Osmopriming with Polyethylene Glycol (PEG-6000) improves the action of seed germination, growth, and physiology in carrot

ABSTRACT

In order to improve germination and vigour, the current study was conducted using three carrot varieties viz. Carrot Florence (G_1), Deb Kuroda-1 (G_2), and Deb Kuroda-3 (G_3), and various concentrations and durations of PEG-6000, including 0.1 MPa for 24 hours (T_2), 0.1 MPa for 48 hours (T_3), 0.25 MPa for 24 hours(T_4), 0.25 MPa for 48 hours (T_5), 0.40 MPa for 24 hours (T_6), and 0.40 MPa for 48 hours (T_7), non-primed seeds (T_1). A pre-sowing technique called seed priming produces a physiological environment that promotes more efficient seed germination. The experiment was carried out in the Department of Seed Science and Technology's seed testing lab at the BCKV, Mohanpur, Nadia, West Bengal, India. According to the experiment's results, seeds treated with 0.25 MPa PEG-6000 soaking for 48 hours produced the best results among treatments over genotype; these seeds showed notably greater potential than seeds treated with other priming concentrations and durations. Deb Kuroda-3 is the best from a germination perspective, and Deb Kuroda-1 is the best from a vigour perspective. The best results were clearly obtained with a 0.25 MPa PEG-6000 soaking duration of 48 hours for seed quality parameters like germination energy (47.273), seedling Vigour Index-I (639.032), and germination index (5.503). Therefore, to improve seedling establishment, PEG-6000 0.25 Mpa pre-sowing treatment for 48 hours is recommended for carrot.

Keywords: *Germination, PEG-6000, priming, vigour.*

INTRODUCTION

One of the most important vegetable crop in India is carrot (*Daucus carota* L.) (2n=18). This is a biennial plant in the Apiaceae family. Since seed is a key component of crop production, optimal seed germination is a prerequisite for a successful stand establishment. These days, the proportion of seed germination, emergence, and vigour of seedlings has been negatively impacted by many environmental and abiotic stressors, which eventually leads to low crop output. Numerous physiological and non-physiological methods are available to improve seed performance and overcome environmental limitations in order to speed up the germination process. Seed priming is a low-cost effective hydration technique to stimulate seed germination. During priming, seeds go through a physiological process, i.e. controlled

hydration and drying which results in enhanced and improved pre-germinative metabolic process for rapid germination . Seed priming can synchronize seed germination, and increase emergence (Heydecker 1973). ~~The theory of seed priming was proposed by Heydecker in 1973.~~

Instead of using pure water, osmopriming entails soaking of seeds in an osmotic solution with a low water potential. The low water potential of osmotic solutions causes water to enter seeds slowly, allowing for progressive imbibition and the activation of early germination phases while preventing radicle protrusion. Various osmotic solutions, including sugar, polyethylene glycol (PEG), glycerol, sorbitol, and mannitol, are used depending on the type of plant, and they are then allowed to air dry before being sown (----------). Seed priming can improve crop performance under stress conditions, speed up germination, and reduce germination time ().

Benefits of seed priming include improved crop production, maturity, photo and thermo-dormancy release, nutrient uptake, and water use efficiency (). Therefore, our goal was to ascertain the proper PEG 6000 concentration and duration, which are crucial for carrot seed priming. Given the aforementioned factors, the current study investigated the effects of PEG-6000 seed priming at different doses and periods, along with dry seeds as a control, on vigour status, seedling growth, and germination in a laboratory setting.

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MATERIALS AND METHODS

In the current study, three carrot genotypes and different osmo priming concentrations and durations were used which was carried out during 2022 at the Seed Testing Laboratory, Department of Seed Science and Technology, BCKV, Mohanpur, Nadia, West Bengal, using a completely randomised design with three replications. Three carrot genotypes were Carrot Florence (G_1), Deb Kuroda-1 (G_2), Deb Kuroda-3 (G_3). PEG-6000 was applied at 0.1 MPa for 24 hrs (T_2), 0.1 MPa for 48 hrs (T_3), 0.25 MPa for 24 hrs (T_4), 0. 25 MPa for 48 hrs (T_5), 0.40 MPa for 24 hrs (T_6), 0.40 MPa for 48 hrs (T_7). The control (T_1) was non-primed seeds. AICRP Vegetable provided the seeds, which were analyzed in the Seed Testing Laboratory.

Time to 50% germination

The number of seeds that germinated each day was noted using the AOSA method. The following formulas from Coolbear *et al.* (1984), as modified by Farooq *et al.* (2005), were used to calculate the time of 50% germination (T_{50}):

$$T_{50} = t_i + \frac{\left(\frac{N}{2} - n_i\right)(t_j - t_i)}{(n_j - n_i)}$$

Where, N stands for final number of germination and n_i, n_j are cumulative number of seeds germinated by adjacent counts at times t_i and t_j when $n_i < N/2 < n_j$.

Mean germination time (MGT)

The Ellis and Roberts (1981) equation was used to calculate the mean germination time (MGT):

$$MGT = \frac{\sum Dn}{\sum n}$$

Where D is the number of days measured from the start of germination and n is the number of seeds that germinated on day D.

Germination percentage

Germination percentage (G) is computed as:

$$G = \frac{X}{Y} \times 100$$

Where X is the number of normal seedlings produced and Y is the total number of seeds taken for germination (ISTA, 1996). Percentage is used to illustrate it.

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Germination index (GI)

According to Ruan *et al*., 2002, the germination index (GI) was calculated using this formula:

$$GI = \frac{\text{Number of germinated seeds}}{\text{Day of first count}} + - - - - + \frac{\text{Number of germinated seeds}}{\text{Day of last count}}$$

Germination Energy

On the fourth day after planting, the germination energy (GE) was noted. In relation to the total number of seeds tested, it is the percentage of seeds that germinated 4 days after planting (Ruan *et al*., 2002).

Germination percentage

Cotton was placed in the petridish, and after that blotting paper was placed on it. Then it was wetted by distilled water. After the seeds were prepared, they were put on the blotting paper and covered with a lid. Such eight pairs of petridish as were kept in the germinator for each genotype and lot. The petridishes were removed from the seed germinator after fourteen days, and the numbers of normal seedlings were counted.

$$\text{Germination (\%)} = \frac{\text{Number of normal seedlings}}{\text{Total number of seeds}} \text{ X } 100$$

Seedling parameters: Root lengths and shoot lengths of ten seedlings were measured at 14 days after germination using the glass plate method in the laboratory with the help of a scale and graph paper and after that average was made out, expressed in centimetre (cm). A digital balance was used to measure the fresh weight of ten seedlings. After two hours of drying in a hot air oven at 80^0C, the seedlings were weighed using a digital balance. The fresh weight and dry weight of the seedlings were both stated in grams (g).

Vigour index: Vigour index (VI) was computed by using the formula advised by Abdul-Baki and Anderson (1973): VI= G X L Where, 'G' stands for germination percentage and 'L' denotes average seedling length (cm).

Comment [A6]: Add details of statistical procedures adopted for data analysis

RESULTS AND DISCUSSION

Time of 50% Germination (Days)

The highest time to 50% germination over genotypes (6.529) was observed to produce by T_1 on an average followed by T_2, T_3 and T_4; while it was of shortest length for T_5 preceded by T_6 and T_7. Elkoca *et al.* (2007) observed that Osmo- priming by PEG solution improved time of 50% germination after seed treatment in pea. Highest time to 50% germination (5.725) was observed for G_1 and lowest time to 50% germination was recognized for G_3, (4.020) over treatments (Table 1). When the interaction effect of genotypes and seed treatments were taken into consideration, G_1T_1 showed highest value (7.753) for this parameter. Kundu and Bordolui (2024) found a similar result in carrots primed with Ag-nano particles.

Table 1. Effect of osmo-priming on Time of 50% Germination (days) of carrot genotypes

	T_1	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**Mean T**
G_1	7.753	6.367	6.000	5.733	4.233	4.767	5.220	5.725
G_2	6.433	5.900	5.200	4.600	3.800	4.033	4.333	4.900
G_3	5.400	4.797	4.067	3.667	3.207	3.450	3.550	4.020
Mean G	6.529	5.688	5.089	4.667	3.747	4.083	4.368	
		G	**T**	**GXT**				
SEm (±)		**0.039**	**0.060**	**0.104**				
LSD (0.05)		**0.113**	**0.173**	**0.299**				

Note: G = Genotypes, **G_1** = Carrot Florence, **G_2** = Deb Kuroda-1, **G_3** = Deb Kuroda-3; **T** = Treatment, **T_1** = Control, **T_2** = 0.1 MPa PEG-6000 for 24 hrs, **T_3** = 0.1 MPa PEG-6000 for 48 hrs, **T_4** = 0.25 MPa PEG-6000 for 24 hrs, **T_5** = 0. 25 MPa

PEG-6000 for 48 hrs, **T_6** = 0.40 MPa PEG-6000 for 24 hrs, **T_7** = 0.40MPa PEG-6000 for 48 hrs.

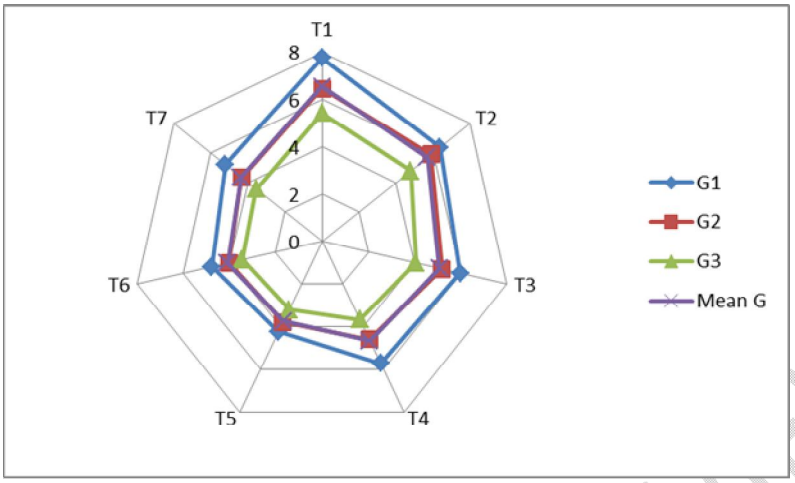

Fig.1. Graphical representation of Time of 50% Germination (days)

Mean Germination Time (Days)

Treatments over genotypes, highest mean germination time was observed in T_1 (7.922) followed by T_2, T_3 and T_4; while it was minimum for T_5 preceded by T_6 and T_7. Hasan *et al.* (2016) found that Osmo- priming improved mean germination time after seed treatment in rice. Over treatments the highest mean germination time was observed in G_1 (7.130) and lowest for G_3, (5.407) (Table 2). G_1T_1 showed highest value (9.147) for this parameter when interaction was made between genotypes and seed treatments. But interaction value was non-significant. G_2T_1, G_1T_2; G_3T_2, G_1T_6; G_3T_3, G_2T_6 were statistically at par. Ray and Bordolui found a similar result in tomatoes (2022a).

Table 2. Effect of osmo-priming on Mean Germination Time (days) of carrot genotypes

	T_1	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**Mean T**
G_1	9.147	7.793	7.393	7.147	5.660	6.160	6.613	7.130
G_2	7.827	7.290	6.593	5.993	5.187	5.427	5.707	6.289
G_3	6.793	6.140	5.460	5.060	4.623	4.860	4.910	5.407
Mean G	7.922	7.074	6.482	6.067	5.157	5.482	5.743	
		G	**T**	**GXT**				
SEm (±)		**0.037**	**0.056**	**0.098**				
LSD (0.05)		**0.106**	**0.162**	**0.280**				

Note: G = Genotypes, **G_1** = Carrot Florence, **G_2** = Deb Kuroda-1, **G_3** = Deb Kuroda-3; **T** = Treatment, **T_1** = Control, **T_2** = 0.1 MPa PEG-6000 for 24 hrs, **T_3** = 0.1 MPa PEG-6000 for 48 hrs, **T_4** = 0.25 MPa PEG-6000 for 24 hrs, **T_5** = 0. 25 MPa PEG-6000 for 48 hrs, **T_6** = 0.40 MPa PEG-6000 for 24 hrs, **T_7** = 0.40MPa PEG-6000 for 48 hrs.

Germination index

Highest germination index over genotypes was observed in T_5 (5.503) followed by T_6, T_7, and T_4, whereas T_1 (control) had the lowest germination index (2.089) proceeded by T_2 and T_3. Sadeghi *et al.* (2011) found that Osmo- priming by PEG solution improved time of germination index after seed treatment in soybean. Over the treatments, G_3 (4.922) had the highest germination index and G_1 (4.130) had the lowest (Table 3**).**When the interaction effect of genotypes and seed treatments were taken into consideration, G_3T_5 (5.670) showed highest value for this parameter. But G_1T_1 G_2T_1; G_1T_5, G_2T_7 and G_3T_3; G_3T_4, G_3T_7 were statistically at par.

Table 3. Effect of osmo-priming on Germination index of carrot genotypes

	T_1	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**Mean T**
G_1	2.087	3.700	4.067	4.250	5.247	5.033	4.530	4.130
G_2	2.057	4.633	5.153	5.213	5.593	5.377	5.250	4.754
G_3	2.123	5.157	5.280	5.353	5.670	5.500	5.370	4.922
Mean G	2.089	4.497	4.833	4.939	5.503	5.303	5.050	
		G	**T**	**GXT**				
SEm (±)		**0.016**	**0.025**	**0.044**				
LSD (0.05)		**0.047**	**0.072**	**0.125**				

Note: G = Genotypes, **G_1** = Carrot Florence, **G_2** = Deb Kuroda-1, **G_3** = Deb Kuroda-3; **T** = Treatment, **T_1** = Control, **T_2** = 0.1 MPa PEG-6000 for 24 hrs, **T_3** = 0.1 MPa PEG-6000 for 48 hrs, **T_4** = 0.25 MPa PEG-6000 for 24 hrs, **T_5** = 0. 25 MPa PEG-6000 for 48 hrs, **T_6** = 0.40 MPa PEG-6000 for 24 hrs, **T_7** = 0.40MPa PEG-6000 for 48 hrs.

Germination Energy (%)

The highest germination energy over genotypes was observed in T_5 (**47.273**) on an average followed by T_6, T_7 and T_4; while it was of lowest for T_1 (control) preceded by T_2 and T_3. Sadeghi *et al.* (2011) found that Osmo- priming by PEG solution improved time of germination energy after seed treatment in soybean. Highest germination energy (42.450) was observed for G_3 and lowest germination energy was recognized for G_1 (40.256) over treatments (Table 4). When the interaction effect of genotypes and seed treatments were taken into consideration, G_3T_5 showed highest value (47.687) for this parameter, though G_1T_3 and G_2T_2; G_3T_7 and G_2T_7; G_2T_6, G_3T_6; were statistically at par with each other.

Table 4. Effect of osmo-priming on Germination Energy (%) of carrot genotypes

	T_1	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**Mean T**
G_1	18.833 (25.707)	40.467 (39.488)	42.377 (40.599)	43.680 (41.353)	46.700 (43.091)	45.367 (42.324)	44.367 (41.749)	40.256 (39.187)
G_2	21.667 (27.721)	42.167 (40.477)	42.967 (40.940)	45.167 (42.209)	47.433 (43.511)	46.333 (42.880)	45.333 (42.305)	41.581 (40.006)

G_3	23.833 (29.208)	43.500 (41.248)	44.100 (41.595)	45.333 (42.305)	47.687 (43.656)	46.767 (43.139)	45.933 (42.650)	42.450 (40.542)
Mean G	21.444 (27.545)	42.044 (40.405)	43.148 (41.045)	44.727 (41.956)	47.273 (43.419)	46.156 (42.778)	45.211 (42.235)	
		G	**T**	**GXT**				
SEm (±)		**0.087**	**0.133**	**0.230**				
LSD (0.05)		**0.249**	**0.380**	**0.659**				

Note: G = Genotypes, **G_1** = Carrot Florence, **G_2** = Deb Kuroda-1, **G_3** = Deb Kuroda-3; **T** = Treatment, **T_1** = Control, **T_2** = 0.1 MPa PEG-6000 for 24 hrs, **T_3** = 0.1 MPa PEG-6000 for 48 hrs, **T_4** = 0.25 MPa PEG-6000 for 24 hrs, **T_5** = 0. 25 MPa PEG-6000 for 48 hrs, **T_6** = 0.40 MPa PEG-6000 for 24 hrs, **T_7** = 0.40MPa PEG-6000 for 48 hrs.

Shoot Length (cm)

The longest shoot length over genotypes (3.759cm) was observed to produce by T_5 followed by T_6, T_7 and T_4; while it was of shortest length for T_1 (control) preceded by T_2 and T_3. Farooq *et al.* (2005) showed increased shoot length after seed treatment with Osmo-priming by PEG solution in rice. Highest shoot length (3.686 cm) was observed for G_3 and shortest shoot length (2.907 cm) was recognized for G_1, over treatments (Table 5). Though G_2 and G_3 over treatment were non-significantly differ. When the interaction effect of genotypes and seed treatments were taken into consideration, G_3T_5 showed highest value (4.392 cm) for this parameter, though G_1T_1 and G_2T_1; G_2T_2 and G_3T_2; G_1T_6, G_1T_7 were statistically at par with each other. Similar outcomes were noted by Choudhury and Bordolui (2022a) in Bengal gram when they used sodium molybdate (Na_2MoO_4) nutri-priming to increase shoot length.

Table 5. Effect of osmo-priming on Shoot Length (cm) of carrot genotypes

	T_1	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**Mean T**
G_1	2.400	2.743	2.880	2.970	2.550	3.474	3.330	2.907
G_2	2.503	2.925	3.090	3.585	4.335	3.726	3.774	3.420
G_3	2.823	2.947	3.437	4.266	4.392	4.074	3.864	3.686
Mean G	2.576	2.872	3.136	3.607	3.759	3.758	3.656	
		G	**T**	**GXT**				
SEm (±)		**0.037**	**0.057**	**0.099**				
LSD (0.05)		**0.107**	**0.164**	**0.284**				

Note: G = Genotypes, **G_1** = Carrot Florence, **G_2** = Deb Kuroda-1, **G_3** = Deb Kuroda-3; **T** = Treatment, **T_1** = Control, **T_2** = 0.1 MPa PEG-6000 for 24 hrs, **T_3** = 0.1 MPa PEG-6000 for 48 hrs, **T_4** = 0.25 MPa PEG-6000 for 24 hrs, **T_5** = 0. 25 MPa PEG-6000 for 48 hrs, **T_6** = 0.40 MPa PEG-6000 for 24 hrs, **T_7** = 0.40MPa PEG-6000 for 48 hrs.

Root length (cm)

T_5 (3.165 cm) produced highest root length (3.141 cm) over genotypes, followed by T_4, T_6 , and T_3 , whereas T_1 (control) had the least root length, preceded by T_2 and T_7 . In pea,

Yanglem *et al.* (2021) found that Osmo- priming by PEG solution improved root length after seed treatment. Over the treatments, G_2 had the highest root length (3.124 cm), and G_1 had the smallest root length (2.210 cm) (Table 6). Despite the fact that G_1 and G_3, over treatments showed non-significant difference.The interaction between genotypes and seed treatments G_3T_5 showed highest value (3.165 cm) for this parameter, though G_1T_2 and G_2T_2; G_1T_3 and G_1T_4 were statistically at par with each other. Choudhury and Bordolui (2022b) used potassium nitrate to observe a similar kind of result in Bengal gram.

Table 6. Effect of osmo-priming on Root length (cm) of carrot genotypes

	T_1	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**Mean T**
G_1	2.267	2.136	2.289	2.175	2.634	2.020	1.950	2.210
G_2	2.523	3.193	3.247	3.381	3.623	3.057	2.844	3.124
G_3	2.313	2.397	2.445	2.610	3.165	2.913	2.994	2.691
Mean G	2.368	2.575	2.660	2.722	3.141	2.663	2.596	
		G	**T**	**GXT**				
SEm (±)		**0.041**	**0.062**	**0.108**				
LSD (0.05)		**0.117**	**0.178**	**0.309**				

Note: G = Genotypes, **G_1** = Carrot Florence, **G_2** = Deb Kuroda-1, **G_3** = Deb Kuroda-3; **T** = Treatment, **T_1** = Control, **T_2** = 0.1 MPa PEG-6000 for 24 hrs, **T_3** = 0.1 MPa PEG-6000 for 48 hrs, **T_4** = 0.25 MPa PEG-6000 for 24 hrs, **T_5** = 0. 25 MPa PEG-6000 for 48 hrs, **T_6** = 0.40 MPa PEG-6000 for 24 hrs, **T_7** = 0.40MPa PEG-6000 for 48 hrs.

Seedling length (cm)

Among the treatments over genotypes, T_1 (control) observed shortest seedling lengths, which was preceded by T_2 and T_3 , while T_5 produced seedlings with highest length of 6.900 cm, followed by T_6 , T_4 , and T_7 . According to Singh *et al.* (2015), cowpea seeds treated with Osmo-priming by PEG solution produced longer shoots. Here, G_1 and G_2 are non-significantly differ. According to Singh *et al.*, cowpea seeds treated with Osmo-priming by PEG solution produced longer shoots (2014). G_2 had the longest shoots (6.544 cm) and G_1 had the shortest shoots (5.117 cm) over treatments (Table 7). When the interaction effect of genotypes and seed treatments were taken into consideration, G_3T_5 showed highest value (7.557 cm) for this parameter, though G_3T_1 and G_1T_4; G_1T_3 and G_1T_4 were statistically at par with each other.

Table 7. Effect of osmo-priming on Seedling length (cm) of carrot genotypes

	T_1	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**Mean T**
G_1	4.667	4.879	5.169	5.145	5.184	5.494	5.280	5.117
G_2	5.027	6.118	6.337	6.966	7.958	6.783	6.618	6.544
G_3	5.137	5.343	5.882	6.876	7.557	6.987	6.858	6.377

Mean G	4.943	5.447	5.796	6.329	6.900	6.421	6.252	
		G	**T**	**GXT**				
SEm (±)		**0.060**	**0.091**	**0.158**				
LSD (0.05)		**0.171**	**0.261**	**0.453**				

Note: G = Genotypes, $\mathbf{G_1}$ = Carrot Florence, $\mathbf{G_2}$ = Deb Kuroda-1, $\mathbf{G_3}$ = Deb Kuroda-3; **T** = Treatment, $\mathbf{T_1}$ = Control, $\mathbf{T_2}$ = 0.1 MPa PEG-6000 for 24 hrs, $\mathbf{T_3}$ = 0.1 MPa PEG-6000 for 48 hrs, $\mathbf{T_4}$ = 0.25 MPa PEG-6000 for 24 hrs, $\mathbf{T_5}$ = 0. 25 MPa PEG-6000 for 48 hrs, $\mathbf{T_6}$ = 0.40 MPa PEG-6000 for 24 hrs, $\mathbf{T_7}$ = 0.40MPa PEG-6000 for 48 hrs.

Germination percentage (%)

In case of treatments over genotypes significantly differ with each other. But T_3 recorded highest germination percentage (93.644), followed by T_4, T_2, and T_6 whereas T_1 (control) produced the lowest germination percentage preceded by T_7 and T_5. T_3 and T_4 were non-significantly differ with each other. Lemmens *et al.* (2019) found that Osmo- priming by PEG solution improved germination percentage in wheat .Over the treatments, G_1 showed the lowest germination percentage (91.312) while G_3 had the highest germination percentage (92.126) (Table 8). Interaction between genotypes and seed treatments G_3T_3 observed highest value (93.967). G_1T_1, G_3T_1; G_2T_2, G_3T_2, G_1T_3, G_3T_2; G_2T_4 and G_2T_5 were statistically at per. Ray and Bordolui (2022b) discovered a similar kind of outcome in tomato.

Table 8. Effect of osmo-priming on Germination percentage of carrot genotypes

	$\mathbf{T_1}$	$\mathbf{T_2}$	$\mathbf{T_3}$	$\mathbf{T_4}$	$\mathbf{T_5}$	$\mathbf{T_6}$	$\mathbf{T_7}$	**Mean T**
$\mathbf{G_1}$	85.583 (67.661)	91.300 (72.833)	93.367 (75.128)	93.400 (75.091)	93.533 (75.245)	91.867 (73.404)	90.133 (71.666)	91.312 (73.004)
$\mathbf{G_2}$	87.083 (68.910)	93.600 (75.323)	93.600 (75.380)	92.333 (73.904)	92.833 (74.444)	93.267 (74.933)	90.833 (72.356)	91.936 (73.607)
$\mathbf{G_3}$	85.917 (67.932)	93.933 (75.748)	93.967 (75.768)	93.867 (75.634)	91.767 (73.307)	93.267 (74.954)	92.167 (73.726)	92.126 (73.867)
Mean G	86.194 (68.168)	92.944 (74.635)	93.644 (75.425)	93.200 (74.876)	92.711 (74.332)	92.800 (74.430)	91.044 (72.583)	
		G	**T**	**GXT**				
SEm (±)		**0.192**	**0.294**	**0.509**				
LSD (0.05)		**0.551**	**0.842**	**1.458**				

Note: G = Genotypes, $\mathbf{G_1}$ = Carrot Florence, $\mathbf{G_2}$ = Deb Kuroda-1, $\mathbf{G_3}$ = Deb Kuroda-3; **T** = Treatment, $\mathbf{T_1}$ = Control, $\mathbf{T_2}$ = 0.1 MPa PEG-6000 for 24 hrs, $\mathbf{T_3}$ = 0.1 MPa PEG-6000 for 48 hrs, $\mathbf{T_4}$ = 0.25 MPa PEG-6000 for 24 hrs, $\mathbf{T_5}$ = 0. 25 MPa PEG-6000 for 48 hrs, $\mathbf{T_6}$ = 0.40 MPa PEG-6000 for 24 hrs, $\mathbf{T_7}$ = 0.40MPa PEG-6000 for 48 hrs.

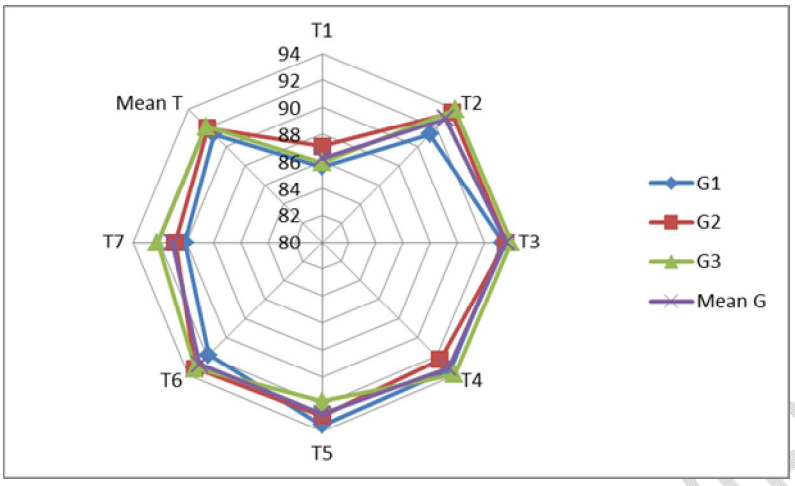

Fig. 2. Graphical representation of Germination (%)

Vigour Index

The highest vigour index over genotypes was observed in T_5 (639.032) followed by T_6, T_4 and T_7; while it was lowest for T_1 (control) preceded by T_2 and T_3. Rouhi *et al.* (2010) found that Osmo-priming by PEG solution improved vigour index in clover. Highest vigour index (602.773) was observed for G_2 and lowest vigour index (467.527) was recognized for G_1, over treatments (Table 9). Though G_1 and G_3 over treatment were non-significantly differ. When the interaction effect of genotypes and seed treatments were taken into consideration, G_3T_5 showed highest value (693.447) for this parameter, though G_2T_1 and G_1T_1; G_1T_2, G_3T_1; G_1T_4 and G_1T_5 were non-significant with each other.

Table 9. Effect of osmo-priming on Vigour Index of carrot genotypes

	T_1	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**Mean T**
G_1	399.333	445.413	482.173	480.330	484.873	504.630	475.937	467.527
G_2	437.747	572.743	593.107	643.340	738.777	632.587	601.113	602.773
G_3	441.340	501.860	552.717	645.407	693.447	651.760	631.950	588.354
Mean G	426.140	506.672	542.666	589.692	639.032	596.326	569.667	
		G	**T**	**GXT**				
SEm (±)		**5.390**	**8.234**	**14.261**				
LSD (0.05)		**15.438**	**23.582**	**40.845**				

Note: G = Genotypes, **G_1** = Carrot Florence, **G_2** = Deb Kuroda-1, **G_3** = Deb Kuroda-3; **T** = Treatment, **T_1** = Control, **T_2** = 0.1 MPa PEG-6000 for 24 hrs, **T_3** = 0.1 MPa PEG-6000 for 48 hrs, **T_4** = 0.25 MPa PEG-6000 for 24 hrs, **T_5** = 0. 25 MPa PEG-6000 for 48 hrs, **T_6** = 0.40 MPa PEG-6000 for 24 hrs, **T_7** = 0.40MPa PEG-6000 for 48 hrs.

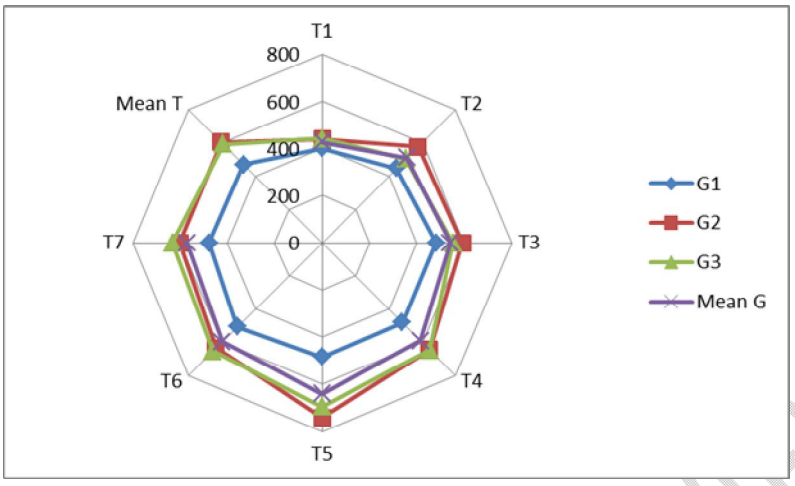

Fig. 3. Graphical representation of Vigour Index (%)

Seedling Fresh weight (mg) of 10 seedlings

Over genotypes, T_5 produced the highest fresh weight (107.556 mg) followed by T_6, T_7, and T_4; whereas T_2 showed the lowest fresh weight, preceded by T_1 and T_3. Ghiyasi *et al.* (2008) found that Osmo- priming by PEG solution improved fresh weight after seed treatment in case of wheat. Similarly, Chakraborty and Bordolui (2021) discovered that Ag nano priming increased the fresh weight of green grams seedlings compared to other treatments. Genotypes over treatments, G_3 had the highest fresh weight (93.714 mm) and G_1 observed the lowest fresh weight (79.667 mg) (Table 10). When the interaction effect of genotypes and seed treatments were taken into consideration, G_3T_5 showed highest value (108.333 mg) for this parameter but they were non-significantly differ with each other.

Table 10. Effect of osmo-priming on Seedling Fresh weight (mg) of carrot genotypes (10 seedlings)

	T_1	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**Mean T**
G_1	62.333	49.000	76.000	87.333	102.000	95.000	86.000	79.667
G_2	72.333	80.000	86.000	94.667	112.333	104.333	106.333	93.714
G_3	74.667	79.000	82.667	92.000	108.333	103.000	103.333	91.857
Mean G	69.778	69.333	81.556	91.333	107.556	100.778	98.556	
		G	**T**	**GXT**				
SEm (±)		**1.806**	**2.759**	**4.779**				
LSD (0.05)		**5.173**	**7.902**	**NS**				

Note: G = Genotypes, **G_1** = Carrot Florence, **G_2** = Deb Kuroda-1, **G_3** = Deb Kuroda-3; **T** = Treatment, **T_1** = Control, **T_2** = 0.1 MPa PEG-6000 for 24 hrs, **T_3** = 0.1 MPa PEG-6000 for 48 hrs, **T_4** = 0.25 MPa PEG-6000 for 24 hrs, **T_5** = 0. 25 MPa

PEG-6000 for 48 hrs, **T_6** = 0.40 MPa PEG-6000 for 24 hrs, **T_7** = 0.40MPa PEG-6000 for 48 hrs.

Seedling Dry Weight (mg) of 10 seedlings

The highest dry weight over genotypes was observed in T_5 (11.508) followed by T_6, T_7, and T_4. But, T_2 showed the lowest dry weight, preceded by T_1 and T_3. T_1 and T_2 were statistically at par. Ghiyasi *et al.* (2008) found that Osmo- priming by PEG solution improved dry weight after seed treatment in case of wheat. Over the treatments, G_3 had the highest dry weight (10.028), and G_1 had the lowest dry weight (8.522) (Table 11). G_1 and G_2 over treatments were non-significantly differing. The interaction effect of genotypes and seed treatments were non-significantly variation with each other but G_3T_5 showed highest dry weight (11.590).

Table 11. Effect of osmo-priming on Seedling Dry Weight (mg) of carrot genotypes (10 seedlings)

	T_1	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**Mean T**
G_1	6.670	5.223	8.133	9.343	10.913	10.167	9.203	8.522
G_2	7.740	8.560	9.203	10.130	12.020	11.163	11.380	10.028
G_3	7.990	8.453	8.843	9.847	11.590	11.020	11.057	9.829
Mean G	7.467	7.412	8.727	9.773	11.508	10.783	10.547	
		G	**T**	**GXT**				
SEm (±)		**0.193**	**0.295**	**0.511**				
LSD (0.05)		**0.553**	**0.845**	**NS**				

Note: G = Genotypes, **G_1** = Carrot Florence, **G_2** = Deb Kuroda-1, **G_3** = Deb Kuroda-3; **T** = Treatment, **T_1** = Control, **T_2** = 0.1 MPa PEG-6000 for 24 hrs, **T_3** = 0.1 MPa PEG-6000 for 48 hrs, **T_4** = 0.25 MPa PEG-6000 for 24 hrs, **T_5** = 0. 25 MPa PEG-6000 for 48 hrs, **T_6** = 0.40 MPa PEG-6000 for 24 hrs, **T_7** = 0.40MPa PEG-6000 for 48 hrs.

Conclusion

Carrot seeds treated with PEG-6000 had better seed quality than the control. In comparison to other treatments, PEG-6000 @ 0.25Mpa soaking for soaking duration 48 hours was the most effective treatment over genotypes. Significantly highest germination index, germination energy, germination percentage and lowest mean germination time were noted for Deb Kuroda-3 (G_3) while highest seedling length, fresh weight, dry weight and vigour index were observed for Deb Kuroda-1(G_2) although these genotypes were statistically at par. So, in germination point of view, Deb Kuroda-3 is best and in vigour point of view, Deb Kuroda-1 is best. For seed quality parameters such as germination energy (47.273), seedling vigour Index-I (639.032), and germination index (5.503), PEG-6000 @ 0.25Mpa soaking for 48 hours shown noticeably the best results. Consequently, PEG-6000 @ 0.25Mpa for soaking

duration 48 hours is advised as a pre-sowing treatment for carrot seeds in order to improve seedling establishment.

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