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Effect of Grain Priming with Salicylic Acid on Germination Speed, Seedling Characters, Anti-Oxidant Enzyme Activity and Forage Yield of Teosinte

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Abstract: Three experiments (laboratory, field and pots) were conducted at Giza Agric. Res. Station, ARC, Egypt, during the two successive summer seasons 2012 and 2013. Seed of teosinte variety (local) were primed in five concentrations of salicylic acid (0.4, 0.6, 0.8, 1.0 and 1.2 g L^{-1}) for 24 hours, as well as control with non priming. The aims of this study was to determine the best level of salicylic acid of pre-sowing treatment for teosinte seeds to improve germination performance, germination speed, seedling characters, anti-oxidant enzyme activity and forage yield. A completely randomized design (CRD) at laboratory experiment, a randomized complete block design (RCBD) at field experiment and a split plot design at pot experiment with four replications were used. The results showed that seed priming with 0.6 g L^{-1} salicylic acid gave the highest germination speed, germination percentage, shoot and radical length and increased plant leaf area at pot experiment. And it increased fresh and dry forage yield fed^{-1}, plant height, number of tillers $plant^{-1}$, number of leaves $plant^{-1}$ and stem diameter of teosinte plants at the field experiment. The highest concentration of salicylic acid (1.2 g L^{-1}) increased catalase (CAT), peroxidase (PoD) and chlorophyll a and b, while (0.6 g L^{-1}) concentration increased carotenoids content of teosinte plants.

Key words: Teosinte · *Zea mexicana* · Priming · Germination speed · Anti-oxidant enzyme activity · Chlorophyll · Carotenoids · Salicylic acid · Forge yield

INTRODUCTION

Teosinte (*Zea mexicana*) is one of the most important summer forge crops in Egypt. Seed priming is widely used for enhancing seed performance by improving the rate and uniformity of germination and decreasing seed sensibility to external factors [1]. The seed priming has been used for improving stand establishment at semi arid conditions, enhancing seed with low vigor, improving dormancy breakdown or increasing productivity [2 - 6]. Salicylic acid (SA) is known as an endogenous growth regulator of phenolic type distributing in a wide range of plant species, which induces biotic and a biotic stress tolerance in crops [7-10]. The role of salicylic acid in seed germination, enzymatic activity and plant growth and yield have been described by salicylic acid mediated in photosynthesis transpiration, stomata regulation, nutrient uptake and transport [11-14]. Agarwal *et al*. [15] demonstrated the enhanced chlorophyll levels and relative water content as well as the lessened hydrogen peroxide (H_2O_2) and lipid per-oxidation when the wheat leaves were treated with salicylic acid under water stress conditions.

Several endogenous defense mechanisms, including enzymatic and non enzymatic, act in the cells to provide protection against oxidative damage, important enzymes that scavenge reactive oxygen species (ROS) include superoxide dismutase, ascorbate peroxidase and catalase [16].

Therefore, this investigation was conducted to determine the best level of salicylic acid of pre-sowing treatment for teosinte grains to improve performance of germination, germination speed, seedling vigor, enzyme activity and forage yield.

MATERIALS AND METHODS

The present work includes three experiments (laboratory, pots and field) which were conducted at Giza Agric. Res. Station, ARC, Egypt, during 2012 and 2013

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growing seasons, to determine the best level of salicylic acid of pre-sowing treatment for teosinte grain to improve performance of germination percent and speed, seedling vigor, enzyme activity and forage yield. The experiments were laid out in a completely randomized design (CRD) for laboratory experiment, a split plot design for pot experiment and a randomized complete block design (RCBD) for field experiment with four replications during both seasons.

Laboratory Experiment: A laboratory experiment was conducted at Seed Technology Res. Dept., Field Crops Res. Institute, ARC, Giza, Egypt, during the two successive summer seasons 2012 and 2013. Enough amount of local teosinte seeds were prepared for the three experiments by soaking seeds in solutions of (0.4, 0.6, 0.8, 1.0 and 1.2 g L^{-1}) of salicylic acid for 24 hours and control by non-priming seeds. After that seeds were washed with distilled water.

Laboratory Characters

Germination Percentage: Fifteen seeds from each treatment were seeded in boxes of (40 x 20 x 20 cm) dimensions containing sterilized sandy soil. The boxes were incubated at 25 °C in germination chamber for 10 days. The boxes were arranged in a completely randomized design (CRD) with four replicates during both seasons. Germination percentage and speed of germination were estimated according to I.S.T.A. [17].

Shoot and Radical Length and Fresh and Dry Seedling Weight: Were taken as an average of ten normal seedlings from each replication according to Kirshnasamy and Seshu [18].

Seedling Vigor Index: Was determined according to the formula given by Reddy and Khan [19].

Seedling vigor index (1) = Germination percentage X Seedling length

Seedling vigor index (2) = Germination percentage X Seedling dry weight

Catalase (CAT): Activities of catalase (CAT) were measured using the methods of Chance and Maehly [20] with modification. The CAT reaction solution (3 mL) contained 50mM phosphate buffer (pH 7.0), 15 mM H_2O_2 and 0.1mL enzyme extract. Reaction was initiated by addition of enzyme extract; change in absorbance of the reaction solution at 240 nm was read every 20 s. One unit CAT activity was defined as an absorbance change of 0.01 unit min.

Peroxidase (POD): Activities of peroxidase (POD) were measured using the methods of Chance and Maehly [20] with modification. The POD reaction solution (3 mL) contained 50 mM Soduim acetate buffer (pH 5.0), 20 mM guaiacol, 40 mM $H_2O_2$and 0.1 mL enzyme extract, change in absorbance of reaction solution at 470 nm was determined every 20 s. One unit POD activity was defined as an absorbance change of 0.01 unit min^{-1}. The activity of each enzyme was expressed on a protein basis.

Photosynthetic Pigments: 0.25 g from young and full-developed leaves were homogenized with 5ml of acetone (80 %) using pestle and mortar and centrifuged at 3,000 rpm. The absorbance of supernatant was measured with using the equations proposed by Lichtenthaler and Wellburn [21] given below.

Chlorophyll a (μ g /ml) =12.21(A_{663}) - 2.81 (A_{646}).
Chlorophyll b (μ g /ml) = 20.13(A_{646}) - 5.03(A_{663}).
Carotenoids (μ g /ml) = (1000A_{470}-3.27[chl a] - 104[chl b]) /227

Pot Experiment: Hundred seeds from each treatment were grown in pots of 40 cm in diameter and four replications. Bots were arranged in a split plot design, whereas salicylic acid levels in main plots and the intervals were allocated in sub plots. Shoot length and fresh seedling weight were measured after 7, 10, 14, 21, 28, 35 or 45 days from sowing.

While leaf area (LA) was determined after 14, 21, 28, 35 and 45 days from sowing using a leaf area meter.

Field Experiment: Two field experiments were conducted at the Giza Agric. Res. Station, ARC, Egypt, during 2012 and 2013 summer seasons. The soil texture of the experimental site was clay loam and their physical and chemical analyses shown in Table (1) were determined according to Page *et al*. [22].

The preceding crop was faba bean in both seasons. The experiments were laid out in a randomized complete block design with four replications during both seasons. The plot size was 10.5 m^2 consisted of five ridges 3.5 m long and 60 cm wide. Seeds were planted on May 19th and 23th in the first and second season, respectively,

Table 1: Physical and chemical properties of the used soil (average of the two seasons).

Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture	O.M (%)	$CaCO_3$(%)		
7.81	19.32	41.99	30.88	Clay loam	0.67	1.95		
		Soluble cations (meq L^{-1})				Soluble anions (meq L^{-1})		
pH (1:2:5)	EC (dS/m)	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO^{-}_3	Cl^{-}	$SO^{=}_4$
7.73	1.12	4.22	2.88	3.00	1.19	3.28	4.33	3.68
Available macronutrients (ppm)			Available micronutrients (ppm)					
N	P	K	Fe	Mn	Zn	Cu		
46.65	10.85	371.50	6.80	3.35	1.31	0.79		

in hills spaced 25 cm at one side of ridge. A local teosinte variety was used for the study. After complete emergence, hills were thinned to one plant hill^{-1}.The experimental sit was 22.5 kg P_2O_5 fed^{-1} at time of sowing. Nitrogen fertilizer (at a rate of 120 kg N fed^{-1}) was added at three equal doses in form of urea (46.5 % N). Also, the experimental sit was received 25 kg K_2O fed^{-1} added at three equal doses. The first dose for nitrogen and potassium fertilizers was added after 21 days from sowing, the second and the third doses were added after the first and the second cuts, respectively. Recommended cultural practices for teosinte production were followed. Three cuts were taken during each growing season. The first cut was taken after sixty days from sowing and, the other two cuts were taken subsequently every thirty days. Fresh and dry forage yield (ton fed^{-1}), plant height (cm), number of tillers plant^{-1}, number of leaves plant^{-1} and fresh and dry leaf / stem ratio (%) were measured.

Data were statistically analyzed according to procedures outlined by Steel *et al*. [23] using MSTAT computer program V. 4 [24]. Bartlett's test was done to test the homogeneity of error variances. The test was non significant for all traits, thus combined analysis was carried out for all studied traits in both seasons.

RESULTS AND DISCUSSION

Laboratory Experiment: Data in Table 2 shows that speed germination percentage, germination percentage, shoot and radical length, fresh seedling weight and seedling vigor index (1) were high significantly affected by salicylic acid concentration while dry seedling weight and seedling vigor index (2) were not significantly affected by treatments.

Results revealed that different levels of salicylic acid concentrations significantly effect on germination percentage, germination speed percentage, shoot and radical length, fresh seedling weight and seedling vigor index (1), while dry seedling weight and seedling vigor index (2) were not significantly affected. For initial emergence, the seed priming with 0.4 g L^{-1} and 0.6 g L^{-1} had early initial emergence (3-days). Masoud [25] indicated that hormonal priming, especially with 2 mM salicylic acid can be a good treatment for corn (*Zea mays* L.var SC.704) to enhance uniformity to emergence and seedling establishment under normal as well as saline conditions and it was concluded that seed priming had reduced the severity of the effect of salinity. Jadhav and Bhamburdekar [26] reported that pre-treatment of seeds

Table 2: Mean performance of seedling characters of teosinte priming in salicylic acid concentrations (combined across 2012 and 2013 seasons.)

Salicylic acid concentrations	Initial emergence	Speed germination %	Germination (%)	Shoot length (cm)	Radical length (cm)	Fresh seedling weight (g)	Dry seedling weight (g)	Seedling vigor index (1)	Seedling vigor index (2)
0.4 g L^{-1}	3-days	81.0	82.0	25.28	6.69	0.84	0.10	2637.67	8.18
0.6 g L^{-1}	3-days	85.0	88.0	28.52	5.59	0.95	0.12	2920.00	9.80
0.8 g L^{-1}	4-days	79.0	76.0	20.76	5.26	0.62	0.09	2012.30	5.01
1.0 g L^{-1}	4-days	75.0	73.0	24.10	4.76	0.80	0.10	2044.33	7.16
1.2 g L^{-1}	4-days	70.0	69.0	18.52	4.51	0.52	0.08	1585.33	5.00
Control	7-days	66.0	64.0	16.60	4.20	0.43	0.05	1294.67	4.80
Mean	----	76.00	75.33	22.30	5.17	0.69	0.09	2082.38	6.66
L.S.D at 0.05	-----	1.72	3.59	0.28	0.08	0.04	n.s	50.85	n.s

Table 3: Effect of priming in salicylic acid on chlorophyll a and b, carotenoids, catalase (CAT) and peroxidase (POD) in teosinte (combined across 2012 and 2013 seasons)

Salicylic acid concentrations	Chl a (mg 100 m L^{-1})	Chl b (mg 100 mL^{-1})	Carotenoids (mg 100 mL^{-1})	CAT	POD
0.4 g L^{-1}	3.97	2.70	0.06	0.57	0.62
0.6 g L^{-1}	3.30	2.50	0.09	0.79	0.54
0.8 g L^{-1}	4.10	3.00	0.07	0.75	0.69
1.0 g L^{-1}	4.40	3.20	0.06	0.80	0.72
1.2 g L^{-1}	4.80	3.40	0.05	0.83	0.71
Control	2.20	1.90	0.06	0.36	0.30
Mean	3.79	2.68	0.07	0.68	0.60
L.S.D at 0.05	0.10	0.15	0.02	0.06	0.05

with salicylic acid increased germination and emergence of seeds. A low level concentration of salicylic acid gave a higher speed germination (85% under 0.6 g L^{-1}) followed by 81 % under 0.4 g L^{-1}. In addition to that, application of 0.8 g L^{-1}, 1.0 g L^{-1} and 1.2 g L^{-1} gave seed initial emergence after 4-days and the germination speed were 79.0,75.0 and 70.0%, respectively, as compared with control of 7-days emergence and germination speed of 66.0%. The improved seedling emergence in treated seeds with H_2O_2, ASA and SA may be attributed induction of physiological processes like hydrolysis, imbibitions, enzyme activation and protrusion which trigged of germination speed and germination percentage; early emergence reduced by various priming strategies under stressful conditions of low temperature was due to enhanced pre-emergence metabolic activities during priming and results in triggering emergence [27]. Results of mean comparison indicated that seed priming with low concentration of salicylic acid gave the highest values of characters. SA and ASA induced the emergence in low concentration, highest shoot length was 5.88 cm for ppm SA and the lowest length was 2.05 cm that attributed to ASA treatment [28].

Seed imbibitions with SA leads to an activation of germination and seedling growth [29]. Seed priming with 0.6 g L^{-1} salicylic acid concentration had the highest final germination (88%), seedling vigor index (1) (2920.00) and maximum shoot length (28.52 cm,) fresh seedling weight (0.95 g) compared to control (66%, 1294.67, 16.60 cm and 0.43g), respectively. Seed priming with salicylic acid improved final germination count and decreased electrolyte leakage [30]. Tabatabaei [31] found that highest germination percentage (83.3%), normal seedling percentage (69.67), germination index (25.29) and minimum means of time to germination (2.87 days) were attained from priming with salicylic acid in control conditions followed by 82% germination, 2637.67 seedling vigor index (1), 25.28 cm shoot length and 0.84g fresh seedling weight, respectively, under 0.4 g L^{-1} salicylic acid application. The increased emergence percentage in seeds primed with salicylic acid may be due to enhanced oxygen uptake and the efficiency of mobilizing nutrient from the cotyledons to the embryonic axis [32]. SA significantly by stimulated the activities of enzyme involved in germination such as transkelolase, enolase, malate dehydrogenase, phospoglycerate kinase, glyceraldehyde 3-phosphate, dehydrogenase, fructose 1,6 diphosphatase and pyruvate decarboxylase. In addition, seeds germinated in SA supplemented media showed abundant levels of isocratic lyase and malate syntheses, key enzyme of glyoxylate cycle [33]. In addition, application of 0.4 g L^{-1} salicylic acid concentration on seed had maximum radical length (6.69 cm) followed by 5.59 cm under 0.6 g L^{-1} salicylic acid compared to control of 4.20 cm. The improvement in root length of maize might be due to up-regulating cell number of size by salicylic acid [34]. Bulks of research studies have shown that salicylic acid enhances growth in shoot and root and production of biomass in different plant species and under various environmental stress [35]. In addition, application of a high concentration (1.2 g L^{-1}) of salicylic acid decreased germination percentage to 69%, seedling vigor index (1) to 1585.33, shoot length to 18.52 cm and fresh seedling weight to 0.52 g, respectively. Sharafizad *et al*. [36] reported that after the control treatment (priming with distilled water), gave the highest percentage of germination was for low concentration of SA and germination percentage decreased with increasing concentration of SA. Several works reported that stimulating effect of SA on germination are concentration dependent [33].

Chlorophyll a and B Carotenoids and Enzyme Activity: Data in Table 3 revealed that chlorophyll a and b and enzyme activity (catalase and peroxidase) were high significantly affected by treatments.

Results in Table (3) show that seed priming with the concentration of 1.2 g L^{-1} salicylic acid increased chlorophyll a to 4.80 and b to 3.40 followed by (4.40 and 3.20) under 1.0 g L^{-1} application concentration, respectively, compared to control of 2.20 and 1.90. Zhou *et al*. [37] reported that photosynthetic pigments were increased in corn with SA application. In bean plants, foliar spray with salicylic acid, increased Chl a, b and carotenoids under normal field conditions [38]. Khan *et al*. [39] showed that SA increased photosynthetic rate in corn and soybean. In addition, the concentration of 0.4 g L^{-1} salicylic acid decreased Chl a and b; the values were 3.30 and 2.50, respectively. While carotenoids increased under the concentration of 0.06 g L^{-1} salicylic acid (0.09) followed by 0.08 g L^{-1} (0.07), respectively, compared to control (0. 06). Mohammed *et al*. [40] reported that salicylic acid treatments increased carotenoids content of the plants.

Catalase (CAT): Data pertaining CAT activity in teosinte are shown in Table (3). Maximum and statistically similar CAT activity of 0.83 units mg $^{-1}$ of protein were observed when teosinte seeds were primed with 1.2 g L^{-1} SA followed by 0.80and 0.79 units mg $^{-1}$ protein under 1.0 and 0.6 g L^{-1} SA concentration, respectively, compared with control of 0.36 units mg^{-1} of protein. The priming strategies enhanced activity of free radical scavenging enzymes such as CAT and POD [41]. Several endogenous defense mechanisms, both enzyme like POD and CAT and non enzymatic that quench these oxygen radicals and protect membranes from injurious [16].

Peroxidase (POD): Data revealed that seed priming induced significantly POD activity. Maximum POD activity of 0.72 units mg^{-1} of protein were observed when seeds were primed with 1.0 g L^{-1} SA, followed by 0.71 and 0.69 units mg^{-1} of protein under 1.2 g L^{-1} and 0.8 g L^{-1} SA application, respectively compared with control of 0.30 units mg $^{-1}$ of protein.

Pot Experiment

Effect of Salicylic Acid Concentrations on Shoot Length

Seedling: Figures 1 to 7 showed relationship between salicylic acid and intervals of seedling stage (7, 10, 14, 21, 28, 35 and 45 days). The highest shoot length was 6.73, 28.52, 47.00, 66.00, 86.67, 97.67 and 105.00 cm under 0.6 g L^{-1} salicylic acid concentration in Figures 1 to 7 respectively, followed by 6.33, 25.58, 45.67, 55.00, 80.67, 95.33 and 100.00 cm under 0.4 g L^{-1} salicylic acid in Figures 1 to 7, respectively compared to control

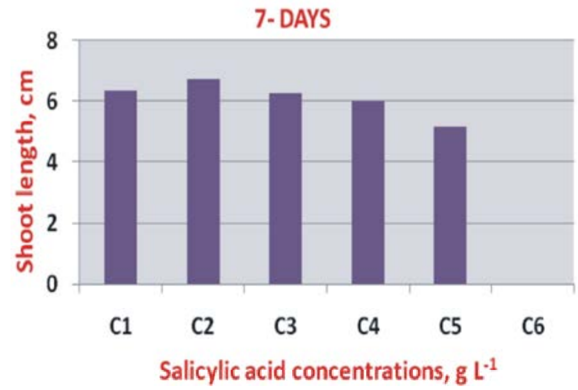

Fig. 1: Relationship between shoot length and salicylic acid concentrations at seedling stage (7 days from sowing)

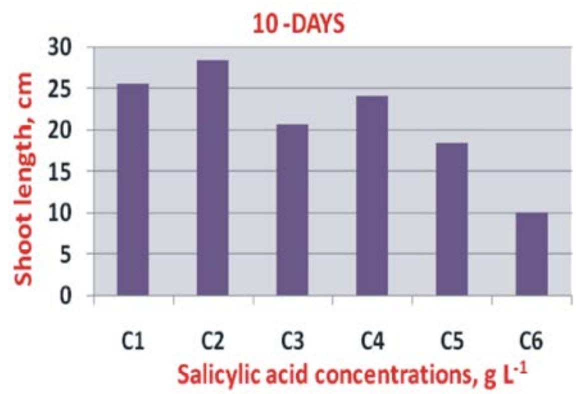

Fig. 2: Relationship between shoot length and salicylic acid concentrations at seedling stage (10 days from sowing)

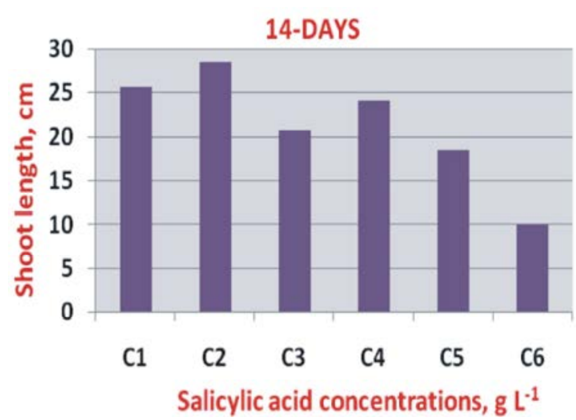

Fig. 3: Relationship between shoot length and salicylic acid concentrations at seedling stage (14 days from sowing)

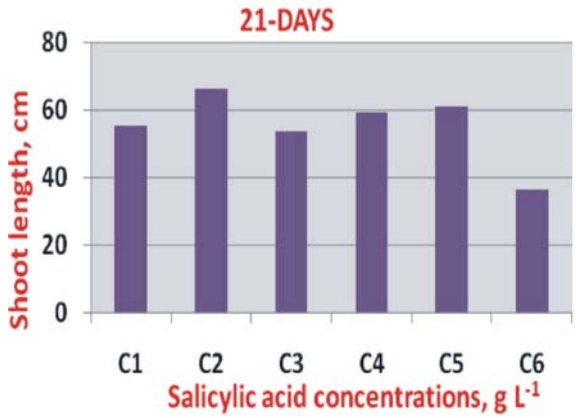

Fig. 4: Relationship between shoot length and salicylic acid concentrations at seedling stage (21 days from sowing)

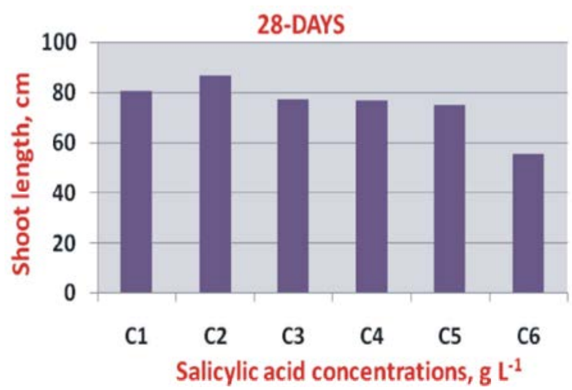

Fig. 5: Relationship between shoot length and salicylic acid concentrations at seedling stage (28 days from sowing)

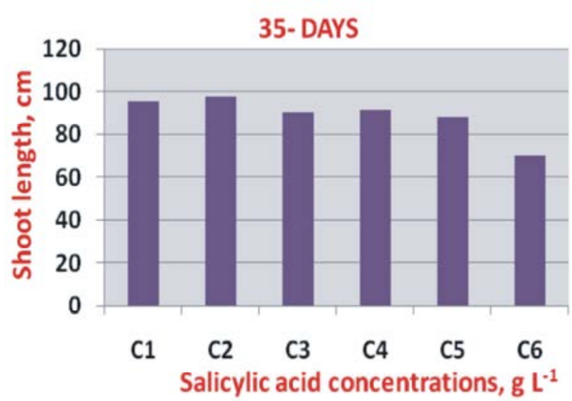

Fig. 6: Relationship between shoot length and salicylic acid concentrations at seedling stage (35 days from sowing)

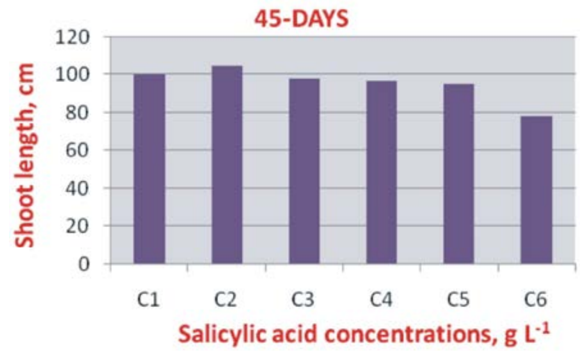

Fig. 7: Relationship between shoot length and salicylic acid concentrations at seedling stage (45 days from sowing)

(0.0, 1.00, 25.00, 36.33, 55.33, 70.00 and 78.00 cm) at the respective Figures. Airin and Mohammadi [28] reported that the highest shoot length was 5.88 cm for 50 ppm salicylic acid treatment. Salicylic acid enhances growth in shoot and root and production of biomass in different plant species and under various environmental stresses [35]. The maximum shoot length was recorded for intervals 28, 35 and 45 days from seedling stage.

Effect of Salicylic Acid Concentrations on Fresh Seedling Weight: Figures 8 - 14 showed relationship between fresh seedling weight and salicylic acid concentrations at intervals of seedling stage (7, 10, 14, 21, 28, 35 and 45 days). The highest fresh seedling weight in Figures 8 to 14 were 0.29, 0.96, 2.78, 9.45, 12.90, 17.10 and 37.60 g under 0.6 g L^{1} salicylic acid concentration respectively, followed by 0.27, 0.84, 2.32, 7.84, 11.66, 15.20 and 26.18 g) under 0.4 g L^{1} salicylic acid, respectively, compared to the control of 0.0, 0.19, 1.42, 2.90, 6.12, 10.65 and 16.00 g in the respective Figures. Boroumandjazi *et al*. [42] and Khodory [35] reported that SA increased the fresh and dry weight of shoot and root of salt stressed maize. SA application significantly increased plant fresh and dry weight [40].

Effect of Salicylic Acid Concentrations on Leaf Area Seedling: Figure 15 showed relationship between leaf area and salicylic acid concentrations at intervals of seedling stage (14, 21, 28, 35 and 45 days). The highest leaf area in Figure 15 was 47.00, 65.33, 108.33, 145.76 and 172.33 cm under 0.6 g L^{-1} salicylic acid concentration, compared to control (1.00, 36.33, 50.00, 75.67 and 79.67 cm), respectively. Zamaninejad *et al.* [43] and Fahraji *et al*. [10] reported that application of salicylic acid increased leaf area compared to control treatments under drought stress.

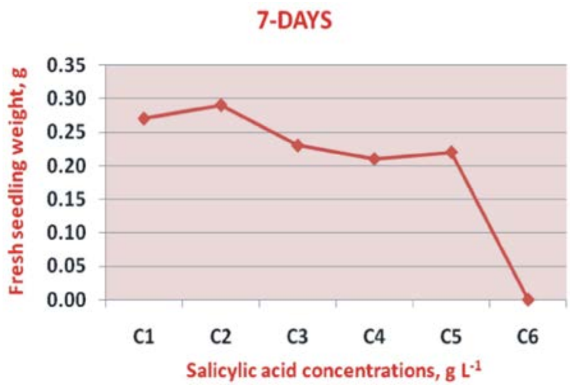

Fig. 8: Relationship between fresh seedling weight and salicylic acid concentrations at seedling stage (7 days from sowing)

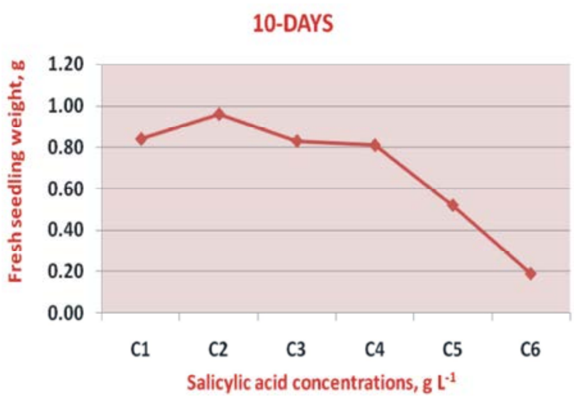

Fig. 9: Relationship between fresh seedling weight and salicylic acid concentrations at seedling stage (10 days from sowing)

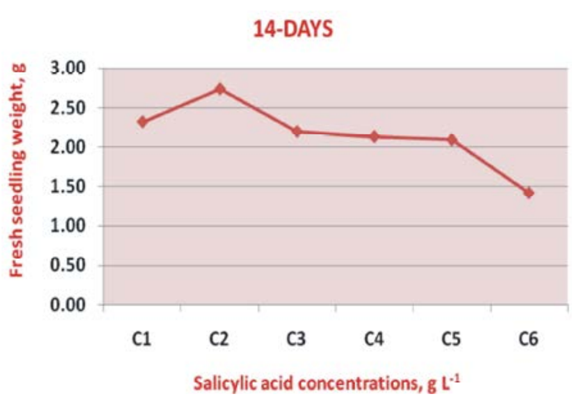

Fig. 10: Relationship between fresh seedling weight and salicylic acid concentrations at seedling stage (14 days from sowing)

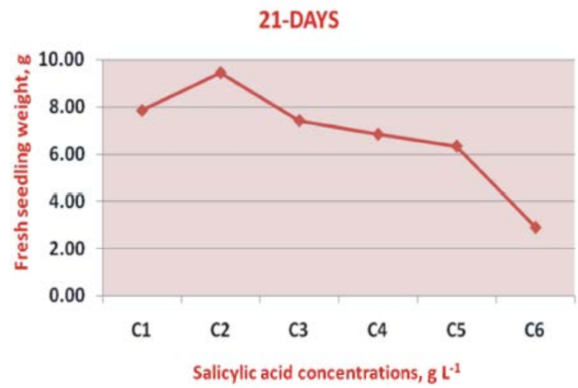

Fig. 11: Relationship between fresh seedling weight and salicylic acid concentrations at seedling stage (21 days from sowing)

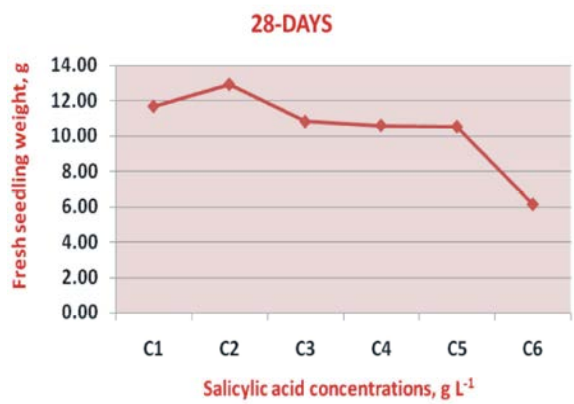

Fig. 12: Relationship between fresh seedling weight and salicylic acid concentrations at seedling stage (28 days from sowing)

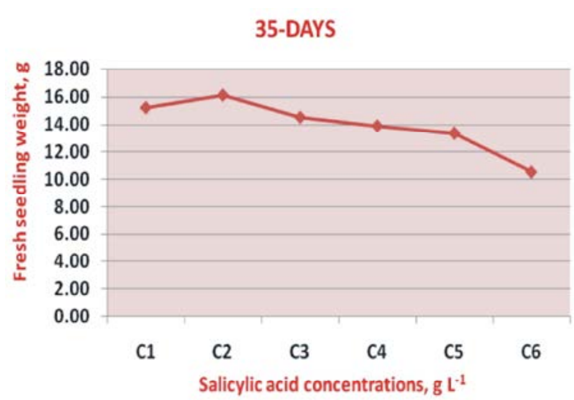

Fig. 13: Relationship between fresh seedling weight and salicylic acid concentrations at seedling stage (35 days from sowing)

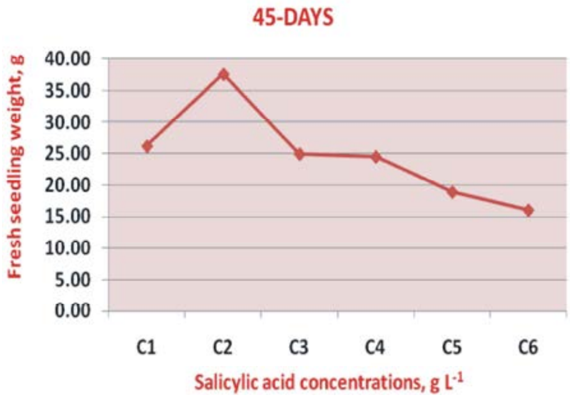

Fig. 14: Relationship between fresh seedling weight and salicylic acid concentrations at seedling stage (45 days from sowing)

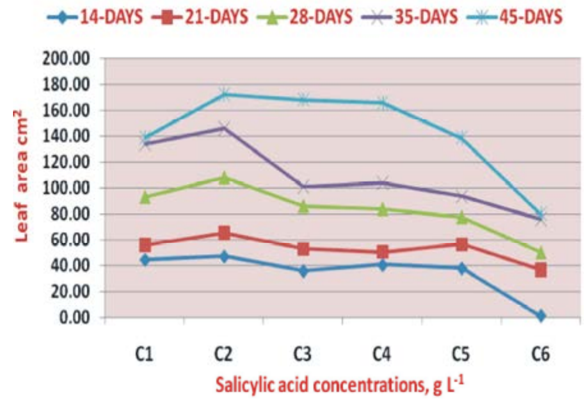

Fig. 15: Relationship between leaf area and salicylic acid concentrations at intervals (14, 21, 28, 35 and 45 days from sowing)

Table 4: Means of total fresh and dry forage yield, plant height, number of tillers and leaves, stem diameter and leaf stem ratio of teosinte under different salicylic acid concentrations across two years

					leaf/stem ratio (%)			
Salicylic acid concentrations	Plant height (cm)	Number of tillers plant^{-1}	Number of leaves plant^{-1}	Stem diameter (cm)	Fresh	dry	Fresh forage yield (ton fed^{-1})	Dry forage yield (ton fed^{-1})
0.4 g L^{-1}	109.56	11.21	9.23	1.72	72.47	109.54	24.91	4.69
0.6 g L^{-1}	120.86	14.22	10.16	1.93	68.36	103.33	25.88	5.15
0.8 g L^{-1}	102.37	10.23	8.45	1.56	75.36	113.91	24.20	4.49
1.0 g L^{-1}	104.06	10.56	8.67	1.60	73.96	111.80	24.32	4.54
1.2 g L^{-1}	98.36	8.50	8.24	1.43	76.46	115.58	24.03	4.45
Control	93.76	7.19	7.9	1.21	78.83	119.16	23.20	4.17
Mean	104.83	10.32	8.78	1.58	74.24	112.22	24.42	4.58
L.S.D at 0.05	1.79	0.97	0.33	0.11	1.49	2.88	0.46	0.18

Field Experiment: Data in Table (4) showed that all characters were significantly affected by SA concentrations.

The highest values of plant height (120.86 cm), number of tillers plant^{-1} (14.22), number of leaves (10.16), stem diameter (1.93 cm) and fresh and dry yield (25.88 and 5.15 ton fed^{-1}) were obtained when seeds of teosinte were primed at 0.6 g L^{-1} SA compared to control (93.76 cm, 7.19, 7.9, 1.21, 23.20 and 4.17 ton fed^{-1}) for the same characters, respectively. Singh and Usha [44] and Fahraji *et al*. [10] observed that application of salicylic acid increased the plant dry weight. Liu *et al*. [45] found that salicylic acid increased plant length. Aldesuquy *et al.* [46] and Azimi *et al*. [47] found that application of salicylic acid increased tillers number under stress condition. This positive effect of SA may be related to increasing of CO_2 assimilation and photosynthetic rates and increasing of mineral uptake in stressed plant under SA application [48].

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