jk	12.123 ij	12.755 kl	12.159 ijk	8.421k-n
20		**Proline**	1.261 klm	1.288 kl	19.784 de	20.077 def	14.967 def	15.262 efg	12.632 f-i	10.620 de
Mean			**2.180 B**	**2.109 B**	**17.540 C**	**16.523 D**	**12.807 D**	**13.413 D**	**12.111 D**	**9.130 D**
21	**Humic acid (HA)**	**Control**	2.271 ef	2.243 cde	16.705 ij	14.893kl	11.531 jk	12.855 kl	9.777 op	8.184 lmn
22		**Essential oils**	1.638 kl	1.858 f-j	20.673 bcd	20.195 def	15.300 de	15.508 d-g	13.710 b-e	10.401 ef
23		**Ascorbic acid**	2.019 g	2.041 e-i	19.907 cde	19.445 efg	14.277 efg	14.727 f-i	13.528 c-f	9.518g-j
24		**SiO_2**	2.178 fg	2.142 d-g	19.119 ef	18.022 hi	13.520 fg	13.998 hij	12.454 ghi	9.069 h-k
25		**Proline**	1.352kl	1.274 l	21.526 ab	20.963 cd	16.739 bc	16.576 bcd	14.083 bcd	11.213 bcd
Mean			**1.892 C**	**1.912 C**	**19.586 B**	**18.704 C**	**14.273 C**	**14.733 C**	**12.710 C**	**9.677 C**
Control			**2.356 A**	**2.279 A**	**15.432 E**	**13.498 E**	**11.032 E**	**11.938 E**	**10.359 E**	**7.466 E**
Essential oils			**1.782 D**	**1.774 D**	**19.664 B**	**19.273 B**	**14.937 B**	**15.182 B**	**13.044 B**	**10.134 B**
Ascorbic acid			**1.944 C**	**1.948 C**	**18.817 C**	**18.346 C**	**14.108 C**	**14.357 C**	**12.618 C**	**9.461 C**
SiO_2			**2.042 B**	**2.093 B**	**17.810 D**	**17.177 D**	**13.204 D**	**13.525 D**	**11.873 D**	**8.800 D**
Proline			**1.277 E**	**1.278 E**	**20.464 A**	**20.398 A**	**16.009 A**	**16.256 A**	**13.789 A**	**11.000 A**

Means of each column for every separate factor and interaction followed with the same letters are not significantly different according to Duncan multiple range test at the probability of 0.05 levels.

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Table 3: Physiological characteristics of potato plants and tuber quality as affected by soil amendments and foliar application with osmoprotectants and their interactions in 2015 and 2016 seasons.

No.	Treatments		Tuber dry matter (%)		Specific gravity		Proline (mg/g F.W.)		Catalase (µmol H_2O_2/min/mg protein)		Polyphenol oxidase (µmol catechol /min/mg protein)	
	A (Soil amendments)	B (Foliar application)	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
1	Control	Control	20.047 o	18.083 n	1.0772 l	1.0768 k	42.26 a	41.77 a	0.25 p	0.22 q	529.00 a	479.00 a
2		Essential oils	20.123 no	20.007 ij	1.0859 h	1.0847 hi	39.40 bc	37.67 bcd	0.48 i	0.43 lm	483.33 b	410.00 c
3		Ascorbic acid	20.097 no	19.587 kl	1.0801 j	1.0791 jk	40.50 b	39.10 bc	0.45 jk	0.28 o	433.33 c	361.33 d
4		SiO_2	20.087 no	19.073 m	1.0789 k	1.0782 k	40.50 b	40.07 ab	0.29 o	0.26 p	400.00 d	358.67 de
5		Proline	20.200 n	20.117 g-j	1.0894 ef	1.0881 fgh	17.60 jk	17.60 hi	0.50 h	0.44 kl	363.33 e	326.00 g
Mean			**20.110 D**	**19.373 D**	**1.0823 E**	**1.0814 D**	**36.05 A**	**35.24 A**	**0.39 E**	**0.33 E**	**441.80 A**	**387.00 A**
6	Farmyard manure (FYM)	Control	21.027 k	20.300 ghi	1.0891 fg	1.0877 fgh	14.90 lm	16.13 ij	0.47 ij	0.45 k	330.00 fg	326.00 g
7		Essential oils	22.843 l	21.860 ab	1.0961 b	1.0949 bc	13.80 mn	11.00 l	0.72 b	0.66 c	231.67 klm	225.67o
8		Ascorbic acid	22.633 c	21.550 bc	1.0919 d	1.0908 def	12.93 no	12.77 kl	0.67 d	0.63 de	218.33 lm	218.67 p
9		SiO_2	22.317 de	21.167 cde	1.0908 de	1.0893 efg	14.90 lm	14.00 jk	0.62 e	0.54 gh	215.00 lm	210.67 q
10		Proline	22.917 a	21.957 a	1.0997 a	1.0985 a	11.60 o	8.50 m	0.75 a	0.73 a	200.00 m	197.00 r
Mean			**22.347 A**	**21.367 A**	**1.0935 A**	**1.0922 A**	**13.63 E**	**12.48 E**	**0.65 A**	**0.60 A**	**239.00 D**	**235.60 E**
11	Gypsum (GYP)	Control	21.963 gh	20.043 hij	1.0786 g	1.0775 k	27.50 gh	26.93 fg	0.45 jk	0.42 m	278.67 hij	249.00 m
12		Essential oils	22.463 d	21.340 cd	1.0893 efg	1.0917 cde	18.70 ij	17.60 hi	0.62 e	0.62 e	353.33 ef	307.00 h
13		Ascorbic acid	22.183 ef	21.017 de	1.0829 i	1.0814 ij	20.17 i	19.51 h	0.58 fg	0.56 fg	318.67 g	298.33 i
14		SiO_2	22.050 fg	20.117 g-j	1.0807 j	1.0794 jk	26.40 h	24.77 g	0.58 fg	0.50 i	299.33 gh	290.67 j
15		Proline	22.733 bc	21.823 ab	1.0916 d	1.0905 def	12.70 no	10.50 lm	0.69 c	0.68 b	480.00 b	430.00 b
Mean			**22.279 A**	**20.868 B**	**1.0846 D**	**1.0841 C**	**21.09 D**	**19.86 D**	**0.58 B**	**0.56 B**	**346.00 B**	**315.00 B**
16	Sulfur (S)	Control	20.397 m	19.210 lm	1.0879 fg	1.0866 gh	38.10 cd	37.67 bcd	0.32 n	0.28 o	219.00 lm	217.33 p
17		Essential oils	21.820 hi	20.813 ef	1.0940 c	1.0929 cd	33.60 e	32.50 e	0.44 k	0.48 j	246.00 jkl	240.00n
18		Ascorbic acid	21.263 j	20.513 fg	1.0920 d	1.0910 def	36.90 d	35.20 d	0.41 l	0.43 lm	232.67 klm	228.67 o
19		SiO_2	20.843 kl	19.767 jk	1.0888 fg	1.0877 fgh	36.90 d	36.70 cd	0.38 m	0.36 n	226.33 lm	223.00 op
20		Proline	21.960 gh	20.923 e	1.0988 a	1.0977 ab	16.50 kl	15.17 jk	0.59 f	0.58 f	323.33 fg	337.00 f
Mean			**21.257 C**	**20.245 C**	**1.0923 B**	**1.0912 A**	**32.40 B**	**31.45 B**	**0.43 D**	**0.42 D**	**249.47 D**	**249.20 D**
21	Humic acid (HA)	Control	20.953 kl	19.953 ijk	1.0832 i	1.0821 ij	30.00 f	36.84 cd	0.39 m	0.37 n	246.33 jkl	256.00 l
22		Essential oils	22.073 fg	20.290 ghi	1.0922 d	1.0911 def	28.70 fg	26.87 fg	0.57 g	0.55 g	298.67 gh	291,33 j
23		Ascorbic acid	21.897 gh	20.413 fgh	1.0876 g	1.0864 gh	29.90 f	28.33 f	0.51 h	0.52 hi	284.33 hi	285.67 j
24		SiO_2	21.723 i	19.790 jk	1.0830 i	1.0851 hi	30.00 f	31.81 e	0.45 jk	0.47 j	262.67 ijk	276.67 k
25		Proline	22.463 d	20.790 ef	1.0948 bc	1.0935 cd	15.90 l	14.80 jk	0.63 e	0.64 cd	363.33 e	354.00 e
Mean			**21.821 B**	**20.247 C**	**1.0882 C**	**1.0876 B**	**26.90 C**	**27.73 C**	**0.51 C**	**0.51 C**	**291.07 C**	**292.73 C**
			#	#	#	#	#	#	#	#	#	#
Control			**20.877 E**	**19.518 E**	**1.0832 E**	**1.0821 E**	**30.55A**	**31.87 A**	**0.38 E**	**0.35 E**	**405.13 A**	**385.20 A**
Essential oils			**21.864 B**	**20.862 B**	**1.0915 B**	**1.0911 B**	**26.84 D**	**25.13 D**	**0.57 B**	**0.55 B**	**322.60 B**	**294.80 B**
Ascorbic acid			**21.580 C**	**20.616 C**	**1.0869 C**	**1.0858 C**	**28.08 C**	**26.98 C**	**0.52 C**	**0.48 C**	**297.47 C**	**278.53 C**
SiO_2			**21.439 D**	**19.983 D**	**1.0845 D**	**1.0839 D**	**29.74 B**	**29.47 B**	**0.46 D**	**0.43 D**	**280.67 D**	**271.93 D**
Proline			**22.054 A**	**21.122 A**	**1.0949 A**	**1.0936 A**	**14.86 E**	**13.31 E**	**0.63 A**	**0.62 A**	**261.47 E**	**249.07 E**

Means of each column for every separate factor and interaction followed with the same letters are not significantly different according to Duncan multiple range test at the probability of 0.05 levels salinity stress was decreased the growth, tuber dry matter, total photosynthetic pigments through reduced leaf growth, and suppressed photosynthesis, limiting its ability to grow. The application of FYM had the highest tuber quality overall treatments (GYP, S and SiO_2) and control in both seasons. Moreover, the exogenous application of Pro alone gave the same trend compared to other treatments and control (Table 3).

Concerning the effects of SC x BMs, results in Table 3 indicate that these treatments had significant decreases in Pro content and PPO compared to control plants in both seasons. The highest depression was recorded with the application of FYM and GYP with Pro or EOs. Generally, the application of our substances with salinity caused a significant reduction in proline concentration compared to untreated plants. These compounds probably are playing a vital role in osmotic adjustment in response to salinity stress. These results were confirmed with those reported by Adane (2019). Salinity, oxidative stress occurs during life cycle of plant, leading a disparity between the production and elimination of reactive oxygen species (ROS), such as H_2O_2, O^{2-}, and HO, from the plant tissues. The safeguard of plant cells from oxidative damage count on the level of antioxidant enzymes, like catalase (CAT) (Mittler, 2002; Zhang *et al*., 2010). CAT stimulates the decomposition of H_2O_2 to water and oxygen, and this enzyme is usually found in almost organisms exposed to O_2 (Chelikani *et al*., 2004). PPO catalyzes enzymatic browning, which responsible for brown color affects vegetables and fruits (Jiang *et al*., 2004). Catalase CAT and polyphenol oxidase PPO are physiological parameters reflecting the health condition of plants. Data of the physiological profile of potato tubers as affected by the tested treatments are presented in Table 3. CAT activity was significantly influenced by the application of FYM-Pro (Table 3). The increases were 214, and 145%, respectively compared to the control (average of the two seasons). In this regard, the second and third treatments in CAT activity were FYM-EOs and GYP-SiO_2, respectively. In contrast, PPO was significantly depressed by the addition of FYM-Pro (Table 3). The reduction was 180% compared to the control. The treatment of FYM-SiO_2 occupied the second-order lowering PPO by 161% compared to the control (average of the two seasons).

It alleviates salinity stress injury by scavenging the ROS and increasing the contents of Pro over with the increased activities CAT (Table 3), all of these by expressing at the transcription and/or translation levels and the endogenous scale of Pro (Murmu *et al*., 2017). Besides, it provisions energy for survival and plant growth, serving it to afford stress. Likewise, it conserves plants from salinity-induced deterioration of membrane stability, chlorophyll degradation and electrolytes leakage (Kavi Kishor *et al*., 2005), and improves growth, photosynthesis, leaf water potential by protecting plasma membranes from metal-induced oxidative stress (Okuma *et al*., 2004).

In conclusion, exogenous application of FYM at 30 $ton.fed^{-1}$ (soil amendment), and Pro at 5 mM (foliar spray) applied to potatoes, improved plant growth, antioxidant enzyme defense system, and plant health estimated as increased CAT and decreased PPO activity under 5.2 dS m^{-1} stress condition. Under salinity stress, the improving effect was more declared with FYM+Pro treatment followed by FYM+EOs treatment, therefore increasing the tolerance of potato plants to saline soil stress enhanced their growth and health

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