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Phenological and yield response of primed carrot (*Daucus carota* L.) seeds under deficit irrigation

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Abstract: Seedling emergence and stand establishment of carrot seeds are often slow and erratic which results in low productivity. Poor seed quality together with lack of pre-sowing seed treatments and improper irrigation management can be mentioned as the major factors that influence the yield and productivity of carrot. The present study was carried out with the objective to evaluate the effects of different seed priming techniques on early seedling establishment, growth and yield of carrot (*Daucus carota* L. cultivated variety Nantes) exposed to different irrigation intervals, under field conditions at Gerado, South Wollo, Ethiopia. Four seed priming treatments (no priming, hydro priming, halo priming and hormonal priming) and three irrigation intervals (4, 7 and 10 days) were combined as factorial RCBD in split plot arrangement with three replications. The irrigation intervals were assigned to main plots and the seed priming techniques to sub plots. Result indicated that the interaction effects of priming techniques and irrigation intervals significantly affected the phenological and yield parameters. Distilled water treatment in seven and ten days irrigation interval recorded the highest marketable carrot root yields of 33.73 t h^{-1} and 30.63 t h^{-1}, respectively. Hence, hydro priming and seven days irrigation interval can be recommended for the production of carrot in the study area and similar agro-ecologies. Given the promising results obtained, further repetitions of the study are recommended to validate the use of these techniques in further locations and in different seasons.

1. Introduction

Carrot (*Daucus carota* L.) is a crop that belongs to the family *Apiaceae* previously *Umbelliferea* (Thiviya *et al.*, 2021). Carrot is among the top ten most economically important vegetable crops in the world in terms of areas of production and market value (Simões *et al.*, 2010). Its yield can range from 30 to 100 t ha^{-1} in major carrot growing countries of the world (Tegen and Jembere, 2021).

Carrot is one of the major root vegetable crops produced in Ethiopia. It is nowadays cultivated predominantly as a cash crop throughout the country, for sale to urban markets, including Hotels and Restaurants as indicated by Getachew and Mohammed (2012). According to CSA (2022) about 6,759.92 ha has been covered by carrots with a total production of 31,671.6 tons and productivity of 4.7 t ha^{-1}. In 2022, the area coverage of carrots increased by 30% compared to the production year of 2021 whereas, in the Amhara region about 1,619.58 ha has covered by carrots with a total production of 9,145.8 tons and productivity of 5.6 t ha^{-1}. The productivity of carrots in Ethiopia is very low (4.7 t ha^{-1}) compared to other countries which can be up to 100 t ha^{-1} in major carrot-growing countries of the world as reported by CSA (2022).

Carrot has remarkable nutritional and health value and is considered as a rich source of carotenoids, phenolic compounds, polyacetylenes, and vitamins (Alhariri and Boras, 2020; Glowka *et al.*, 2021). The health benefits and public awareness of nutritional health security are positively influencing the demand and consumption of carrots by consumers and by the nutraceutical-based industry (Selvakumar *et al.*, 2019).

Heterogeneous, asynchronized and lower rates of seed germination are major challenges in *Apiaceae* (*Umbelliferae*) family and have a major impact on final yield and quality especially for vegetable crops established by direct seeding such as carrot and parsley (Mozumder and Hossain, 2013). Improvement in seeds' homogenous, longevity and germination speed are major concerns for carrot growers and the seed agribusiness sector. Recently, different pre-sowing seed treatments have been proposed to improve seed vigour, uniformity and seedling emergence (Sagvand *et al.*, 2022). The crop is usually established by direct seeding and therefore, low soil moisture content may lead to poor crop stand (Mahmood-Ur-Rehman *et al.,* 2020). Low soil moisture content delay or inhibit seed germination in the field, reduce uniformity of seedling performance, total stand establishment and ultimately reduce the yield of carrot. In addition, before sowing the seeds, it is essential to ensure that the soil is adequately moist. This can be achieved by irrigating the field a few days before planting. The moisture content should be sufficient for the seeds to absorb water and germinate.

The production and productivity of carrot in the study area is low mainly due to low quality seeds and poor cultural practices including improper irrigation intervals. Carrot producers mainly use seeds stored for long periods which hardly germinate in the field. The germination is not uniform and fails to establish a homogeneous crop stand especially under limited irrigation intervals. Different seed priming techniques help to enhance seed quality thereby improving seedling emergence percentage and uniformity even under stress conditions. Even though a number of researches have been done on seed priming (Pereira *et al.*, 2009; Paparella *et al.*, 2015), there is no single method of seed priming technique that can be best suited to all crops. Thus, it's of paramount importance to examine the different priming techniques to enhance the quality of carrot seeds. Further, water requirement studies for proper irrigation scheduling of carrot also has great importance. However, information regarding the efficient use of irrigation water for improved growth and yield of carrot has also lacking in Ethiopia. Scarcity of irrigation water is an acute problem for successful crop production in Ethiopia. Hence the need for more efficient utilization and management of scarce irrigation water is crucial. Therefore, this research was initiated to investigate the use of different seed priming techniques on seedling emergence, growth and yield of carrot under different irrigation frequencies in South Wollo, Ethiopia.

2. Materials and Methods

Description of experimental site

The experiment was conducted at Gerado, mid-altitude of south Wollo administrative zone, Amhara regional state, Ethiopia during 2020/21 cropping season. The study area is geographically situated 11 12' 00'' north and 39 42' 00'' east with an elevation between 2200-2800 m a.s.l. (Fig. 1) The general climate is midland with a mean annual rainfall ranging

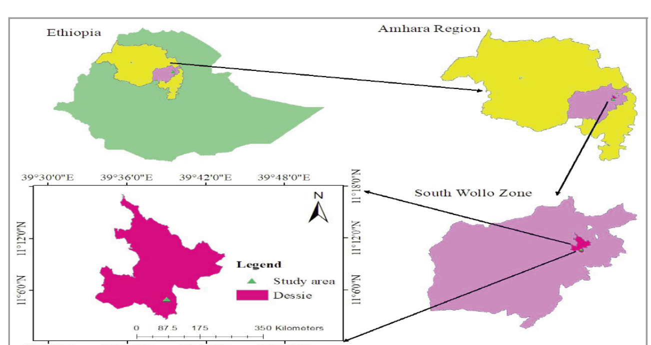

Fig. 1 - Geographical location of the study area.

from 900 mm to 1000 mm and mean annual temperature between 15°C to 20°C (Tamru, 2006). The major soil type in the area is sandy-loam. Gerado has three permanent rivers which have the potential to irrigate throughout the year. These are Yito Medehanialem, Negewoliy and Gerado. In the study area the most cultivated crops are maize, teff, wheat and barley. Vegetable crops such as carrot, cabbage, tomato, and potato are cultivated using irrigation water from the nearby rivers (Bahir *et al.*, 2015).

Experimental material

Carrot (*Daucus carota* var. *Nantes)* seed (250 g), were obtained from vegetable seed providing enterprise in Dessie city andused as a test crop since it is adapted to the experimental area and preferred by most small- holder farmers and consumers. Nantes variety has orange colour and cylindrical roots with a blunt end and strong leaves. It has a wide adaptability and grows well at altitudes ranging from 1600-2400 m a.s.l with annual precipitation of 760-1010 mm and can be produced all year round both under rain-fed and irrigation condition (Hubbard *et al.*, 2012).

Treatment and experimental design

This study applied two treatments concerning priming techniques and irrigation levels. In total four techniques of priming; none primed/control (NP), potassium nitrate (KNO_3), gibberelic acid (GA_3), and distilled water (DW) where seeds were dipped in the respective solutions 12 priming hours. Irrigation treatment consisted of three irrigation intervals: four days interval (I4), seven days interval (I7) and ten days interval (I10).KNO_3 was used at a concentration level of 50mM (Lara *et al.*, 2014) and GA_3 was used at a concentration level of 0.05 mM (Kwon *et al.*, 2020). The ratio (W/V) of seed: priming solutions was 1:5 (g/ml) (Ruan *et al.*, 2002).

The experiment was laid out in Randomized Complete Block Design (RCBD) in split plot arrangement with three replications. There were 3 main plots in each replication and each main plot was further divided into 4 sub plots where irrigation intervals assigned as main plots and the priming techniques was assigned to sub-plots. The gross area of the experimental site was 240 m^2 (30x8) and the net area was 103.68 m^2. The area of a single plot was 2.88 m^2 (1.6x1.8 m). Spacing between main plots and sub-plots were 1m and 0.5m respectively. Blocks were separated by 1.5 m. The seeds were planted on rows with spacing of 5 cm between plants and 20 cm between rows. Each experimental plot had 7 rows with 36 plants per row. The outer single rows at both sides of the plot and one plant at both ends of the rows were considered as border plants. All management activities except irrigation and priming techniques were applied uniformly in all plots of the experiment.

Experimental procedure and management of plants

At first, seeds were superficially sterilized with sodium hypochlorite solution (2%) for five minutes to sterilize fungal agents and were then thoroughly wash with distilled water and air dried (Farooq *et al.*, 2005). Seed samples of Nantes variety was then divided in to three for each priming media. After that, seeds except the non - primed (control) were fully immersed in different priming medias (distilled water, GA_3 and KNO_3) on Petri dishes for 12 priming hours (Abnavi and Ghobadi, 2012). After the priming application, all seeds were removed from the priming media at the same time and then rinse thoroughly with distilled water, dried on paper towels at room temperature and ventilated until they regained their original weight (Giri and Schillinger, 2003).

CROPWAT version 8.0 was used to calculate the amount of water required by carrot crop and water was applied using calibrated watering can to bring the water requirement of each interval days for the treatments. Crop water requirement (CWR) is the total water needed for evapotranspiration, from planting to harvest for a given crop in a specific climate regime when soil does not limit plant growth and crop yield (Ouda *et al.*, 2015). Considering this the CWR was determined by the formula developed by FAO as follows.

$$ETc = Kc \times ET_0 \qquad \text{Eq. 1}$$

where ETc is crop potential evapotranspiration (mm/unit time), Kc is crop coefficient (Influence of crop type and growth stage) and ET_o is reference evapotranspiration (mm/unit time) [Influence of climate].

The effect of climate on crop water requirements is given by the reference crop evapotranspiration (ET_o) which is defined as the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water. FAO (2005) defined the crop potential evapotranspiration (ET_o) for a given crop as:

$$ET_0 = \frac{0.408\Delta(Rn - G) + \gamma\frac{900}{T+273}U2(es - ea)}{\Delta + \gamma(1 + 0.34U2)} \quad \text{Eq. 2}$$

where ETo is the reference evapotranspiration (mm day^{-1}), Rn is the net radiation (MJ m^{-2} day^{-1}), G is the soil heat flux density (MJ m^{-2} day^{-1}), T is the mean daily air temperature at 2 m height (°C) Δ is the slope of the saturated vapour pressure curve (kPa °C^{-1}), γ is the psychrometric constant (66 Pa °C $^{-1}$), es is the saturated vapour pressure at air temperature (kPa), ea is the prevailing vapor pressure (kPa), and U_2 is the wind speed measured at 2 m height (m s^{-1}).

Based on the above formula water requirement of carrot was 402.4 liter per m^2 of land for all growing season. The gross and net plot sizes were 2.88 m^2 and 2.63 m^2, respectively. Therefore, the total water requirement of each plot was 1,158.912 liters. Each treatment was irrigated with equal amount of total irrigation water during the growth period, which was calculated based on CROPWAT 8 software. Accordingly, the amount of irrigation water applied by three levels irrigation intervals was different, as the irrigation interval increases, the frequency of water application decreases leading to lesser amount of water applied and vice versa. Thus, 46.36 litres of water were supplied within the irrigation interval of 4 days, 82.79 litres in the irrigation interval of 7 days, and 115.89 litres in the irrigation interval of 10 days. The amount of water required for each interval was obtained by dividing the total water requirement of a single plot by the number of irrigation applications over the total growing season).

To determine the baseline of irrigation interval to set up the treatment, input data for the CROPWAT model were obtained from the National Meteorological Services Agency, Soil laboratory results and FAO publications. Metrological data of ten years which were collected from Ethiopian metrology agency, north eastern region, Kombolcha station were used.

Soil analysis of the experimental site

Soil samples were collected from the experimental site before treatment application at a depth of 30 cm in a zigzag pattern from nine randomly selected points by using auger. The collected samples were air dried, mixed and made a composite representative sample of 1 kg for analysis. The composite sample was packed in a polythene bag, labelled and taken to Dessie Soil Testing Laboratory. Soil analysis data on soil texture, pH, organic matter, field capacity, permanent wilting point and organic carbon of the soil were analyzed as shown in (Table 1).

Table 1 - Physical and chemical properties of the soil in the study area

Soil properties	Data
Organic matter (%)	4.13
Organic carbon	2.4
pH	7.02
Texture	
Sand (%)	45
Silt (%)	13
Clay (%)	42
Class	Sandy clay
Field capacity (vol. %)	39
Permanent wilting point	27

Data collection and statistical analysis

Phenological, growth, yield related parameters and yield were collected from net plot area using standard procedures. Data were subjected to two-way analysis of variance (ANOVA) using R-software based on Agricole statistical package. The mean separation was carried out using least significant difference (LSD) at probability level based on the results of ANOVA analysis. The detailed procedures were as follows:

Emergence percentage (%). After emergence of first seedling of every treatment, the numbers of emerged seedlings were counted daily up to 14 days after sowing. Emergence percentage was calculated as:

$$\text{Emergence (\%)} = \frac{\text{total number of emerged seedling}}{\text{total seeds sown}} \times 100$$

Mean emergence time (count). It was calculated according to (Ellis and Roberts, 1980):

$$MET = (\Sigma n \times D)/\Sigma n$$

where n is the number of seeds emerged at day D, and D the number of days since the start of emergence test (sowing).

Days to 90 % maturity (days). It was measured by counting the number of days elapsed from date of sowing to the date when 90% of the plant in each plot attained physiological maturity and used for further analysis. Carrot plants were physiologically matured when the leaf color turns in to yellow and roots are at harvestable size and the crown attained a diameter ranging from 2-3.8 cm diameter as described by UNECE (2018).

Marketable root yield (t ha^{-1}). Carrot roots, which are free from mechanical damages, disease and insect pest attack and sizes (>50 g) were considered as marketable (UNECE, 2018). The weight of such carrots harvested from the net plot area was weighed using scale and expressed as ton per hectare.

Unmarketable root yield (t ha^{-1}). Carrot roots which are diseased, insect pest damaged, cracked and under sized (<50 g) was considered as unmarketable as described by UNECE, 2018. The weight of such carrots harvested from the net plot area was weighed using scale and expressed as ton per hectare.

Total root yield (t ha^{-1}). It was obtained by summation of marketable and unmarketable yields and then converted to hectare basis and expressed in t ha^{-1}.

3. Result and Discussion

Phenology

Emergence percentage. Increasing the frequency of irrigation as well as treating seeds with different priming solution increased the emergence percentage of carrot plants. In the interaction effect, the results showed that, decreasing irrigation interval along with priming techniques improved the emergence percentage of carrot plants. Therefore, the highest emergence percentage of carrot (83%) was observed by the treatment combination of four days irrigation interval and distilled water treatment. The lowest EP values were obtained using 10 days of irrigation interval for all the priming treatments, with minimum value in non-primed seeds (46.67%) (Table 2).

The highest emergence percentage of carrot plants in treatments receiving short irrigation intervals combined with pre-sowing seed treatment might be due to priming-induced changes in biochemical contents of the seeds, membrane integrity and enhanced physiological activities during seed germination and available moisture which is required for germination (Alam *et al.*, 2013). On the other hand, the lowest emergence percentage recorded from longer intervals might be due to moisture deficiency. The result of this study was in agreement with Selvarani and Umaran (2011), who found that hydro priming is the best priming technique for *Daucus carota* seeds. Dessalew *et al.* (2022) also reported that Halo, Hydro and Hormonal-priming techniques improved germination, seedling growth, seedling vigour and seed yield of carrot (*Daucus carota*).

Table 2 - Interaction effect of seed priming and irrigation interval on phonological parameters of carrot

Treatment combinations		Emergence (%)	Mean emergence time (Days)	DM
Irrigation interval	Priming treatment			
4 days	Gibberelic acid	77.67 b	11.33 f	99.33 f
	Distilled water	83.00 a	10.7 f	97.00 f
	None primed	76.33 c	12.96 bc	104.57 cde
	Potassium nitrate	77.67 b	12.3 d	103.90 de
7 days	Gibberelic acid	69.00 bc	13.00 bc	103.37 de
	Distilled water	75.67 ab	11.40 ef	102.20 e
	None primed	56.00 d	13.10 b	105.40 bcd
	Potassium nitrate	66.33 c	12.33 cd	104.80 bcd
10 days	Gibberelic acid	57.00 d	13.10 b	107.00 abc
	Distilled water	55.33 d	13.0 b	106.57 bc
	None primed	46.67 e	13.93 a	109.00 a
	Potassium nitrate	55.33 d	13.16 b	107.37 ab
LSD (5%)		0.07	0.66	2.41
CV (%)		6.50	3.40	1.40
SE+/-		0.03	0.42	1.40

Means with the same letter/s in column are not significantly different; * = significant (p<0.05); CV = Coefficient variance; LSD = least significant difference; SE= standard error, DM= Days to 90% maturity (Days).

Similarly, Mehri (2005) reported that the maximum germination percentages were obtained from water treatment while the least value was recorded from non-primed seeds.

Mean emergence time. Treating seeds with different soaking chemicals as well as frequent irrigation generally reduced the spread of emergence times. The different priming techniques significantly decreased the mean emergence time across the increasing frequency of irrigation as compared to control. The shortest mean emergence time (10.70 days) was recorded from seeds treated with distilled water and irrigated at four days interval. However, the combined effect of longest irrigation interval (ten days) with unprimed seeds recorded the longest mean emergence time (Table 2).

The significant reduction in emergence time derived from the combination of seed priming with frequent irrigation intervals might be due to the completion of pre-germinative metabolic activities during the priming process (Bourioug *et al.*, 2020). Primed seeds germinated soon after planting compared to untreated dry seeds since seed priming stimulates an array of biochemical changes such as hydrolysis of starch, activation of enzymes and breaking dormancy in the seed (Patel and Rai, 2018; Tania *et al.*, 2020). Furthermore early reserve breakdown and reserve mobilization might also be the cause of significant reduction in emergence time due to readily available assimilate during germination (Farooq *et al.*, 2005; Farooq *et al.*, 2006).

The results are in line with Alhariri and Boras (2020) and Mahmood-Ur-Rehman *et al.* (2020) who reported that seeds treated with different chemicals germinated faster than untreated seeds (control). Moreover, Alam *et al.* (2013) found that unprimed spinach seeds took longer to emerge compared to primed seed. Synchronized emergence of primed seeds can insure a vigorous and better crop stand with rapid canopy development, giving plants a preliminary advantage over weeds resulting in increased weed competitiveness (Dhage and Anishettar, 2007; Raj and Syriac, 2017; Juraimi *et al.*, 2020). Moreover, Safiatou (2012) reported that seed priming improved the competitive ability of a crop against weeds, and faster emergence along with increased vigour of a primed stand is the key factors for tolerating weeds.

Days to 90% maturity. Seed soaking in different priming chemicals along with frequent irrigation resulted in lowest mean number of days to reach 90% maturity. The result of interaction effect showed that, the earliest days to maturity (97.00 days) was recorded from the treatment combination of four days irrigation intervals with distilled water treatment which was statistically similar to the combined effect of gibberelic acid seed treatment and four days irrigation interval (99.33 days). The longest days to maturity (109.00 days) was recorded on unprimed seeds with the longest irrigation interval (Table 2).

The accelerated maturity of carrot roots irrigated with frequent irrigation interval might be associated with easily uptake of nutrients as the available water helps the plant to dissolve the nutrients and move through transpiration pull which in turn helps carrot roots to mature early. In addition, early emergence due to priming can contribute to early maturity. Plants which emerge early can reach maturity earlier. The results of the present study are in agreement with the findings of Reid and Gillespie (2017), who observed accelerated maturity of carrot roots with frequent irrigation intervals. Similarly, Safiatou (2012), Singh *et al.* (2015) and Aluko *et al.* (2020) also reported that compared to unprimed seeds, primed seed took significantly fewer days to emerge and reach maturity.

Yield

Marketable yield. Distilled water treatment consistently increased marketable yield of carrot similarly, increasing the duration of irrigation interval up to seven days intervals hasincreased the marketable yield of carrot. In the interaction effect, the highest marketable yield (33.73 t ha^{-1}) was recorded from seeds soaked in distilled water and irrigated in every seven days interval followed by seeds primed with distilled water and irrigated at ten days interval with the values of (28.30 t ha^{-1}) which was statistically similar with that of plants grown in the treatment combination of four days irrigation interval with distilled water treatment (27.96 t ha^{-1}). On the other hand the lowest (16.53 t ha^{-1}) marketable carrot yield was obtained from the combination of unprimed seeds with ten days irrigation interval (Table 3).

The reason for higher marketable yield from primed seeds and irrigated at seven days irrigation interval might be due to uniform and vigorous seedling growth, well-developed root system and efficient subsequent growth with lesser competition for nutrient and water that eventually led to higher yield. The lower marketable yield resulted from non-primed seeds might be associated with suboptimal uniformity at emergence resulting in poor uniformity

Table 3 - Interaction effect of seed priming techniques and irrigation interval on yield parameters of carrot

Treatment combinations		Total root yield (t ha^{-1})	Marketable root yield (t ha^{-1})
Irrigation intervals	Priming techniques		
Four days intervals	Gibberelic acid	29.03 cd	26.76 cd
	Distilled water	29.23 bc	27.03 bcd
	None primed	23.33 f	20.66 f
	Potassium nitrate	27.73 cde	25.03 cde
Seven days intervals	Gibberelic acid	29.53 bc	27.96 bc
	Distilled water	35.23 a	33.73 a
	None primed	24.46 ef	22.06 ef
	Potassium nitrate	28.90 cd	27.36 bcd
Ten days intervals	Gibberelic acid	27.63 cde	25.63 cde
	Distilled water	32.53 ab	30.63 ab
	None primed	19.33 g	16.53 g
	Potassium nitrate	25.73 def	24.03 def
LSD (5%)		3.08	3.23
CV (%)		5.40	6.30
SE+/-		1.51	1.62

Means with the same letter/s in column are not significantly different; * = significant ($p<0.05$); CV = Coefficient variance; LSD = Least significant difference; SE= standard error.

in plant size. On the other hand longer irrigation interval with non- primed seed resulted in carrot roots which are unfit for the market. Similar studies were made by Knox *et al.* (2012) who reported that supply of adequate water was critical for high quality vegetable production. The current results are supported by the findings of Govinden-Soulange and Levantard (2008), Alam *et al.* (2013) and Castañares and Bouzo (2018) who reported that seed priming is a mean to improve early flowering, maturity time and yield of a crop due to early seedling growth.

Total carrot root yield. The interaction effect of irrigation interval and priming techniques significantly impacted total carrot root yield. The highest total fresh root yield of carrot (35.23 t ha^{-1}) was recorded from distilled water seed treatment combined with seven days irrigation interval which was statistically similar with total yield obtained from the combination of ten days irrigation interval and distilled water treatment (32.53 t ha^{-1}) followed by the average fresh total root yield obtained from the interaction effects of gibberelic acid with seven days irrigation interval (29.53 t ha^{-1}). On the other hand the lowest (19.33 t ha^{-1}) total fresh root yield of carrot was recorded for plants produced from non-primed seeds and irrigated at ten days interval (Table 3).

The increased total root yield due to priming and seven days irrigation interval might be due to early seedling growth, and improved plant stands with the benefits of priming. Moreover, seven days irrigation interval produced higher yield because of sufficient soil moisture in the root zone which enhanced the uptake and assimilation of nutrients. This result was in agreement with the finding of Hamma *et al.* (2012) who reported that optimum irrigation interval significantly produced higher plant height, weight of individual root and yield per hectare of carrot.

4. Discussion and Conclusions

The results of the present study showed that phenological and yield related parameters of carrot plant were significantly influenced by both seed priming techniques, irrigation intervals and their interaction. Frequent irrigation intervals led to higher marketable root yield due to the increment in the percentage emergence, decrease in the mean emergence time and in the number of days to reach 90% maturity. The highest marketable carrot root yield 33.73 t ha^{-1} was obtained combining distilled water treatment and seven days irrigation interval.

Based on the results of the present study, plants obtained from distilled water primed seeds and irrigated at seven days interval recorded the shortest days to mean emergence time, day to maturity and, highest marketable root yield of carrot which can be recommended for economical production of carrot in the study area and areas with similar agro-ecologies. Future research will focus on studying the effect of different concentrations of priming solutions and the duration of seed priming on seedling emergence, growth and yield.

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