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Seed Osmo-priming in Chickpea Enhances Seed Quality and Crop Performance under Normal and Water Deficit Conditions

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ABSTRACT

Background: The average productivity of chickpea is quite low (939 kg/ha) because of several factors including its cultivation in rain fed/low moisture and marginal lands, low seed replacement rate (25.4%), use of old and low-quality seed by the majority of farmers. This in turn gives poor germination, delayed emergence and sick seedlings that lead to poor yield. Osmo priming of seed with different in-organic salts has been reported to improve the germination, speed of emergence, seedling vigour, growth and yield of different vegetable and field crops but information's on response of seed priming with in-organic salts on enhancement of seed quality parameters and crop performance of naturally aged seeds of chickpea is lacking over a wide range of environmental conditions including normal and water deficit conditions.

Methods: An experiment was conducted under laboratory as well as in plastic pots with 05 seed osmo- priming level, two varieties of chickpea (Ujjawal and JG-14) and two moisture level (Normal at field capacity and water deficit at half of the field capacity) during *rabi* season 2017-18 and 2018-19 at the Research farm of ICAR- IIPR, Kanpur (U.P.) to study the influence of seed osmo-priming with in-organic salts on seed quality parameters and crop performance under normal and water deficit conditions. The observations were recorded on seed quality, growth and crop efficiency parameters at their appropriate time.

Result: Osmo-priming of one-year-old chickpea seeds with KNO_3, $MgSO_4$, $Ca(NO_3)_2$ at 0.2% solution and tap water for 06 hours significantly enhanced the seed quality parameters in both the varieties evaluated under normal as well as under water deficit conditions over their respective control. Amongst, the priming agents used, KNO_3 performed better than $MgSO_4$, $Ca(NO_3)_2$ and tap water in respect of most of the seed quality parameters studied. Variety Ujjawal responded better the priming treatments than JG-14 under both normal and water deficit conditions. Osmo-priming treatments also showed the positive response in the enhancement of Nitrogen balance index (NBI), chlorophyll, Flavonols, Stomatal conductance, photosynthetic rate and transpiration rate in both the varieties evaluated under normal as well as water deficit condition.

Key words: Chickpea, Ca $(NO_3)_2$, Germination, JG-14 KNO_3, $MgSO_4$, Priming, Seeds, Ujjwal.

INTRODUCTION

Chickpea is one of the most important pulse crops cultivated in India occupying 88.25 lakh ha area and having 82.904 lakh tonnes production and 939 kg/ha productivity. The average productivity is quite low (939 kg/ha) because of several factors including its cultivation in rain fed/low moisture and marginal lands. Low Seed replacement rate (25.4%), use of old and low quality seed by the majority of farmers. This in turn gives poor germination, delayed emergence and sick seedlings that lead to poor yield.

In addition, age-induced seed deterioration of chickpea crops due to poor storage conditions is an inexorable phenomenon which gets in the way of successful chickpea production Seed priming is a powerful tool in which seed are soaked in water or an osmotic solution allows water imbibition's and permits early stages of germination but does not permit radical protrusion through seed coat (Heydecker *et al*., 1973). Priming with different in-organic salts including KNO_3 and $MgNO_3$ and $MgSO_4$ *etc.* has been reported to improve the germination, speed of emergence, seedling vigour, growth and yield of different vegetable and field crops *viz*, beet root, brinjal, cabbage, cauliflower, carrot, summer squash, tomato, water melon, hot pepper, tobacco, maize, mustard, okra 'ground nut, moong bean and pigeon pea by several workers Durran *et al.* (1983), Saxena and Singh (1987), Fujikera and Karseen (1992), Broklehurst and Dearman 1983, Mauromicale *et al.* (1994), Min Taigi (2001), Kundu and Basu (1981), Pandita *et al.* (2003). Misra and Sahoo (2003), Thakur and Thakur (2006). Dhedhi *et al.* (2006) and Tiwari *et al.* (2013, 2014 2018 and 2020). Considerable evidences exist that repair of proteins and enzymes occurs during imbibition of seeds (McDonalds, 2000). The information regarding the response of seed priming with in-organic salts on enhancement of seed quality parameters including germination, vigor, growth and crop efficiency of naturally aged seeds of chickpea is lacking over

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a wide range of environmental conditions including normal and water deficit conditions. In the light of above, to understand the response of seed priming with in-organic salts on seed quality parameters and crop performance under normal and water deficit conditions in chickpea, the present research wok was formulated.

MATERIALS AND METHODS

Experiments were conducted under laboratory as well as in plastic pots of 10 kg capacity with 05 seed osmo- priming level, two varieties of chickpea (Ujjawal and JG-14) and two moisture level (Normal at field capacity and water deficit at half of the field capacity) under complete randomized design (CRD) with four replications during *rabi* season 2017-18 and 2018-19 at the Research farm of ICAR- IIPR main campus Kanpur to study the influence of seed osmo-prming with in-organic salts on seed quality parameters and crop performance under normal and water deficit conditions. Recommended doses of fertilizers (NPK) and cultural practices were applied and moisture level were maintained by regulating the quantity of irrigation water in allocated normal and water deficit pots. Observations were recorded on seed quality parameters as per ISTA procedure as described below.

Laboratory experiments (Seedling studies)

Total 1000 seeds were taken for each variety of Chickpea for germination using between of the paper method as described by ISTA procedures (Anonymous, 1999). After sowing, the germination count was started just after one day and counted up to seventh day and the germination was recorded by counting total number of seeds germinated in each treatment and percent germination was expressed on normal seedling basis. Root length was measured from the collar region to the tip of the primary root and mean was calculated and expressed in centimeters similarly shoot length was measured from collar region to the base of uppermost leaf and mean was calculated and expressed in centimeters. The seedlings root + shoot length was expressed as seedling length and the same seedlings were used for estimating dry weight. Seedlings were dried in a hot air oven maintained at 70 ± 2°C for 24 h and after drying, the weight of 10 dry seedlings was recorded and the mean seedling dry weight was calculated and expressed in milligrams. Vigour of the seeds was assessed based on germination percentage, seedling length and seedling dry weight as suggested by Abdul-Baki and Anderson (1973) and expressed in whole number.

Seedling vigour index I = Germination (%) × Mean seedling length (cm)

Seedling vigour index II = Germination (%) × Mean seedling dry weight (mg)

Growth parameters including leaf area, plant height were measured at the termination of vegetative phase. Crop efficiency parameters *viz*: Nitrogen balance index (NBI), chlorophyll and flavonols were measured using Dualex-Force A Leaf Clip Sensor(France), Photosynthetic rate, Stomatal conductance and transpiration rate were measured at pod formation stage using IRGA-Portable Photosynthesis measurement system. LICOR-6400(USA) in between 11.0 AM to 2.00 PM during clear sky. Data collected were statistically analyzed using SAS soft ware.

RESULTS AND DISCUSSION

Osmo-priming of one-year-old chickpea seeds with KNO_3 $MgSO_4$, $Ca(NO_3)_2$ at 0.2 % solution and tap water for 06 hours separately significantly enhanced the germination (%), seedling length, seedling dry weight and vigour index I and II in both the varieties evaluated under normal as well as under water deficit conditions over their respective control (Table 1A-E). Maximum germination followed by seedling length, seedling dry weight and finally vigour index I and II was recorded with KNO_3 priming in both the varieties under normal as well as drought conditions. Amongst, the priming agents used, KNO_3 performed better than $MgSO_4$, $Ca(NO_3)_2$ and tap water in respect of most of the seed quality parameters. Per cent improvement due to osmo-priming over their respective control was higher in water deficit condition than normal moisture in all the seed quality parameters in general and reflected finally in vigour Index-I and Vigour Index-II (Fig 1 and 2) indicating thereby the role of osmo-priming under limiting environment. Similar findings have also been reported by Sathyamoorthy and Nakaumura (1995) in potato, Afzal *et al*. (2002) in maize, Yoganada *et al*. (2004) in bell papper, Satishkumar (2005) in brinjal, Poonam Singh *et al.* (2006) in sunflower, Tiwari *et al.* (2013) in mung bean, Tiwari *et al.* (2014) in pigeon pea, Tiwari *et al.* (2015) in rice, Tiwari *et al.* (2015) in mung bean and Tiwari *et al.* (2016) in wheat and Tiwari *et al.* (2018, 2019 and 2020) in pigeon pea have explained that osmo- priming with various chemicals to seeds eventually enhances rate of seed germination and encourages fast emergence of seedling in the field and this might have led to an improvement in subsequent phases of plant growth and ultimately to higher yield of crop. This is well known that during soaking of seed in KNO_3 Mg SO_4 or $Ca(NO_3)_2$ solution the cations Ca^{++}, Mg^{++} or K^+ and anions SO_4-, or NO_3 in fluxed in the seeds and showed their carry over effect during vegetative growth period. Both the varieties responded priming treatments under both normal and water deficit conditions. Seed priming with different in-organic salts and plant growth regulator GA_3 in pigeon pea crop have also been reported to improve the seed germination and seedling growth due to their nutritive role in the germination process by Tiwari *et al.* (2019) and Tiwari and Agarwal (2021). Significant effects of osmo priming with PEG-6000 were also noted on germination and crop performance of sun flower by Bourioug *et al.* (2020). Our finding with respect to response of seed priming with in- organic salts are very similar with findings of other workers in the field.

Seed priming with in-organic salts showed a slight improvement in plant height and leaf area over their

Table 1: Influence of seed osmo-priming on Seed quality parameters.

Treatments	Normal			Drought			Average
of priming	V1	V2	Mean	V1	V2	Mean	
				A- Germination (%)			
Control	43.30	53.30	48.30	36.60	53.30	44.95	46.62
Tap water	60.00	66.00	63.00	56.60	66.60	61.60	62.30
KNO_3 (0.2%)	73.30	83.30	78.30	70.00	73.33	71.66	74.98
$MgSO_4$ (0.2%)	73.30	80.00	76.65	63.30	70.00	66.65	71.65
$Ca(NO_3)_2$ (0.2%)	66.60	70.33	68.46	63.30	70.00	66.65	67.55
Mean	63.30	70.58		57.96	66.64		
C.V.	10.90			V×T-0.82			
LSD at 5%	V-0.36			V×M-0.52			
	T-0.58			T×M-0.82			
	M-0.36			V×T×M-NS			
				B- Seedling length (cm.)			
Control	11.64	14.19	12.91	7.93	12.83	10.38	11.64
Tap water	13.28	13.92	13.60	11.90	12.63	12.26	12.93
KNO_3 (0.2%)	16.18	15.97	16.07	14.90	15.06	14.98	15.52
$MgSO_4$ (0.2%)	13.91	16.45	15.18	13.53	15.50	14.51	14.84
$Ca(NO_3)_2$ (0.2%)	13.60	14.52	14.06	13.00	13.90	13.45	13.75
Mean	13.82	15.01		12.25	13.98		
C.V	4.07			V×T-NS			
LSD at 5%	V-1.70			V×M-NS			
	T-1.76			T×M-NS			
	M-1.70			V×T×M-NS			
				C- Seedling dry weight (g.)			
Control	1.121	1.676	1.398	1.020	1.460	1.240	1.319
Tap water	1.255	1.750	1.502	1.127	1.420	1.273	1.387
KNO_3 (0.2%)	1.810	2.210	2.010	1.612	2.112	1.862	1.936
$MgSO_4$ (0.2%)	1.464	2.014	1.739	1.340	1.900	1.620	1.679
$Ca(NO_3)_2$ (0.2%)	1.420	1.999	1.709	1.289	1.785	1.537	1.623
Mean	1.414	1.929		1.277	1.735		
C.V	4.212			V×T-NS			
LSD at 5%	V-0.114			V×M-NS			
	T-0.297			T×M-NS			
	M-0.114			V×T×M-NS			
				D- Vigour index-I			
Control	504.41	756.33	630.37	290.24	683.84	487.04	558.70
Tap water	796.80	927.07	861.93	673.54	841.16	757.35	809.64
KNO_3 (0.2%)	1185.99	1330.30	1258.14	1043.00	1103.90	1073.45	1165.79
$MgSO_4$ (0.2%)	1019.60	1316.80	1168.20	856.45	1085.00	970.72	1069.46
$Ca(NO_3)_2$ (0.2%)	905.76	1064.32	985.04	822.90	973.00	897.95	941.49
Mean	882.51	1078.96		737.22	937.38		
				E- Vigour index-II			
Control	48.54	89.33	68.93	37.33	77.82	57.57	63.25
Tap water	75.30	116.55	95.92	63.78	94.57	79.17	87.54
KNO_3 (0.2%)	132.67	184.09	158.38	112.84	154.81	133.82	146.10
$MgSO_4$ (0.2%)	107.31	161.12	134.21	84.82	133.00	108.91	121.56
$Ca(NO_3)_2$ (0.2%)	94.57	146.53	120.55	81.60	124.95	103.27	111.91
Mean	91.67	139.52		76.07	117.03		

respective unprimed control (Table 2A and B) under both normal and water deficit condition but statistically the improvements were insignificant though improvement in growth characters including leaf area index have been reported in late sown wheat by Jatana *et al*. (2020) using salicylic acid as priming agent. In the present study piming with tap water, KNO, Mg SO_4 and Ca (NO) in 0.2% solution did not improve the plant height and leaf area in varieties Ujjwal and JG-14 both under normal as well as drought condition. The moisture level also did not affect the plant height and leaf area in both the varieties evaluated. Interactions of V×T, V×M, T×M and V×T×M were not significant. Osmo-priming treatments showed the significant and positive response in improvement of biochemical parameters including nitrogen balance index(NBI). Chlorophyll and flavonol over unprimed control and tap water priming in both the varieties evaluated under both normal and water deficit conditions (Table 3 A, B and C). Highest values of nitrogen balance index and chlorophyll were noted with Mg SO_4 followed by KNO_3 and Ca $(NO_3)_2$ because of their nutritive role in the respective metabolic synthesis but flavonols were higher with KNO_3 followed by $MgSO_4$ and were relatively higher under drought condition might be due to more synthesis in the moisture stress condition. Chlorophylls are vital pigments that absorb a considerable amount of light energy and perform photosynthesis reactions

Table 2: Influence of seed osmo-priming on plant growth characters.

Treatments of priming	Normal			Drought			Average
	V1	V2	Mean	V1	V2	Mean	
			A- Plant height (cm.)				
Control	30.33	26.00	28.16	30.33	26.00	28.16	28.16
Tap water	30.33	26.66	28.49	31.00	27.00	29.00	28.74
KNO_3 (0.2%)	32.33	27.66	29.99	30.33	28.66	29.49	29.74
$MgSO_4$ (0.2%)	31.66	26.66	29.16	30.00	28.66	29.33	29.24
$Ca(NO_3)_2$ (0.2%)	33.33	25.66	29.49	30.66	26.66	28.66	29.07
Mean	31.59	26.52		30.46	27.39		
C.V	7.314			V×T-NS			
SE	V-NS			V×M-NS			
CD at 5%	T-NS			T×M-NS			
	M-NS			V×T×M-NS			
			B- Leaf area cm^2/plant				
Control	30.52	30.40	30.46	29.99	30.51	30.25	30.35
Tap water	30.36	30.47	30.41	31.16	30.97	31.06	30.73
KNO_3 (0.2%)	30.40	30.44	30.42	31.50	31.03	31.26	30.84
$MgSO_4$ (0.2%)	30.27	30.86	30.56	30.90	32.50	31.70	31.13
$Ca(NO_3)_2$ (0.2%)	30.99	31.37	31.18	32.21	31.31	31.76	31.47
Mean	30.50	30.70		31.15	31.26		
C.V	2.639			V×T-NS			
LSD at 5%	V-NS			V×M-NS			
	T-NS			T×M-NS			
	M-NS			V×T×M-NS			

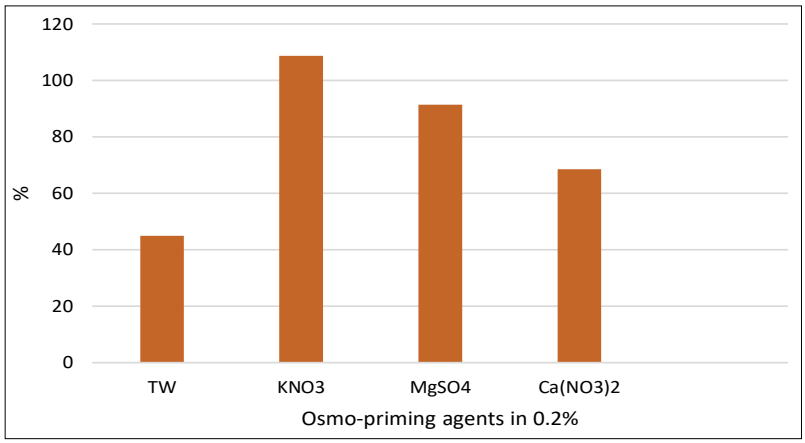

Fig 1: % improvement in Vigour Index-I through osmo-priming in chickpea.

in plant. Chlorophyll is very sensitive to various environmental stress, thus caused a significant reduction in chlorophyll contents and biosynthesis, thus effects plant growth (Demir and Mavi, 2004; Khan *et al.,* 2009; Shah *et al.,* 2012). In the present study seed priming significantly increased chlorophyll contents in chickpea seedlings. The results are in agreement with previous studies, who have reported that priming significantly enhanced chlorophyll contents in wheat leaves (Jiajin *et al.,* 2010; Rahimi, 2013; Siri *et al.,* 2013; Sharma *et al.,* 2014). Chlorophyll contents is an important parameter often used as an indicator for developments of chloroplast and photosynthetic capacity (Xia *et al.,* 2009; Anwar *et al*. (2020). Meena *et al*., 2016), thus considered as a base for plant growth and developmental process. These results suggested that seed priming enhanced chlorophyll contents thus leads to improve seedlings growth. Leaf nitrogen balance and chlorophyll have strong correlation and affects the photosynthetic capacity (Castro *et al.,* 2014), which is a key molecule for photosynthesis. In the present study, we have reported that seed priming enhanced nitrogen balance and chlorophyll accumulation in chickpea leaves but their utilization by the plant was affected with moisture stress and resulted in relative decrease in photosynthetic efficiency under drought conditions.

Osmo-priming treatments with different in-organic salts and tap water also showed the positive response in improvement of Stomatal conductance, photosynthetic rate and transpiration rate in both the varieties evaluated under normal as well as water deficit condition (Table 4 A, B and C). Amongst the in- organic salts used, KNO_3 and Ca (NO_3) were found more effective for enhancing the above parameters over the rest of the priming treatments and un primed control. Variety JG-14 showed higher values in the most of the parameters studied. In this study, Photosynthetic activities including photosynthetic rate, stomatal

Table 3: Influence of seed osmo- priming on biochemical characters.

Treatments of priming	Normal			Drought			Average
	V1	V2	Mean	V1	V2	Mean	
				A- Nitrogen balance index (NBI)			
Control	22.20	25.73	23.96	41.96	18.33	30.14	27.05
Tap water	24.86	27.53	26.19	42.23	19.20	30.71	28.45
KNO_3 (0.2%)	30.90	29.97	30.43	47.86	26.40	37.13	33.78
$MgSO_4$ (0.2%)	29.33	24.53	26.93	73.83	35.46	54.64	40.71
$Ca(NO_3)_2$ (0.2%)	41.17	14.30	27.73	48.60	19.33	33.96	30.84
Mean	29.63	24.41		50.89	23.74		
C.V	15.76			V×T-NS			
SE	V-4.70			V×M-NS			
CD at 1%	T-7.08			T×M-NS			
	M-4.70			V×T×M-NS			
				B- Chlorophyll			
Control	19.27	13.53	16.40	36.20	18.17	27.18	21.79
Tap water	23.36	29.47	26.41	36.33	24.00	30.16	28.28
KNO_3 (0.2%)	44.53	44.80	44.66	42.03	38.00	40.01	42.33
$MgSO_4$ (0.2%)	42.03	43.06	42.54	73.83	40.73	57.28	49.91
$Ca(NO_3)_2$ (0.2%)	32.73	31.50	32.11	37.33	28.17	32.75	32.43
Mean	32.38	32.47		45.14	29.81		
C.V	9.530			V×T-NS			
SE	V-2.80			V×M-NS			
CD at 1%	T-8.66			T×M-NS			
	M-2.80			V×T×M-NS			
				C- Flavonols			
Control	0.47	0.00	0.23	0.74	0.78	0.76	0.49
Tap water	0.78	0.51	0.64	0.76	1.13	0.94	0.79
KNO_3 (0.2%)	1.52	1.29	1.40	0.96	1.37	1.16	1.28
$MgSO_4$ (0.2%)	1.17	1.04	1.10	0.95	1.43	1.19	1.14
$Ca(NO_3)_2$ (0.2%)	1.02	0.87	0.94	0.89	1.28	1.08	1.01
Mean	0.99	0.74		0.86	1.20		
C.V	13.93			V×T-NS			
SE	V-0.29			V×M-NS			
CD at 1%	T-0.46			T×M-NS			
	M-0.29			V×T×M-NS			

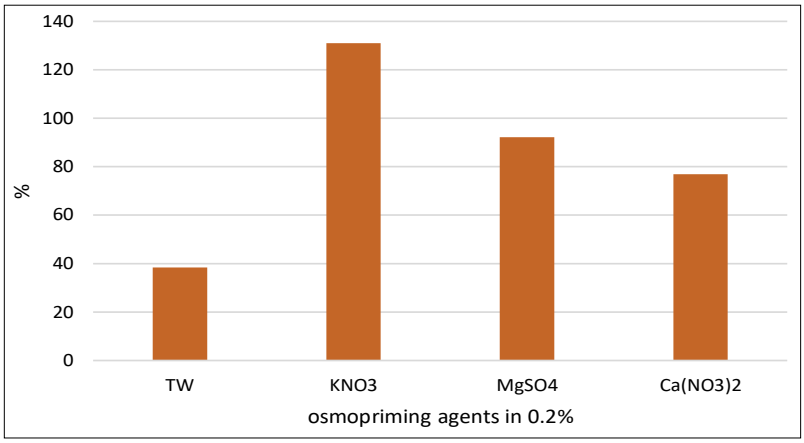

Fig 2: % improvement in vigour index-II over control through osmopriming in chickpea.

Table 4: Influence of seed osmo-priming on crop efficiency parameters.

Treatments of priming	Normal			Drought			Average
	V1	V2	Mean	V1	V2	Mean	
A- Stomatal conductance (mmol m^{-2} S^{-1})							
Control	0.017	0.001	0.009	0.017	0.019	0.018	0.013
Tap water	0.031	0.003	0.017	0.032	0.031	0.031	0.024
KNO_3 (0.2%)	0.094	0.149	0.121	0.102	0.040	0.071	0.096
$MgSO_4$ (0.2%)	0.038	0.069	0.053	0.025	0.021	0.023	0.038
$Ca(NO_3)_2$ (0.2%)	0.113	0.092	0.102	0.017	0.17	0.093	0.097
Mean	0.058	0.063		0.039	0.056		
C.V	2.0763			V×T-NS			
S.E.	V-0.044			V×M-NS			
LSD at 1%	T-0.070			T×M-NS			
	M-0.044			V×T×M-NS			
B- Photosynthetic rate (µmol CO_2 $m^{-2}S^{-1}$)							
Control	3.558	3.594	3.576	3.206	3.236	3.221	3.398
Tap water	7.978	8.410	8.194	7.892	7.870	7.881	8.037
KNO_3 (0.2%)	9.478	15.129	12.303	11.720	10.695	11.207	11.755
$MgSO_4$ (0.2%)	6.094	11.054	8.574	7.168	8.760	7.964	8.269
$Ca(NO_3)_2$ (0.2%)	11.702	12.932	12.317	7.318	10.940	9.129	10.723
Mean	7.028	9.36		7.460	8.300		
C.V	2.043				V×T-NS		
S.E.	V-2.94				V×M-NS		
LSD at 1%	T-4.65				T×M-NS		
	M-2.94				V×T×M-NS		
C- Transpiration rate (mmol $m^{-2}s^{-1}$)							
Control	0.458	0.023	0.240	0.392	0.589	0.490	0.365
Tap water	0.837	0.058	0.447	0.801	0.786	0.793	0.620
KNO_3 (0.2%)	2.360	3.634	2.997	2.335	1.063	1.699	2.348
$MgSO_4$ (0.2%)	0.944	1.730	1.337	0.686	0.656	0.671	1.004
$Ca(NO_3)_2$ (0.2%)	3.164	2.396	2.780	0.577	1.500	1.038	1.909
Mean	1.552	1.568		0.958	0.918		
C.V	1.572				V×T-NS		
S.E.	V-0.010				V×M-NS		
LSD at 1%	T-0.016				T×M-NS		
	M-0.010				V×T×M-NS		

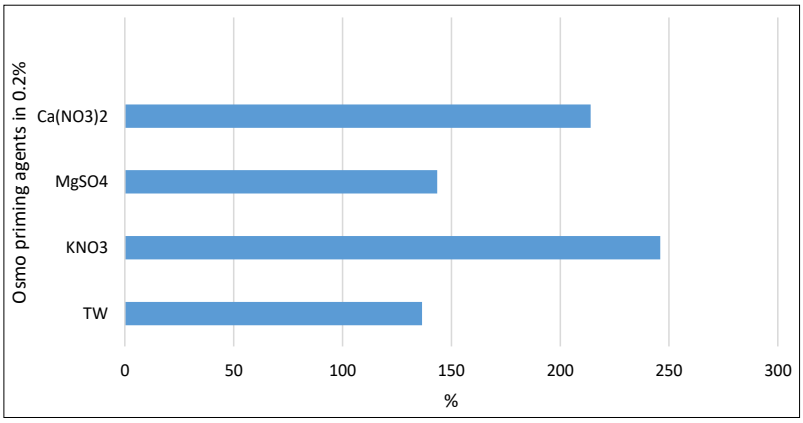

Fig 3: % improvement in photosynthetic rate over control through osmo priming in chickpea.

conductance and transpiration rate were significantly improved by seed priming in chickpea seedlings, as compared to un primed control (Fig 3). Chlorophylls accumulation are important parameter frequently used as an indicator of photosynthetic capacity, in the present study we reported that seed priming enhanced chlorophyll accumulation resulted a significant increment in photosynthetic capacity. These results are similar to those of earlier studies, which reported that seed priming with Salicylic acid and PEG enhanced photosynthesis in rice seedlings, Li and Zhang, (2010); Shaheen *et al.,* (2016) and Zhang *et al.* (2012), who had reported that photosynthesis capacity in cucumber plant were increased by seed priming and also increased photochemical efficiency of PS II. Seed priming enhanced significantly nutrients uptake and balancing of membrane potential and regulating of osmotic pressure cells (Chérel, 2004), thus it might be reasoning that seed priming regulate nitrogen balance, chlorophylls accumulation and there by photosynthetic efficiency and leads significant enhancement in chickpea seedlings growth.

Conflict of interest

All authors declared that there is no conflict of interest.

REFERENCES

Abdul-Baki, A.S. and Anderson, J.D. (1973). Vigour determination in soybean by multiple criteria. Crop Science. 13: 630-633.

Afzal, I., Basra, S.M.A., Nazir, A., Akhtar, Mumtaz, C., Warraichand Ahmad, E. and Khaliq Abdul (2002). Effect of priming and growth regulator treatments on emergence and seedling growth of hybrid maize (*Zea mays* L.). International Journal of Agriculture and Biology. 1560-8530/2002/04-2-303-306.

Anonymous (1999). International rules for seed testing. Seed Science and Technology. 27: 27-32.

Anwar Ali, Xianchang, Y.U. and Yansu, L.I. (2020). Seed priming as a promising technique to improve growth, chlorophyll, photosynthesis and nutrient contents in cucumber seedlings. Notulae Botanicae Horti Agrobotanici Cluj-Napoca. 48(1): 116-127. DOI: 10.15835/nbha48111806.

Bourioug, M., Ezzaza, K., Bouabid, R., Alaoui-Mhamdi, M., Bingau, S., Bourgeade, p., Alaoui-sosse, L., Alaoui-sosse B. and Aleya, L. (2020). Influence of hydro and osmo priming on sunflower seeds to break dormancy and improve crop performance under water stress. Environmental Science and Pollution Research. 27: 13215-13226.

Brocklehurst, P.A., Dearman, J. (1983). Interaction between seed priming treatments and nine seed lots of carrot, celery and onion II. Seedling emergence and plant growth. The Annals of Applied Biology. 102: 583-593.

Castro, F.A.D., Campostrini, E., Netto, A.T., Gomes, MDMDA, Ferraz, T.M., Glenn, D.M. (2014). Portable chlorophyll meter (PCM502) values are related to total chlorophyll concentration and photosynthetic capacity in papaya (*Carica papaya* L.). Theoretical and Experimental Plant Physiology. 26: 201-210.

Chérel, I. (2004). Regulation of K^+ channel activities in plants: from physiological to molecular aspects. Journal of Experimental Botany. 55: 337-351.

Demir, I. and Mavi, K. (2004). The effect of priming on seedling emergence of differentially matured watermelon Matsum and Nakai) seeds. Scientia Horticulturae. 102: 467-473.

Dhedhi, K.K. Dangaria, C.J. Parsana, G.J. and Joshi, A.K. (2006). Effect of pre sowing seed treatments for better crop establishment in summer groundnut. Seed Research. 34(2): 168-172.

Durran *et al.* (1983). Seed- A Global Perspective. [(Eds) G. Kalloo, S.K. Jain, Alice K. Vari and Umesh Srivastava. Indian Society of Seed Technology, New Delhi, 2006 edited by K. Vanangamudi and A. Bharathi. pp 194-212.

Fujikera and Karaseen. (1992). Seed- A Global Perspective. [(Eds) G. Kalloo, S.K. Jain, Alice K Vari and Umesh Srivastava. Indian Society of Seed Technology, New Delhi, 2006 edited by K. Vanangamudi and A. Bharathi. pp 194-212.

Heydecker, W., Higgins, J. and Gulliver, R.L. (1973). Accelerated germination by osmotic seed treatment. Nature. 246: 42-44.

Jatana, B.S., Ram, H. and Gupta, N. (2020). Application of seed and foliar priming strategies to improve the growth and productivity of late sown wheat (*Triticum aestivum* L.). Cereal Research Communications. 48 pages. 383-390.

Jiajin, Z., Weixiang, W., Yun, L., Wu, X., Wang, X. (2010). Osmopriming-regulated changes of plasma membrane composition and function were inhibited by phenylarsine oxide in soybean seeds. Journal of Integrative Plant Biology. 51: 858-867.

Khan, H.A., Ayub, C.M., Pervez, M.A., Bilal, R.M., Shahid, M.A., Ziaf, K. (2009). Effect of seed priming with NaCl on salinity tolerance of hot pepper (*Capsicum annuum* L.) at seedling stage. Soil and Environment. 28: 81-87.

Kundu, C. and Basu, R.N. (1981). Hydration-dehydration treatment of restored carrotseed for the maintenance of vigour, viability and productivity. Scientia Horticulturae.15 :117-125.

Li, X. and Zhang, L. (2010). SA and PEG-induced priming for water stress tolerance in rice seedling. In: Information Technology and Agricultural Engineering. Springer, Berlin, Heidelberg. pp 881-887.

Mauromicale, Giovanni and Ierna, Anita. (1995). Effects of gibberellic acid and sowing date on harvest time and yields of seed-grown globe artichoke (*Cynara scolymus* L). Agronomie. 15(9-10). http://dx.doi.org/10.1051/agro:19950902.15.10.1051/agro:19950902.

Mc Donald Miller, B. (2000). Principles of Seed Science and Technology (4th Ed) Publisher-Springer. pp 277.

Meena, S.K., Rakshit, A., Meena, V.S. (2016). Effect of seed bio-priming and N doses under varied soil type on nitrogen use efficiency (NUE) of wheat (*Triticum aestivum* L.) under greenhouse conditions. Bio-catalysis and Agricultural Biotechnology. 6: 68-75.

Min TaiGi (2001). Effects of storage temperature and humidity on germinability and longevity of primed tobacco seeds. Korean Journal of Crop Science. 46(4): 321-324.

Mishra, R.K. and Sahoo, N.C. (2003). Effect of chemical priming and ageing on seed vigour and viability and enzyme activity in tomato and cauliflower. Indian Journal of Plant Physiology (special issue). pp 222-225.

Pandita, V.K., Shantha, N., Sinha, J.P. and Modi, B.S. (2003). Physiological and biochemical changes induced by priming in tomato seed and its relation to germination and field emergence characteristics. Indian J. Plant Physiology (special issue). pp 249-254.

Rahimi, A. (2013). Seed priming improves the germination performance of cumin (*Cuminum syminum* L.) under temperature and water stress. Industrial Crops and Products. 42: 454-460.

Sathishkumar (2005). Influence of pre-sowing seed treatment and seed pelleting on storability in brinjal (*Solanum melongena* L.). M.Sc. (Agri.) Thesis, Univ. Agric. Sci., Dharwad.

Sathiyamoorthy, P. and Nakamura, S. (1995). Effect of gibberlic acid and inorganic salts on breaking dormancy and enhancing germination of true potato seed. Seed Res. 23(1): 5-7.

Saxena, M.C., Singh, K.B. (1987). The Chickpea Published by CAB. Int. ICARDA. pp 250-252.

Shah, H., Jalwat, T., Arif, M., Miraj, G. (2012). Seed priming improves early seedling growth and nutrient uptake in mungbean. Journal of Plant Nutrition. 35: 805-816.

Shaheen, H.L., Iqbal, M., Azeem, M., Shahbaz, M., Shehzadi, M. (2016). K-priming positively modulates growth and nutrient status of salt-stressed cotton (*Gossypium hirsutum*) seedlings. Archives of Agronomy and Soil Science. 62: 759-768.

Sharma, A.D., Rathore, S.V.S., Srinivasan, K., Tyagi, R.K. (2014). Comparison of various seed priming methods for seed germination, seedling vigour and fruit yield in okra [*Abelmoschus esculentus* (L.) Moench]. Scientia Horticulturae. 165: 75-81.

Singh, P., Singh, V., Maurya, C.L. Swarnakar, S.K. and Bajpai, V.P. (2006). Selection of suitable growth regulator and spacing for seed yield and quality of okra.cv KS404. Seed Research. 34(1): 61-65.

Siri, B., Vichitphan, K., Kaewnaree, P., Vichitphan, S., Klanrit, P. (2013). Improvement of quality, membrane integrity and antioxidant systems in sweet pepper (*Capsicum annuum* Linn.) seeds affected by osmopriming. Australian Journal of Crop Science. 7(3): 2068.

Thakur, A.S. and Thakur, P.S. (2006). Effect of pre-sowing treatments on germination and seedling vigour in *Dioscorea deltoida*. Seed Research. 34(2): 162-167.

Tiwari, T.N., Diptikamal, Singh, R.K. and Prasad, S.R. (2015). Plant growth regulators priming enhances seed quality and enzyme activity in mungbean (*Vigna radiata* L). Ann. Agricalture Research New Series. 36(4): 1-8.

Tiwari, T.N. and Agarwal, D.K. (2021). Seed priming influences the seed quality and activities of nitrate assimilation and anti-oxidant enzymes in pigeon pea seedlings. Legume Research- An International Journal. 44(11): 1362-1370. doi: 10.18805/LR-4236.

Tiwari, T.N., Dipti, K., Sinha, A.K. and Singh, R.K. (2016). Relative performance of seed priming with tap water and inorganic salts on germination, invigoration, growth and yield of wheat (*Triticum aestivum* L.). International Journal of Agricultural Sciences. 12(2): 167-175.

Tiwari, T.N., Dipti, K., Singh, R.K. and Prasad, S.R. (2014). Relative efficacy of seed priming with potassium nitrate and tap water in relation to germination, invigoration, growth, nitrate assimilation and yield of pigeon pea (*Cajanus cajan* L). Annals of Agriculture Research. 35(2): 368-371.

Tiwari, T.N., Dipti, K., Kumar, V., Chaturvedi, A.K. and Prasad, S.R. (2013). Relative efficacy of in-organic salt as priming agent on germination, vigour, nitrate assimilation and yield in mung bean. Seed Research. 41(2): 180-189.

Tiwari, T.N., Upadhyay, N. and Prasad, S.R. (2018). Enhancement of seed quality through seed priming in pigeon pea. Journal of Food Legumes. 31(2): 88-92.

Tiwari, T.N., Prasad, S.R. and Agarwal, D.K. (2019). Seed priming improves crop growth and yield performance in pigeon pea (*Cajanus cajan* L.). Journal of Food Legumes. 32(1): 9-12.

Xia, X.J., Huang, L.F., Zhou, Y.H., Mao, W.H., Shi, K., Wu, J.X., Yu, J.Q. (2009). Brassinosteroids promote photosynthesis and growth by enhancing activation of Rubisco and expression of photosynthetic genes in *Cucumis sativus*. Planta. 230: 1185.

Yogananda, D.K., Vyakarnahal, B.S. and Shekhargouda, M. (2004). Effect of seed invigoration with growth regulations and micronutrients on germination and seedling vigour of bell pepper cv. California Wonder. Karnataka J. Agric. Sci. 17(4): 811-813.

Zhang, L., Meng, X.X., Liu, N., Yang, J.H., Zhang, M.F. (2012). Effects of grafting on phosphorus uptake and utilization of watermelon at early stage under low phosphorus stress. Journal of Fruit Science. 29(1): 120-124.