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POTASH APPLICATION ENHANCES THE YIELD AND SEED ATTRIBUTES OF CARROT BY IMPROVING THE QUALITY OF TERTIARY UMBEL SEEDS

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Potash has significant role in improving yield, quality and seed structure but its availability is becoming limiting in most of the areas on the globe. This study was carried out during winter 2015 and 2016 to investigate the impact of various potash levels (0, 20, 40, 60, 80, 100 and 120 kg ha^{-1}) on seed yield and quality of carrot (*Daucus carota*) cv. T-29. Potash significantly affected yield as well as seed quality attributes of carrot. Application of potash @ 80 to 100 kg ha^{-1} produced highest seed yield, 1000-seed weight of primary and secondary umbels. Seed quality traits, including final germination percentage (17% and 15%) and vigour index of seeds (49% and 42%), respectively, from primary and secondary umbels was also enhanced with potash @ 80 to 100 kg ha^{-1}. Moreover, yield and quality, in terms of 1000-seed weight, germination (%) and vigour of tertiary umbel seeds was appreciably enhanced by potash application up to 60%, 45% and 80%, respectively, compared to control. Interestingly, all seed biochemical attributes including electrical conductivity and lipid peroxidation were the lowest, while activities of defense related enzymes (superoxide dismutase, peroxidases, catalase) were enhanced for seeds collected from primary, secondary and tertiary umbel of plants supplied with potash @ 80 or 100 kg ha^{-1}. However, further increase in potash did not result in significant enhancement of various seed attributes from all umbel types. It may be concluded that farmers and seed companies can apply potash @ 80 to 100 kg ha^{-1} for getting higher yield and good quality of carrot seeds from all umbel orders, keeping in view the fertility status of their soils.
Keywords: *Daucus carota*, potash levels, vigour, seed leachates, lipid peroxidation, enzyme activity.

INTRODUCTION

Carrot (*Daucus carota* L.) is an important crop, from family Umbelliferae, cultivated for edible roots (Malek *et al*., 2012). It is economically important vegetable crop worldwide with respect to area (9.90 thousand ha), production (27.39 million tons) and the average yield (22.41 t ha^{-1}) (FAOSTAT, 2014). In Pakistan, carrot ranks third among winter vegetables and is cultivated on an area of 13.3 thousand hectares with 229.1 thousand tons production, having 2.8% share in total vegetable production. Punjab holds 68.4% share in carrot production with 149.9 thousand tons (Anonymous, 2016). Carrot contains β-carotene, xanthophylls, lycopene and anthocyanin, which are present in yellow, orange, red, purple and black coloured carrots (Ahmad *et al*., 2012). It is cooked as vegetable in soups, stews and also used for pickles, jam, sweet dishes preparation (Kabir *et al.*, 2000). Carrot seeds also have aromatic, stimulant and medicinal properties (Tavares *et al*., 2008).

Being a direct seeded crop, seed quality is prerequisite to achieve good yield of carrot (Amjad *et al*., 2004). Seed quality of carrot relies on umbel order (Pereira *et al*., 2008), besides several other factors. Blooming period of carrot is long because primary, secondary, tertiary and quaternary umbels appear sequentially. Moreover, flowering in individual umbel varies from 7-15 days. This long period of flowering causes uneven maturation of seeds produced in umbels of different orders; therefore, vary in physiological quality (Panayotov, 2005; Gomes, 2012). Primary umbels seeds are of superior quality than seeds from secondary and tertiary umbels (Amjad *et al*., 2005a; Pereira *et al*., 2008; Ilyas *et al*., 2013). Seed vigor and conductivity of seed leachates are the main characteristic of seed quality, and used to determine the quality of seed lot (Amjad *et al*., 2004). Increased electrical conductivity of seeds leachates is an indication of reduced vigour and is also associated with malondialdehyde (MDA) contents, an index of membrane lipid peroxidation. Lipid peroxidation is induced by free radicals, which disorganize the membranes (Goel and Sheoran, 2003). According to Vangronsveld and Clijsters (1994), increased production of hydrogen peroxide (H_2O_2), the superoxide radical (O_2^-) and the hydroxyl radical (OH^-), collectively termed as reactive oxygen species (ROS), cause damage to seed membranes. However, cells have an intricate defense system involving antioxidant enzymes (peroxidases (POD), catalase (CAT), ascorbate peroxidase (APX) and superoxide dismutase (SOD), which help in scavenging of these ROS (Martins and Mourato, 2008).

The balanced plant nutrition has marked effect on yield and quality seed by influencing the metabolism and chemical composition of seed (Read *et al*., 2006). Results of various studies revealed that Nitrogen, Phosphorus and Potassium @ 75, 90 and 100 kg per hectare gave good carrot seed yield (Amjad *et al*., 2005b; Ilyas *et al*., 2013). Potassium (K), being a major nutrient, have a vital role in plant growth and sustainable crop production. It is taken up by plants in large quantities than any other component except nitrogen (Baligar *et al*., 2001; IRRI, 2007; Bukhsh *et al*., 2009). K assists in plant cell osmo-regulation, maintenance of turgor pressure and helps in stomatal opening and closing (Yang *et al*., 2004). K sources and doses may influence size of seed, which can affect physiological quality, primarily seed vigor (Rossetto *et al*., 1994; Carvalho and Nakagawa, 2000). K is an essential part of the membranes and known as the activator for pyruvate kinase and other essential enzymes, regulating respiration and carbohydrate metabolism. It also has important role in photosynthesis, activation of enzymes, glucose transportation, improving synthesis of protein and triggers (alpha) α- amylase activity in the seeds, which are considered important processes influencing the seed yield (Mehdi *et al*., 2003; Shad *et al*., 2004; Bukhsh *et al*., 2011). As K levels are raised to certain extent, escalated translocation of photosynthates to the developing seeds leads to formation of large size seeds, while deficiency of this element will lead to either shrunken or undersize seeds (Paricha and Bansal, 2002; Tiwari and Gavin, 2003). Little or less usage of potassium fertilizers is leading to potassium deficiency (Akhtar *et al*., 2003) and is limiting the crop yield (Yang *et al*., 2003; Ali *et al*., 2008). Previously, Amjad *et al*. (2005b) studied the effect of various potash levels on seed yield of carrot, but their findings do not explain the impact of potash on seed quality, particularly lipid peroxidation, EC of seed leachates and antioxidant enzymes in seeds. The present study was therefore contemplated to investigate the effect of different levels of potassium on yield and quality of carrot seed produced under agro-ecological conditions of Faisalabad. Moreover, impact of applied potash doses on improvement of tertiary umbels seed quality was also assessed.

MATERIALS AND METHODS

Experiments were conducted during 2015 and 2016 at Vegetable Area (31.4336° N, 73.0683° E), and Vegetable Seed Lab, Institute of Horticultural Sciences, University of Agriculture, Faisalabad, Pakistan. Soil of the experimental area was prepared to a good tilth. Farmyard manures (40 ton ha^{-1}) and fertilizers (@111:111:123 NPK kg ha^{-1}) were applied, using urea, DAP and sulphate of potash (SOP) as a source of nitrogen, phosphorous and potash, respectively. Seeds of carrot cv. T-29 were sown on September 27 during 2015 and 2016, on both sides of raised beds prepared 75 cm apart. First irrigation was applied just after seed sowing, while subsequent irrigations were applied depending upon the requirement of crop. Carrots were ready for steckling preparation after 120 days of sowing. Off-type (poor coloured) roots, as well as small sized, cracked, injured, diseased and forked roots were discarded and healthy standard sized roots (25-30 cm long and 7-9 cm in diameter) were selected to prepare stecklings for seed production. Land was prepared for steckling plantation and all P (125 kg ha^{-1}) and $1/3^{rd}$ dose of N (41.6 kg ha^{-1}) was applied before ridge preparation.

Uniform sized stecklings were planted on the top of ridges, which were 75 cm apart, keeping plant to plant distance of 30 cm, during first week of January of both years. Field was irrigated after plantation and pre-emergence weedicide (stomp) was sprayed within 24 hours of irrigation. Different doses of potash (0, 20, 40, 60, 80, 100 or 120 kg ha^{-1}) were applied as band placement. Remaining dose of N was applied in two splits, i.e. 41.6 kg ha^{-1} in each split; 30 days after steckling plantation and at the time of flowering. This experiment was laid out according to randomized complete block design (RCBD) with three replications and each replication was comprised of ten plants. Data were collected from five randomly selected plants for various traits related to growth, seed yield and quality, as well as biochemical attributes of seeds viz, plant height at flowering (cm), seed yield per umbel (g), total seed yield per plant (g), and weight (g) of 1000-seed from primary, secondary and tertiary umbels. Seed quality, in terms of germination (%), vigour and electrical conductivity of seed leachates, was assessed. Biochemical attributes of seeds namely, MDA contents and activities of antioxidant enzymes (SOD, POD and CAT), were also determined as described under.

***Seed germination and vigour index*:** Harvested seeds from primary, secondary and tertiary umbels were subjected to germination test, performed at 24±2°C for 7 days, with four replicates of 25 seeds for each treatment. Data were recorded for seed germination (%) and vigour index (Abdul-Baki and Anderson, 1973).

***Electrical conductivity (EC) of seed leachates (µS/cm)*:** EC of seed leachates (an indicator of membrane damage) was determined, after 24 hour by soaking seeds (1.0 g) in 50 ml of deionized water, using a digital conductivity meter (Cyberscan Con 11, Eutech instruments, Singapore). Conductivity of three replicates of seeds from each of primary, secondary and tertiary umbel of each treatment was determined.

***Malondialdehyde (MDA) contents (µmols/g Fw)*:** To estimate lipid peroxidation in carrot seeds, the malondialdehyde contents were assayed using the method of Heath and Packer (1968).

Antioxidant enzymes assays:

***Preparation of extracts*:** For estimation of antioxidant enzymes activities, samples (1 g) were homogenized in two millilitre phosphate buffer (pH 7.2) in pre-chilled mortar and pestle. After thorough centrifugation at 10,000 g for 10 min in a micro-centrifuge (235-A, Pegasus Scientific Inc., USA), supernatant was collected in eppendorf tubes, and used for the further assays of the following enzymes.

***Superoxide dismutase (Unit kg^{-1} protein)*:** Superoxide dismutase (SOD) (EC 1.15.1.1) activity was measured by following the method described by Stajner and Popovic (2009).

***Peroxidase (Unit kg^{-1} protein)*:** Peroxidase (POD) enzyme (EC 1.11.1.7) activity was determined as described previously by Liu *et al*. (2009).

***Catalase (Unit kg^{-1} protein)*:** Activity of catalase (CAT) enzyme (EC 1.11.1.6) was assayed according to the method of Liu *et al*. (2009).

Statistical analysis:

Data were collected during both years and analyzed statistically using analysis of variance (ANOVA) technique (Steel *et al*., 1997) in computer based program Statistix 8.1. Tukey's test (P≤0.05) was used to compare the mean values of treatments for significant difference.

RESULTS

***Plant height (cm)*:** Plant height was significantly affected by the application of various levels of potash, being maximum for 100 kg ha^{-1} potash, during both years. However, it (100 kg ha^{-1}) was statistically at par with 60, 80 and 120 kg ha^{-1} during both years. Shortest sized plants were recorded at 0 kg ha^{-1} (Table 1).

***Seed yield per umbel (g)*:** Seed yield per umbel varied significantly due to the influence of potash levels (Table 2). Seed yield of primary umbel was highest in response to 100 kg ha^{-1} potash, during year 2015 and 2016. On the other hand, seed weight per secondary umbel was highest for 100 kg ha^{-1} potash. Same trend was observed in tertiary umbels seed weight, which was highest in response to 100 kg ha^{-1} potash, but was statistically similar to 80 and 120 kg ha^{-1} potash during 2015, while with 80 kg ha^{-1} during 2016. Minimum seed weight of all umbel types was obtained in treatment where no potash was applied during both years.

***Total seed yield (g)*:** Total seed yield per plant was influenced by different potash levels (Table 1) and was found highest in response to the application of 100 kg ha^{-1} potash that was statistically similar to 120 and 80 kg ha^{-1} during 2015, while with 80 kg ha^{-1} during 2016. The least seed yield per plant was obtained at 0 kg ha^{-1}, which was statistically not different from 20 kg ha^{-1} during 2015 and 2016.

***1000-seed weight per umbel (g)*:** Thousand seed weight per umbel followed almost the same trend as seed weight per umbel, i.e., highest 1000-seed weight was noticed for 100 kg ha^{-1} potash, in all types of umbels, during both years (Table 3). During 2016, there was no statistical difference in

Table 1. Effect of different potash levels on plant height and total seed yield per plant of carrot cv. T-29.

Treatments (kg K ha^{-1})	Plant height (cm)		Seed yield per plant (g)	
	2015	2016	2015	2016
K-0	78.7±1.98d	77.0±1.05d	31.6±1.16d	27.5±1.17d
K-20	81.4±2.70cd	82.0±2.54cd	33.0±1.58d	29.4±0.67d
K-40	86.7±2.63b-d	88.4±2.47b-d	39.6±1.18c	34.4±0.39c
K-60	91.5±3.14a-d	93.4±2.51a-c	45.1±1.32b	41.2±0.43b
K-80	99.5±2.94ab	100.8±2.63ab	50.2±1.47a	47.8±1.52a
K-100	104.4±1.48a	105.4±3.38a	53.3±1.65a	48.6±1.31a
K-120	94.1±5.13a-c	95.7±4.93ab	51.8±1.88a	43.7±1.09b

Data represent the means ± SE of three replicates. Mean values having same letters in a column are statistically similar to each other at P<0.05 according to Tukey Test.

Table 2. Seed yield per umbel of primary, secondary and tertiary umbels of carrot cv. T-29 in response to different potash levels.

Treatments (kg K ha^{-1})	Seed yield per umbel (g)					
	2015			2016		
	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary
K-0	6.00±0.51d	18.3±1.16d	7.25±0.58c	5.12±0.13c	16.1±0.84d	6.27±0.23d
K-20	6.20±0.47d	19.1±0.94d	7.63±0.55c	5.23±0.19c	17.4±1.02cd	6.77±0.27cd
K-40	7.22±0.65cd	23.4±1.00c	8.95±0.50bc	6.27±0.64c	20.4±0.61c	7.75±0.17c
K-60	8.27±0.40bc	27.1±1.62b	9.75±0.13b	7.83±0.24b	24.0±0.71b	9.36±0.46b
K-80	9.45±0.27ab	29.0±1.29ab	11.70±0.14a	9.05±0.08ab	27.8±1.25a	10.90±0.35a
K-100	10.70±0.28a	30.6±1.35a	12.00±0.33a	9.36±0.26a	28.3±0.77a	11.10±0.33a
K-120	10.50±0.48a	29.5±1.47ab	11.90±0.95a	8.78±0.20ab	24.9±1.09ab	10.00±0.51ab

Data represent the means ± SE of three replicates. Mean values having same letters in a column are statistically similar to each other at P<0.05 according to Tukey Test.

weight of 1000-seed from secondary umbels obtained from 80, 100 and 120 kg ha^{-1} treatments, while statistically non-significant difference between 80 and 100 kg ha^{-1} was recorded for 1000-seed weight of tertiary umbels and both were at par with 120 kg ha^{-1}. The lowest weight of 1000-seed from primary, secondary and tertiary umbels was noticed in control treatment during both years and was statistically similar to 20 kg ha^{-1} potash treatment.

***Germination (%) of primary, secondary and tertiary umbel seeds*:** The highest germination in primary, secondary and tertiary umbel seeds was observed when 80 kg ha^{-1} potash was applied during 2015 and 2016. The least germination percentage in seeds of all types of umbels was recorded at 0 kg ha^{-1} during both years (Table 4). Furthermore, overall germination percentage decreased with increase in umbel order, i.e., highest in primary and lowest in tertiary umbel seeds.

***Vigour index of primary, secondary and tertiary umbel seeds*:** Potash application significantly increased vigour of seeds collected from primary, secondary and tertiary umbel seeds up to 80 kg ha^{-1} but, further increase in dose of potash did not significantly enhanced seed vigour during both years. The least vigour index of seeds from all umbel orders was noticed for 0 kg ha^{-1} during both years (Table 4). It is also obvious from overall results that mean vigour index of tertiary umbel seeds was half than that of primary and secondary umbel seeds.

***Malondialdehyde contents (µmols/g Fw)*:** Malondialdehyde (MDA) contents of seeds from primary, secondary and tertiary umbels were lowest in response to 80 kg ha^{-1} potash

Table 3. 1000-seed weight of primary, secondary and tertiary umbels of carrot cv. T-29 in response to different potash levels.

Treatments (kg K ha^{-1})	1000-seed weight (g)					
	2015			2016		
	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary
K-0	2.76±0.24d	2.44±0.15d	1.36±0.05d	2.88±0.11d	2.28±0.12c	1.21±0.06d
K-20	2.84±0.13d	2.53±0.21cd	1.38±0.06d	3.03±0.27cd	2.39±0.14c	1.28±0.03d
K-40	3.62±0.18c	2.89±0.05cd	1.58±0.06cd	3.53±0.15c	2.62±0.09bc	1.47±0.08c
K-60	4.29±0.10b	3.00±0.01bc	1.79±0.02bc	4.18±0.12b	2.97±0.10b	1.71±0.09b
K-80	4.33±0.05ab	3.51±0.12ab	1.99±0.07ab	4.81±0.08a	3.54±0.04a	1.99±0.04a
K-100	4.94±0.06a	3.84±0.11a	2.11±0.01a	4.87±0.07a	3.67±0.13a	2.05±0.01a
K-120	4.91±0.12ab	3.65±0.15a	2.07±0.05a	4.48±0.17ab	3.43±0.06a	1.87±0.07ab

Data represent the means ± SE of three replicates. Mean values having same letters in a column are statistically similar to each other at $P<0.05$ according to Tukey Test.

Table 4. Effect of different potash levels on germination and vigour index of primary, secondary and tertiary umbel seeds of carrot cv. T-29.

Treatments (kg K ha^{-1})	Germination (%)					
	2015			2016		
	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary
K-0	80.4±1.20b	76.5±2.07c	40.2±1.65d	81.0±2.20b	73.5±2.09c	39.2±1.23c
K-20	83.3±3.17ab	78.4±3.17bc	43.1±2.40cd	82.4±2.07b	76.5±2.07bc	41.2±2.08bc
K-40	85.3±2.07ab	80.4±1.20a-c	45.1±2.27b-d	83.3±3.17b	79.4±2.34a-c	44.0±2.06bc
K-60	90.2±4.32ab	81.4±1.34a-c	49.0±1.20a-d	89.2±2.40ab	81.2±1.20ab	46.1±1.24b
K-80	94.1±2.07a	87.2±3.17a	57.8±3.17ab	95.1±1.20a	85.3±2.08a	56.8±1.49a
K-100	92.1±2.39a	85.3±2.07ab	54.9±2.17ab	93.1±2.46a	83.3±3.17a	55.0±1.34a
K-120	91.2±2.07ab	83.3±1.75a-c	51.9±4.32a-c	90.2±1.20ab	82.4±2.47ab	52.9±2.13a
	Vigour index					
K-0	626.1±3.75d	617.7±4.17d	215.5±2.83d	644.1±2.64bc	607.5±2.59b	208.2±3.59d
K-20	633.3±4.31cd	636.4±3.38cd	227.7±3.81d	652.2±3.75bc	624.2±3.84b	225.7±4.13cd
K-40	664.1±5.15cd	656.9±5.03cd	243.4±1.83cd	690.9±3.91bc	673.0±2.96b	248.7±2.18cd
K-60	778.6±4.43bc	701.5±3.86bd	283.81±2.42c	759.4±3.33a	707.6±3.26b	273.6±3.46c
K-80	937.5±4.15a	823.2±5.73a	404.1±3.42a	959.5±4.35a	924.3±3.68a	400.8±4.03a
K-100	876.2±3.36ab	803.5±4.38ab	394.7±4.33a	916.8±2.22a	900.3±2.76a	388.6±4.41a
K-120	822.5±2.28ab	741.4±3.43ac	337.6±3.26b	886.9±3.17a	828.8±3.55a	333.2±2.69b

Data represent the means ± SE of three replicates. Mean values having same letters in a column are statistically similar to each other at $P<0.05$ according to Tukey Test.

Table 5. Effect of different potash levels on malondialdehyde contents (μmols/g Fw) of seeds from primary, secondary and tertiary umbels of carrot cv. T-29.

Treatments (kg K ha^{-1})	Malondialdehyde contents					
	2015			2016		
	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary
K-0	1.92±0.05a	1.99±0.06a	5.01±0.02a	1.99±0.03a	2.2±0.08a	5.14±0.17a
K-20	1.87±0.01ab	1.92±0.02a	4.93±0.09ab	1.95±0.04ab	2.1±0.05ab	5.02±0.11a
K-40	1.71±0.03bc	1.87±0.04a	4.81±0.07ab	1.80±0.02bc	1.92±0.06b	4.74±0.10ab
K-60	1.61±0.05cd	1.65±0.08b	4.51±0.15bc	1.65±0.08cd	1.71±0.02c	4.46±0.12bc
K-80	1.31±0.04e	1.43±0.01c	4.00±0.17c	1.48±0.006d	1.41±0.04d	3.88±0.08d
K-100	1.40±0.09de	1.49±0.007bc	4.18±0.12c	1.49±0.05d	1.53±0.02cd	4.00±0.16cd
K-120	1.51±0.07c-e	1.57±0.03bc	4.27±0.14cd	1.52±0.06d	1.65±0.03c	4.22±0.14cd

Data represent the means ± SE of three replicates. Mean values having same letters in a column are statistically similar to each other at P<0.05 according to Tukey Test.

application during both years. Moreover, MDA contents in response to 80 and 100 kg ha^{-1} potash application were statistically similar or at par with each other in seeds of all umbel types (Table 5). However, highest MDA contents from seeds of primary, secondary and tertiary umbels was noticed for control treatment (0 kg ha^{-1}) during both years.

Electrical conductivity (μS/cm)**:** It is obvious from results that electrical conductivity of seed leachates were lower for potash application @ 80 and 100 kg ha^{-1} during both years (Fig. 1).

The lowest electrical conductivity, after 24 hours of seeds soaking, was recorded from primary umbel seeds that received 80 kg potash ha^{-1} during 2015 and 2016 respectively. Electrical conductivity of secondary umbel seeds was minimum during 2015 and 2016 in response to 80 kg ha^{-1} potash application. The conductivity of seeds from tertiary umbel, after 24 hour of seeds soaking, was the lowest in response to 80 kg ha^{-1} potash during 2015 and 2016. Maximum conductivity of seed leachates from primary, secondary and tertiary umbel was noticed at 0 kg ha^{-1} during both years.

Superoxide dismutase activity (U kg^{-1} protein)**:** Results related to superoxide dismutase activity (SOD) from the seeds of primary umbel exhibited significant increase in SOD activity with increase in potash levels up to 80 kg ha^{-1} and then declined during both years (Fig. 2). Maximum SOD activity was recorded for primary umbel seeds collected from plants fertilized with 80 kg potash ha^{-1} during both years. In the same way, SOD activity of secondary umbel seeds increased in response to potash application, being highest at 80 kg ha^{-1} followed by 100 kg ha^{-1}. Superoxide dismutase activity of tertiary umbel seeds was highest in response to 80 kg potash ha^{-1}, during 2015 and 2016, respectively. However, the least value for superoxide dismutase activity was observed from primary, secondary and tertiary umbel seeds at 0 kg ha^{-1} during 2015 and 2016, respectively.

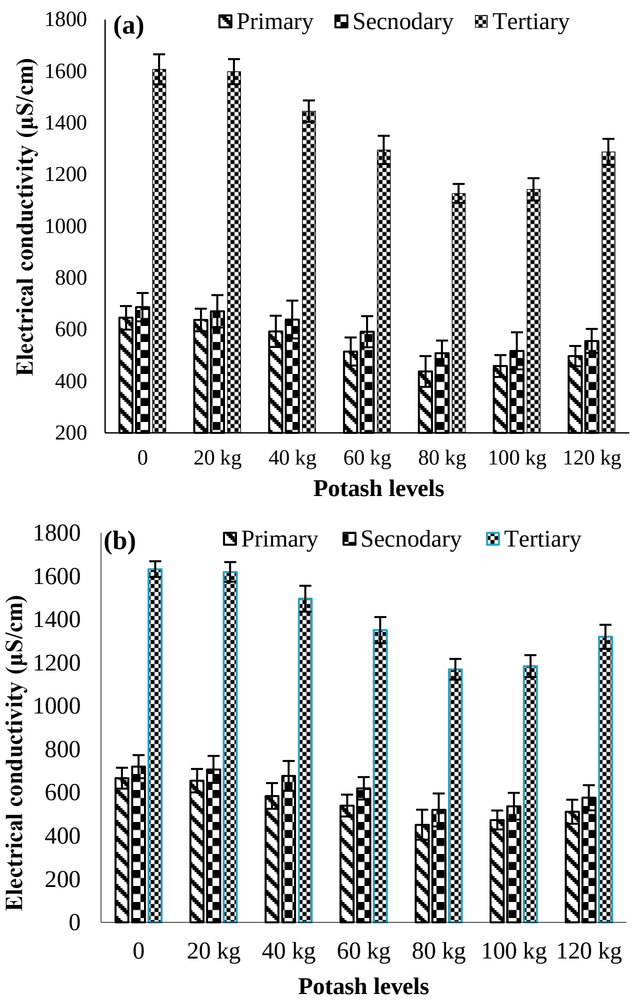

Figure 1. Electrical conductivity of seed leachates of primary, secondary and tertiary umbel seeds of carrot cv. T-29 in response to different potash levels during 2015 (a) and 2016 (b). Vertical bars indicate ± SE of means. n= 3

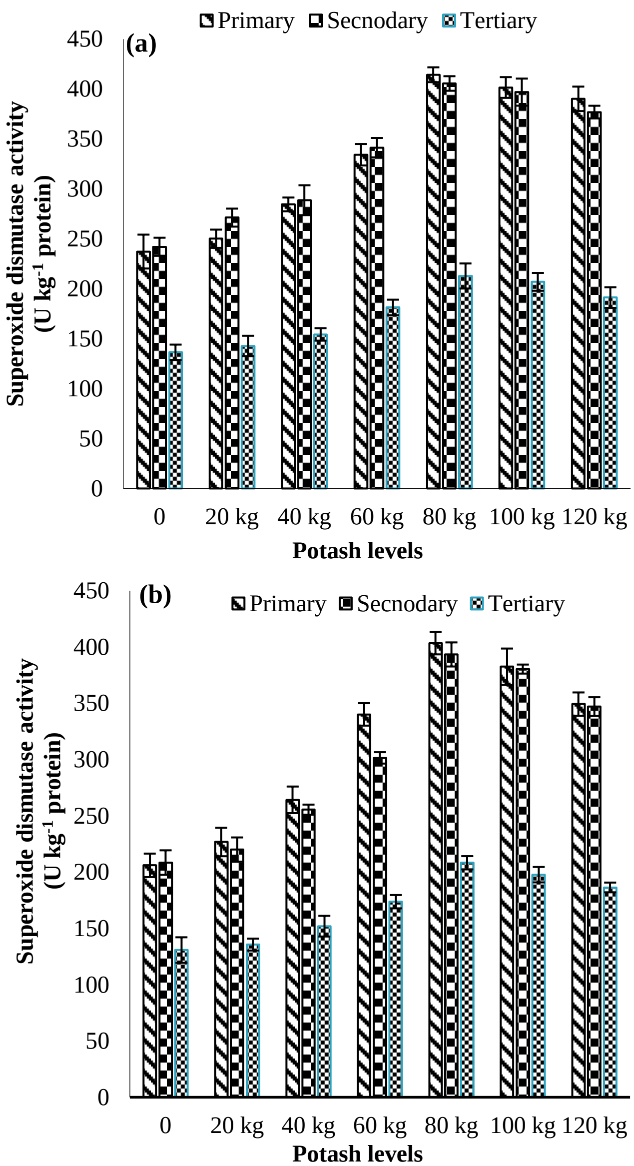

Figure 2. Superoxide dismutase activity of primary, secondary and tertiary umbel seeds of carrot cv. T-29 in response to different potash levels during 2015 (a) and 2016 (b). Vertical bars indicate ± SE of means. n= 3

Peroxidase activity (U kg^{-1} protein)**:** It is explicit from the results that highest peroxidase activity (POD) of seeds collected from primary umbels was recorded for 80 kg ha^{-1} during 2015 and 2016, which implies better natural defense system due to potash application. Seeds of secondary umbels exhibited maximum POD activity at 80 kg ha^{-1} during both years. Highest peroxidase activity of seeds collected from tertiary umbels of plants fertilized with 80 kg ha^{-1} potash, was noticed during 2015 and 2016. The lowest peroxidase activity was recorded for 0 kg ha^{-1} in seeds of all umbel types, during both years (Fig. 3).

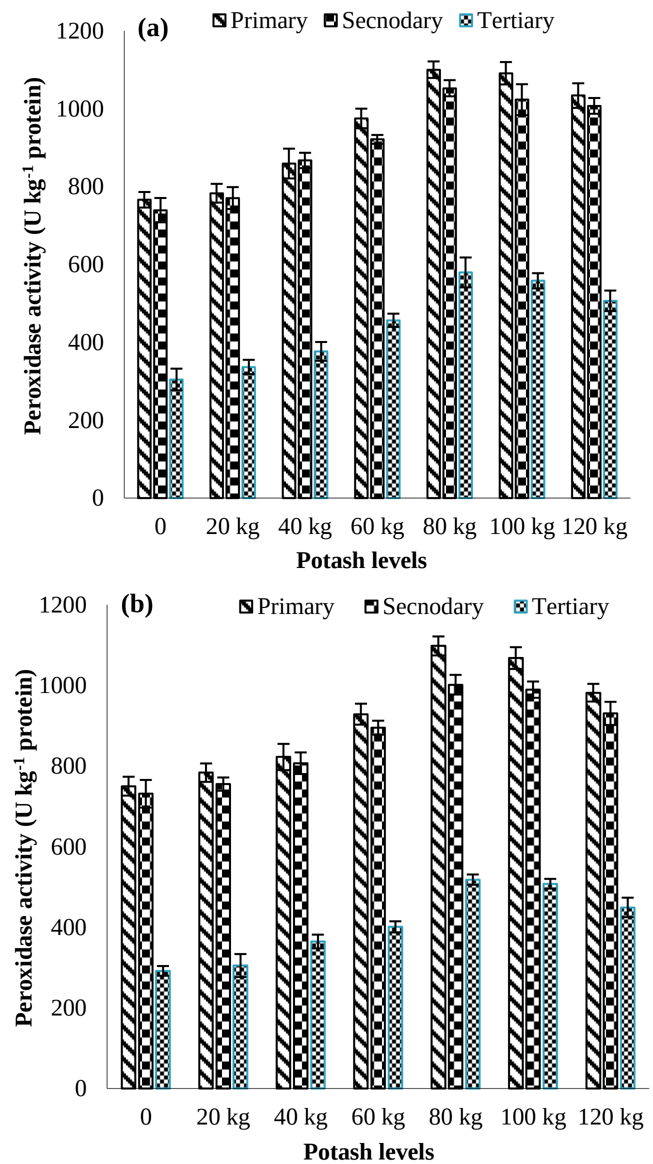

Figure 3. Peroxidase activity of primary, secondary and tertiary umbel seeds of carrot cv. T-29 in response to different potash levels during 2015 (a) and 2016 (b). Vertical bars indicate ± SE of means. n= 3

Catalase activity (U kg^{-1} protein)**:** It is evident from results that catalase activity (CAT) of seeds collected from primary umbels was highest for 80 kg ha^{-1} during both years. Maximum activity of catalase in seeds collected from secondary umbel was noticed for potash @ 80 kg ha^{-1} during 2015 and 2016. Potash application @ 80 kg ha^{-1} resulted in highest catalase activity in tertiary umbel seeds, during both years. However, the lowest catalase activity in primary, secondary and tertiary umbel seeds was noticed for 0 kg ha^{-1} (Fig. 4).

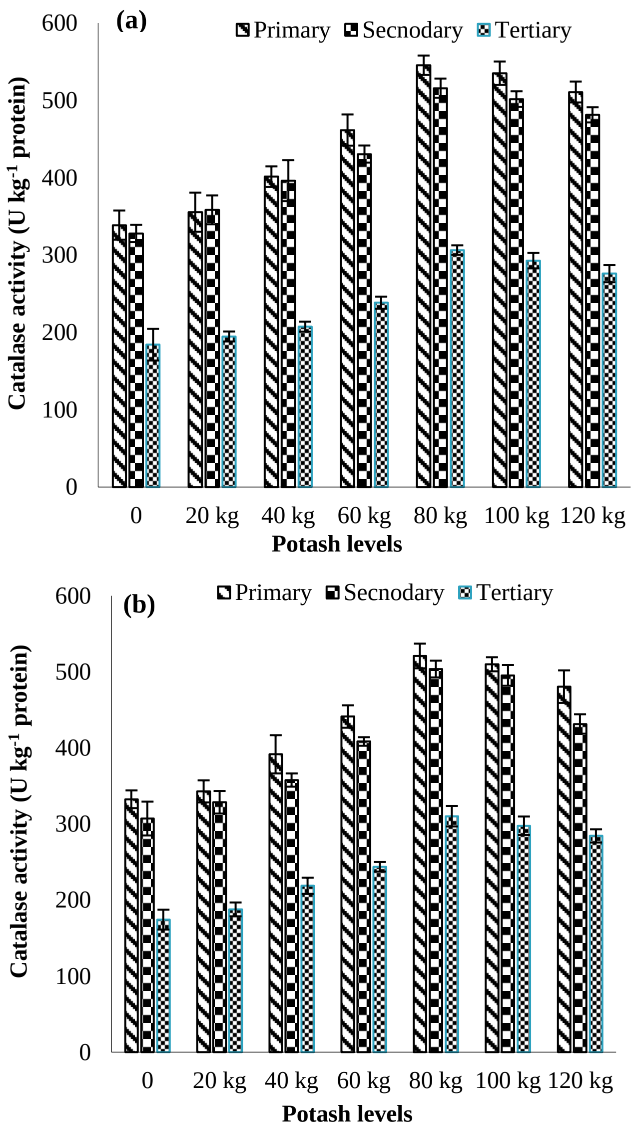

Figure 4. Catalase activity of primary, secondary and tertiary umbel seeds of carrot cv. T-29 in response to different potash levels during 2015 (a) and 2016 (b). Vertical bars indicate ± SE of means. n= 3

DISCUSSION

Potassium is one of the important macronutrients, which is required by crops in large amount next to nitrogen (IRRI, 2007). In Pakistani soils, reserves of potash are reducing day by day more rapidly, probably at an estimated rate of 0.3 kg ha^{-1} year^{-1} (Ahmad and Rashid, 2003). Results of present study showed that potash significantly enhanced all attributes of carrot seed crop when applied up to 100 kg ha^{-1} but further increase in potash application rate did not show any significant difference in measured traits and exhibited statistically similar results with 120 kg ha^{-1}. Similarly, Hussain *et al.* (2011) and Uddin *et al.* (2013) also observed an increase in growth parameters up to a certain level of potash supply but further increase in dose of potash did not show any significant improvement in measured traits of mungbean and rice. Results are also coherent by the findings of Boulbaba *et al.* (2005) who stated that increase in potash supply from 100 kg to 120 kg ha^{-1} did not significantly enhance the chickpea production, yet had depressive impact.

Results of this study validate that soil application of potash to carrot seed plants significantly improved vegetative growth characteristics and productivity as well as seed quality attributes. Carrot seed crop was more responsive to applied potassium up to 100 kg ha^{-1} in terms of plant height, while further increase in potash, did not significantly increased height of plants. Application of potash has been reported to increase nitrogen and phosphorus uptake, which leads to better plant growth (Sahai, 2004), which may be the reason of increased plant height. Nutrients have been reported to exert greater influence on seed yield and plants are responsive to the application of potash. Significant effect of potash application on seed weight per umbel (primary, secondary and tertiary umbels) and total seed yield per plant was noted in this study. Increase in seed yield per umbel due to potash application was highest from primary, i.e., up to 75% higher than respective control, followed by secondary (67%) and tertiary umbels (65%). Higher potash levels (80, 100 and 120 kg ha^{-1}) used in this study resulted in higher seed weight than the lower level of potash (0, 20, 40 and 60 kg ha^{-1}), which may be due to role of potash in photosynthates translocation and its ability to produce healthy seeds (Ali *et al*., 2007). Photosynthates production, accumulation, and translocation depends upon photosynthetic make up as well as source to sink correlation efficiency (Yousuf *et al*., 2014). Increase in carrot seed yield with the increasing potash level as compared to control is concomitant with increased yield of okra (Sadat, 2000), chickpea (Samiullah and Khan, 2003) and carrot (Amjad *et al*., 2005b).

Individual seed weight has a prominent effect on the final seed yield. Santos (2010) reported that heavier seeds than the lighter seeds showed improved physiological performance, and ensured better seedlings growth due to higher reserves per unit dry matter. Nutrient elements have a vital role in seed development and hence, positively affect the seed weight in response to supply of optimum dose. It is obvious from results that all potash levels enhanced 1000-seed weight of carrot from primary, secondary and tertiary umbels as compared to control; while 1000-seed weight was highest in response to 80, 100 and 120 kg potash ha^{-1}. Inamullah *et al*. (2013) also

Table 6. Correlation matrix among different attributes of carrot seeds from primary, secondary and tertiary umbels of carrot cv. T-29 during 2015.

	CATP	CATS	CATT	ECP	ECS	ECT	MDAP	MDAS	MDAT	PG%	PODP	PODS	PODT	SG%	SODP	SODS	SODT
CATS	0.897***																
CATT	0.935***	0.932***															
ECP	0.936***	0.924**	0.927***														
ECS	0.897***	0.935***	0.899***	0.921***													
ECT	0.911***	0.896***	0.890***	0.918***	0.943												
MDAP	0.930***	0.851***	0.881***	0.942***	0.864***	0.887***											
MDAS	-0.904***	0.889***	-0.912***	0.938***	0.917***	0.881***	0.892***										
MDAT	-0.952***	-0.772***	0.843***	0.850***	0.790***	0.838***	0.885	0.810***									
PG%	0.742***	0.667***	0.743***	0.742***	-0.636***	-0.714***	0.721***	-0.731***	-0.759***								
PODP	0.915***	0.946***	0.929***	0.961***	-0.931***	-0.901***	0.848***	-0.924***	-0.818***	0.754***							
PODS	0.916***	0.935***	0.920***	-0.918***	-0.929***	0.899***	-0.904***	0.915***	-0.806***	0.713***	0.896***						
PODT	0.937***	0.931***	0.950***	-0.935***	-0.943***	0.920***	-0.897***	-0.940***	0.823***	0.695***	0.923***	0.953***					
SG%	0.664***	0.755***	0.692***	-0.671	0.789***	-0.723***	-0.640***	0.709***	-0.582***	0.389 NS	0.686***	0.744***	0.773***				
SODP	0.955***	0.947***	0.941***	-0.951***	-0.961***	-0.911***	-0.897***	-0.922***	-0.870***	0.705***	0.957***	0.954***	0.945***	0.707***			
SODS	0.936***	0.913***	0.943***	-0.966***	0.919***	-0.903***	-0.899**	0.906***	-0.853***	0.753***	0.963***	0.922***	0.937***	0.688***	0.964***		
SODT	0.903***	0.913***	0.924***	-0.946***	-0.896***	0.898***	-0.899***	-0.943***	0.838***	0.821***	0.940***	0.897***	0.930***	0.747***	0.909***	0.941***	
TG%	0.851***	0.689***	0.811***	-0.766***	-0.724***	0.819***	-0.795***	-0.692***	-0.887***	0.815***	0.747***	0.720***	0.760***	0.499***	0.777***	0.803***	0.787***

***, * show significant at $P \leq 0.001$ and 0.05 levels, while, NS=non-significant

CATP: catalase activity of primary umbel seeds, CATS: catalase activity of secondary umbel seeds, CATT: catalase activity of tertiary umbel seeds, ECP: electrical conductivity of primary umbel seeds, ECS: electrical conductivity of secondary umbel seeds, ECT: electrical conductivity of tertiary umbel seeds, MDAP: malondialdehyde contents of primary umbel seeds, MDAS: malondialdehyde contents of secondary umbel seeds, MDAT: malondialdehyde contents of tertiary umbel seeds, PG%: germination percentage of primary umbel seeds, PODP: peroxidase activity of primary umbel seeds, PODS: peroxidase activity of secondary umbel seeds, PODT: peroxidase activity of tertiary umbel seeds, SG%: germination of secondary umbel seeds, SODP: superoxide dismutase activity of primary umbel seeds, SODS: superoxide dismutase activity of secondary umbel seeds, SODT: superoxide dismutase activity of tertiary umbel seeds, TG%: germination of tertiary umbel seeds.

observed significant increase in thousand grains weight of *Brassica napus* at the highest potash dose (90 kg ha^{-1}). Moreover, Bhende *et al.* (2015) concluded that 1000 seed weight of okra was increased with increase in level of potash up to 75 kg ha^{-1}. Furthermore, Bednarz and Oosterhuis (1999) recorded increase in 1000-seed weight of cotton with increase in level of potash and thus corroborates our findings. Positive effects of potash on increased seed weight can be attributed to enhanced assimilation of CO_2 and photosynthesis in leaves as well as improved transport of photosynthates (Lemoine *et al*., 2013). It is also evident that seeds of primary umbel showed more increase in 1000-seed weight, i.e., up to 70% compared to control, than secondary (60%) and tertiary (55%) umbel seeds, possibly because these are first sink of photosynthates. Moreover, higher 1000-seed weight value of tertiary umbel seed was more or less similar to control (0 kg ha^{-1}) of secondary umbel, which reflects that quality of tertiary umbel seeds can be improved by using proper dose of potash.

Quality of harvested carrot seed was evaluated through germination test, which exhibited significant variation in germination percentage among potash levels. It can be visualized from results that seed quality, in terms of germination percentage, was highest in response to 80 kg ha^{-1} for primary, secondary and tertiary umbel seeds. It is also obvious from overview of results that germination percentage of primary umbel seed was higher than secondary and tertiary umbel seed during both years, which is an established fact (Amjad *et al*., 2005a; George, 2009). Moreover, significant difference in vigour index was also recorded at varying potash levels in a similar pattern. Vigour index of primary and secondary umbel seeds was more or less same during both years, while that of tertiary umbel seeds was even less than half of the primary and secondary umbel seeds vigour. Ali *et al*. (2007) reported significantly enhanced germination of onion seed with increasing the potash level, which support our results. Generally, seeds from tertiary umbels as compared to primary and secondary umbel seeds displayed lower physiological quality (vigour), but their quality was appreciably improved by potash application. Electrical conductivity of seed leachates indicates integrity of seed

Table 7. Correlation matrix among different attributes of carrot seeds from primary, secondary and tertiary umbels of carrot cv. T-29 during 2016.

	CATP	CATS	CATT	ECP	ECS	ECT	MDAP	MDAS	MDAT	PG%	PODP	PODS	PODT	SG%	SODP	SODS	SODT
CATS	0.922 ***																
CATT	0.880 ***	0.914 ***															
ECP	0.913 ***	-0.846 ***	-0.849 ***														
ECS	-0.881 ***	0.887 ***	-0.944 ***	0.866 ***													
ECT	-0.901 ***	-0.879 ***	0.872 ***	0.952 ***	0.921 ***												
MDAP	0.880 ***	-0.823 ***	-0.914 ***	0.896 ***	0.893 ***	0.906 ***											
MDAS	-0.938 ***	0.889 ***	-0.907 ***	0.940 ***	0.941 ***	0.949 ***	0.903 ***										
MDAT	-0.879 ***	-0.875 ***	0.916 ***	0.924 ***	0.914 ***	0.946 ***	0.920 ***	0.909 ***									
PG%	0.869 ***	0.882 ***	0.798 ***	0.733 ***	-0.815 ***	-0.778 ***	0.746 ***	-0.800 ***	-0.832 ***								
PODP	0.936 ***	0.950 ***	0.895 ***	0.848 ***	-0.893 ***	-0.844 ***	0.850 ***	-0.899 ***	-0.859 ***	0.876 ***							
PODS	0.947 ***	0.937 ***	0.858 ***	-0.854 ***	0.858 ***	-0.826 ***	-0.799 ***	0.897 ***	-0.807 ***	0.852 ***	0.935 ***						
PODT	0.886 ***	0.930 ***	0.943 ***	-0.887 ***	-0.941 ***	0.897 ***	-0.885 ***	-0.894 ***	0.931 ***	0.852 ***	0.918 ***	0.897 ***					
SG%	0.672 ***	0.661 ***	0.731 ***	-0.680	0.814 ***	-0.671 ***	-0.692 ***	0.722 ***	-0.738 ***	0.683 ***	0.729 ***	0.720 ***	0.808 ***				
SODP	0.957 ***	0.922 ***	0.891 ***	0.913 ***	-0.908 ***	-0.943 ***	0.909 ***	-0.953 ***	-0.926 ***	0.882 ***	0.916 ***	0.893 ***	0.901 ***	0.730 ***			
SODS	0.963 ***	0.926 ***	0.931 ***	-0.930 ***	0.934 ***	-0.932 ***	-0.927 **	0.941 ***	-0.941 ***	0.847 ***	0.957 ***	0.896 ***	0.935**	0.728 ***	0.956 ***		
SODT	0.903 ***	0.937 ***	0.942 ***	-0.894 ***	-0.921 ***	0.898 ***	-0.904 ***	-0.910 ***	0.933 ***	0.864 ***	0.923 ***	0.908 ***	0.968 ***	0.808 ***	0.934 ***	0.938 ***	
TG%	0.892 ***	0.861 ***	0.905 ***	-0.894 ***	-0.904 ***	0.888 ***	-0.911 ***	-0.885 ***	0.921 ***	0.779 ***	0.877 ***	0.809 ***	0.921 ***	0.711 ***	0.902 ***	0.948 ***	0.895 ***

***, * show significant at $P \leq 0.001$ and 0.05 levels, while, NS=non-significant

CATP: catalase activity of primary umbel seeds, CATS: catalase activity of secondary umbel seeds, CATT: catalase activity of tertiary umbel seeds, ECP: electrical conductivity of primary umbel seeds, ECS: electrical conductivity of secondary umbel seeds, ECT: electrical conductivity of tertiary umbel seeds, MDAP: malondialdehyde contents of primary umbel seeds, MDAS: malondialdehyde contents of secondary umbel seeds, MDAT: malondialdehyde contents of tertiary umbel seeds, PG%: germination percentage of primary umbel seeds, PODP: peroxidase activity of primary umbel seeds, PODS: peroxidase activity of secondary umbel seeds, PODT: peroxidase activity of tertiary umbel seeds, SG%: germination of secondary umbel seeds, SODP: superoxide dismutase activity of primary umbel seeds, SODS: superoxide dismutase activity of secondary umbel seeds, SODT: superoxide dismutase activity of tertiary umbel seeds, TG%: germination of tertiary umbel seeds.

membrane and thus affect their viability, vigour and ultimately their storage behaviour (Khan *et al*., 2003). Electrical conductivity of the harvested carrot seeds was lowest at higher potash application rate, i.e., up to 100 kg ha^{-1}. Lowest electrical conductivity of seed leachates was recorded with 80 kg ha^{-1} from all types of umbels, which can be attributed to enhanced cell membrane integrity (Bilekudari *et al*., 2005). Yet, conductivity of seed leachates from tertiary umbels was more as compared to primary and secondary umbel seeds, the same pattern as for vigour, which indicates less developed membranes of the former as compared to the latter two umbel types.

Reactive oxygen species through oxidative damage to lipids, proteins and nucleic acids can seriously disrupt normal metabolism (Mittler *et al*., 2004), which can lead to changes in the selective permeability of bio-membranes, causing membrane leakage and changes in the activity of membrane-bound enzymes (Apel and Hirt, 2004). Lipid peroxidation is the primary cause of seed deterioration. Our findings indicate that lipid peroxidation was more than two fold higher in seeds of tertiary umbels compared to seeds from primary and secondary umbels. Considerable reduction in malondialdehyde (MDA) contents was noticed due to sufficient (80 kg ha^{-1}) supply of potash in contrast to its limited (0, 20 and 40 kg ha^{-1}) supply. Moreover, increase in MDA contents coincided with the increase in seed leachates. On the basis of these findings, it can be assumed that lipid peroxidation and electrical conductivity of seeds have strong association and also in line with the findings of Sung (1996). Degradation and inactivation of enzymes, decline in the rate of respiration (Ferguson *et al*., 1990) and cell membrane integrity loss are important changes associated with deterioration of seed quality (Taiz and Zeiger, 2006). Defense mechanisms, involving antioxidative enzymes protect cellular membranes and organelles from the harmful effect of ROS and thus are imperative for the maintenance of seed structures (Campos, 2004; Dussert, 2006). In order to determine the possible involvement of antioxidant enzymes in reducing ROS activity and ultimately limiting lipid peroxidation of membranes, activity of superoxide (SOD), peroxidase (POD) and catalase (CAT) was determined in seeds of primary, secondary and tertiary umbels. High level of positive correlation between germination percentage and SOD, POD, CAT activities was observed in seeds from primary, secondary and tertiary umbels. These results are parallel to those of Silva *et al*. (2016) who collected carrot seeds from different umbel orders. These results support the hypothesis of Bailly *et al*. (1996) that an increased lipid peroxidation is linked to a decrease in activity of antioxidant enzymes. Consequently, Bailly *et al.* (2002) suggested a positive correlation among antioxidant enzyme capacity and the vigour of sunflower seeds. Less antioxidant enzymes activity in seeds of tertiary umbels can be due to their maturation under stress condition, i.e., high temperature at the time of seed setting and maturation, which might have affected maturity of seed, and therefore, their membranes were leaky. However, application of potash at high rates improved the enzymatic activity of tertiary umbel seeds. Role of potash observed in present study can be attributed to the activation of defense mechanism to protect cellular membranes. Studies suggested that increasing nutrition status of plant can hamper the ROS production by reducing the NADPH oxidase activity and balancing the photosynthetic electron transport (Cakmak, 2005). Findings are also concurring with earlier reports suggesting that during germination and early seedling development, super oxide dismutase participates in the defense mechanism (Rogozhin *et al*., 2001; Ducic *et al.,* 2003; Wojtyla *et al*., 2006).

***Conclusion*:** On the basis of the present findings, it can be concluded that application of potash @ 80 to100 kg ha^{-1} resulted in highest yield of the best quality seed. Maximum benefit of potash was noticed for seeds of primary and secondary umbels, which were superior in quality, probably because of active defense system (antioxidant enzymes) to prevent the loss in seed quality. However, application of potash also enhanced the physiological quality of tertiary umbel seeds in comparison with control.

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