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PLANTING GEOMETRY EFFECTS ON SEED YIELD AND QUALITY OF TWO RADISH CULTIVARS

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Radish is a direct seeded vegetable crop of both temperate and tropical regions. Crop stand depends on seed quality, besides other factors. Seed production of radish remained neglected in Pakistan and limited work has been done regarding optimization of various aspects of seed production. Therefore, objective of the current work was to standardize the plant spacing (row and plant spacing) of radish for seed production. Stecklings of two radish cultivars (Forty Days and Mino Early) were planted at 30 or 45 cm plant-to-plant and 45, 60 or 75 cm row-to-row spacing. Results showed that branch length, number of branches, plant height, silique length, silique weight, number of seeds per silique, number of siliques per plant, seed yield per plant, 1000-seed weight, and nitrogen, phosphorus and potash (NPK) contents of seeds were higher for the plant and row spacing of 45 × 75 cm. However, seed yield per plot was (10.47 and 5.36%) higher at closer spacing (30 × 45 cm) during the both years. The two cultivars did not differ significantly for most of the studied traits except, branch length, lodging index, insertion height of first silique and silique weight per plant, which were higher for cultivar Mino Early than Forty Days. In conclusion, seed companies and growers can grow radish seed crop at 45 × 75 cm spacing for obtaining high yield of good quality seed.
Keywords: *Raphanus sativus*, plant spacing, stecklings, seed vigour, lodging index

INTRODUCTION

Radish (*Raphanus sativus* L.) is a popular vegetable crop, grown for its roots, which are used for salad and cooking purpose. World production of radish is estimated to be about 7 million tons per year, representing roughly 2% of all vegetables (Kopta and Pokluda, 2013). Radish is grown in Pakistan on an area of 9769 hectares and its production is 160265 tons (GOP, 2016).But unfortunately, most of the seed available in the market is imported from abroad by national and multinational seed companies, because of poor quality of locally produced seed. Low quality of locally produced seed is because of faulty seed production techniques, starting from seed sowing to harvesting and postharvest handling of seed (Ziaf *et al.*, 2017). Seed crop must be healthy; otherwise seed will be of poor quality. Among these factors, planting geometry is very important that affects the ambient environment of the seed crop field, which in turn modifies the crop phenology (Singh *et al.*, 2013), ultimately affecting yield (Baumhardt *et al.*, 2018) and seed quality (Ashraf *et al.*, 2016).

Optimum plant population is of prime importance to get higher yield (Kang *et al.*, 2015). Optimized plant spacing can increase nutritional availability and biomass production of plants (Horbe *et al*., 2016) and ultimately affect seed quality. Optimal row spacing avoids competition for nutrient elements and soil moisture among the crop plants (Chaudhary *et al*., 2015) as well as with weeds (Ashraf *et al.*, 2016), rather suppresses weeds (Champion *et al*., 1998). Moreover, appropriate plant spacing allows a larger proportion of incident radiation to be intercepted by the crop canopy (Pandey *et al*., 2013) and thus affects photosynthetic efficiency and seed yield (Hussain *et al*., 2012).

Oliveira *et al*. (2011) reported that spatial arrangement of seed plants affected the quality of fodder radish (*Raphanus sativus* var. *oleiferus*) seeds; 0.2 m spacing, keeping a population of 30 seeds m^{-2}, was the best. Similarly, seed yield and yield components were significantly influenced by row spacing in forage turnip (Bilgili *et al*., 2003). Moreover, less planting spacing can cause lodging of the seed crop (Oliveira *et al*., 2011; Bilgili *et al*., 2003) and attack of diseases such as *Alternaria* spp. in radish (Oliveira *et al*., 2011). Gonge *et al*. (2004) recorded highest seed yield of Indian radish (*Raphanus sativus* L.) varieties at closer spacing (60 × 15 cm) but wider spacing (60 × 60 cm) produced highest quality seed. But such studies are scarce in radish varieties grown in Pakistan, specifically in Punjab, namely Mino Early and Forty Days. Forty Days is the only cultivar for very sowing during the hot summer months (July-August), while Mino Early is a popular cultivar grown during winter season in Punjab.

So, this study was conducted to determine the suitable planting geometry for getting high yield of good quality seed of these two important radish cultivars. This expedient information will be helpful for public and private seed sector dealing in radish seed production as well as serve as base in other research work related to radish seed production.

MATERIALS AND METHODS

***Plant material, experimental site and design*:** Seeds of commercially cultivated radish varieties *viz*., Mino Early and Forty Days (later on designated as 40-Days) were obtained from Ayub Agriculture Research Institute Faisalabad. The present study was conducted at vegetable experimental area of Institute of Horticultural Sciences, University of Agriculture Faisalabad (Latitude 31°31 N, Longitude 73°10 E and altitude 213 m). Different weather features during the experimental period are mentioned in the Figure 1. The experiment was conducted under randomized complete block design with factorial arrangement repeated thrice.

***Experimental details*:** Seeds of both radish cultivars (Mino Early and 40-Days) were sown by kera method on both sides of ridges, spaced 75 cm apart, on October 10, 2013 and October 13, 2014 respectively during first and second year of study. Mature roots of these crops were used for steckling preparation. Stecklings were prepared by removing lower ½ portion of the root and upper ½ portion of the leaves, keeping leaf bases intact. These stecklings were planted on ridges at different planting arrangement, during December 20, 2014 (1st trial) and December 22, 2015 (2nd trial), mentioned under.

Plant to Plant Distance (cm)	Row to Row distance (cm)		
	45 cm	60 cm	75 cm
30 cm	30 × 45 cm	30 × 60 cm	30 × 75 cm
45 cm	45 × 45 cm	45 × 60 cm	45 × 75 cm

The soil was sandy loam having pH 8.2, electrical conductivity 1.93 dSm^{-1}, organic matter 0.85%, available nitrogen 0.033%, available phosphorus 32 mg kg^{-1}, and potassium 130 mg kg^{-1}. After soil nutrient analysis, fertilizers were applied at the rate of 100:75:75 kg ha^{-1} N:P:K using DAP (diammonium phosphate) and SOP (sulphate of potash). One third of nitrogen whereas full dose of phosphorus and potash fertilizers was applied at sowing time while remaining nitrogen was applied in two splits. Crop was sprayed with imidacloprid during January-February to control aphid population irrigation was applied as per requirement of the crop. Subsequently, ten representative plants from each treatment in each block were selected and used for the collection of data, which are given below.

***Morphological traits*:** The total number of branches arising from the stem (just above ground level) was counted from each tagged plant and the average was calculated. The length of primary branches was measured from the same plants with the measuring tape (from the base of stem to the inflorescence stalk). Height of insertion of first silique was measured from stem base. Days to initiate flowering were counted from the time of steckling plantation to the appearance of flowers. The lodging index was estimated visually and expressed in percentage, having considered the angle formed in the vertical position of the plant's culm in relation to the ground and the area of lodged plants using the methodology of Moes and Stobbe (1991).

$$\text{Lodging-Index (\%)} = I \times LODG \times 2$$

Here I reflects the plants inclination degree, ranging from 0 to 5 (0 = absence of inclination, and 5 = all plants completely lodged); LODG represents the area with lodged plants in the plot, which ranges from 0 to 10, (0 = absence of lodged plants in the plot, and 10 to lodged plants over the whole plot, regardless of their inclination). Siliques were separated from the selected plants, their number was counted, and average length was calculated and weighed. Number of seeds per siliques was counted from the same plants. For seed yield, all the plants in each plot were harvested, dried in shade, siliques were detached, and seed was threshed manually, and expressed as seed yield per plant and per plot basis.

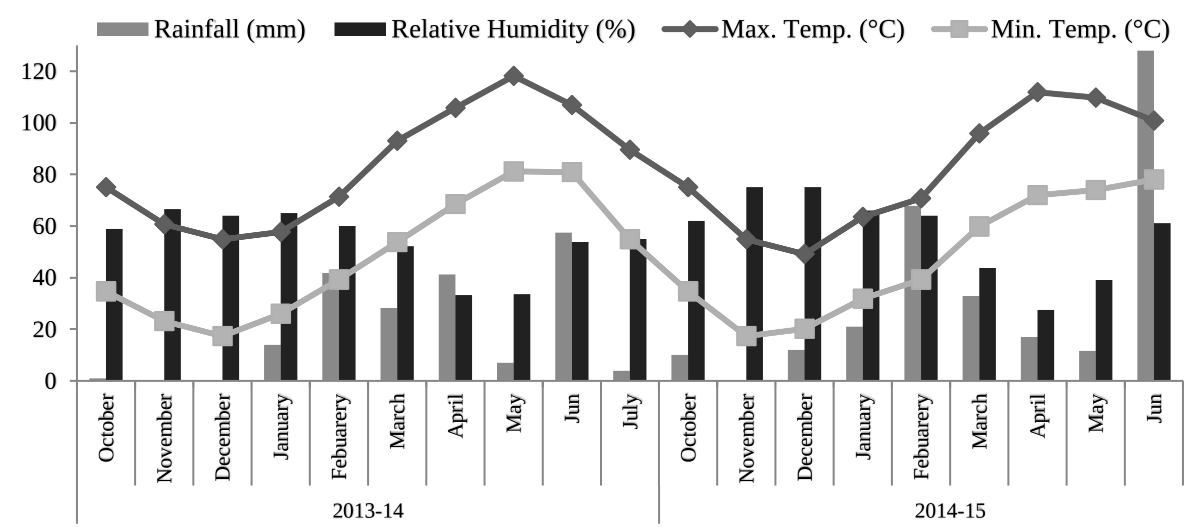

Figure 1. Prevalent temperature, precipitation and relative humidity during the two growing seasons.

***Seed quality assessment*:** Thousand seed weight was determined using an electronic balance (MP-300 Chyo). Standard germination test was performed following rules of AOSA (1990) and vigour index was calculated according the following formula.

Vigour index

= Final germination (%) × total seedling length (cm)

***Nitrogen, phosphorus and potassium contents of seeds*:** Nitrogen content of the seed samples were determined using 0.1 g dry ground sample by using micro-Kjeldhal method as described by Bremner (1982). Phosphorus and potassium contents of seed were determined as per procedure of Wolf (1982).

***Data analysis*:** The collected data were analyzed using the analysis of variance technique using statistical package Statistix 8.1 (Analytical Software, USA).The difference among treatments means were compared using least significant difference test at 5% probability level (Steel *et al.*, 1997).

RESULTS

Plant growth and flowering: Plant height of two varieties did not differ significantly during both years (Table 1). However, planting geometry (row to row and in-row spacing) significantly affected the plant height during both years (Table 1). Plants remained small at closest spacing (30 × 45 cm) but exhibited 52.8% (year 1) to 64.4% (year 2) increase in height at widest spacing used in this study, i.e. 45 × 75 cm, compared with closest spacing. Mino Early produced significantly more branches per plant than 40-Days during both years (Table 1). Number of branches per plant also increased up to 48.6% (year 1) and 45.3% (year 2) at widest spacing (45 × 75 cm) compared with the closest spacing (30 × 45 cm). There was no statistical difference in branch length of two varieties for first year while Mino Early produced longer branches during 2nd year.

Branch length of widely spaced plants was maximum (137.4 and 125.0 cm) during both years, i.e. 91.1% and 72.4% higher

Table 1. Effect of cultivars and spacing on growth parameters of radish seed crop.

	Plant Height (cm)		No of Branches		Branch Length (cm)	
Factors	**2013-14**	**2014-15**	**2013-14**	**2014-15**	**2013-14**	**2014-15**
F 1: variety						
Mino Early	135.39 a	129.33 a	65.52 a	64.82 a	112.14 a	102.28 a
Forty Days	132.44 a	125.50 a	61.69 b	60.47 b	109.42 a	88.11 b
F 2: PS × RS						
30 × 45 cm	100.00 d	91.00 d	49.25 d	49.71 e	71.90 e	72.50 f
30 × 60 cm	125.00 c	115.67 c	56.90 c	55.81 d	104.10 d	77.67 e
30 × 75 cm	135.50 bc	124.83 c	63.98 b	62.48 c	110.80 cd	92.33 d
45 × 45 cm	144.33 ab	138.00 b	67.65 ab	66.92 b	116.02 bc	96.67 c
45 × 60 cm	145.83 ab	145.33 ab	70.65 a	68.65 b	124.42 b	107.00 b
45 × 75 cm	152.83 ab	149.67 a	73.20 a	72.27 a	137.45 a	125.00 a
Interactions:	NS	NS	NS	NS	NS	NS
Variety × Plant Spacing						

NS= Non-significant at 5% probability level.

Table 2. Effect of cultivars and spacing on flowering, silique insertion height and lodging index of radish seed crop.

	Days to Initiate Flowering		Height of Insertion of first silique (cm)		Lodging index	
Factors	**2013-14**	**2014-15**	**2013-14**	**2014-15**	**2013-14**	**2014-15**
F 1: variety						
Mino Early	29.72 a	30.41 a	48.78 a	46.49 a	3.57 a	3.68 a
Forty Days	28.34 a	28.69 a	44.22 b	41.82 b	3.32 a	3.40 b
F 2: PS × RS						
30 × 45 cm	36.17 a	38.60a	51.10 a	48.38 ab	5.92 a	5.82 a
30 × 60 cm	32.18 b	29.85 b	50.65 ab	48.65 a	4.60 b	4.70 b
30 × 75 cm	30.00 b	28.63 b	46.46 abc	44.45 abc	3.26 c	3.53 c
45 × 45 cm	26.50 c	27.88 b	45.40 bc	42.73 bc	2.92 c	3.23 c
45 × 60 cm	25.00 c	26.35 b	43.08 c	40.42 c	2.48 cd	2.58 c
45 × 75 cm	24.35 c	26.20 b	42.33 c	40.33 c	1.50 d	1.38 d
Interactions:	NS	NS	NS	NS	NS	NS
Variety × Plant Spacing						

NS= Non-significant at 5% probability level than the closest spacing (Table 1). Lodging index was statistically same in both varieties for first year, but during 2nd year, variety Mino Early exhibited lodging index was statistically higher than 40-Days (Table 1). Lodging index was statistically lowest at widest plant spacing during both years and increased up to 74.5 to 77.5% at narrowest plant spacing. Closely spaced plants started flowering later than all plants in other spacing, i.e. 36.1 and 38.6 days at 30 × 45 cm spacing during the two years. Moreover, there was no significant difference in flower initiation time among 45 × 45 cm, 45 × 60 cm and 45 × 75 cm. Both varieties started flowering at statistically similar time during both years of study (Table 1).

Height of first silique insertion in 40-Days (44.2 and 41.8 cm) variety was significantly less than Mino Early (48.7 and 46.5 cm). First silique was inserted at significantly lower height in widely spaced plants (45 × 60 cm and 45 × 75 cm) than closest spaced plants (Table 2). Silique length of the two varieties did not differ significantly but was significantly affected by plant spacing. Silique length of widely spaced plants was 35.7 and 39.4% more than the closest spaced plants (Table 3). Number of siliques per silique were statistically same in both varieties but were significantly different for various spacings, being 44.9 and 53.6% higher than the closest spaced plants (Table 3).

Mino Early produced significantly higher silique weight per plant than 40-Days variety during both years of experimentation. Plants spaced 45 × 75 cm apart produced 19.1 and 22.6% higher silique weight than those spaced 30 × 45 cm apart (Table 3). Number of seeds per silique did not differ significantly among the two varieties but were significantly affected by planting geometries (Table 4). Number of seeds per silique was highest at 45 × 75 cm spacing during both years; being 45.9 and 36.8% more number of seeds per silique than the closest spacing (30 × 45 cm).

Seed yield and seed quality: Seed yield per plant of Mino Early was slightly higher than 40-Days variety, but the difference was statistically non-significant (Table 5). Seed yield per plant continued to increase gradually with increase in plant spacing during both years; up to 52% increase was

Table 3. Effect of cultivars and spacing on silique length, number and weight of radish seed crop.

	Silique length (cm)		**No. of Silique per plant**		**Silique weight per plant (g)**	
Factors	**2013-14**	**2014-15**	**2013-14**	**2014-15**	**2013-14**	**2014-15**
F 1: variety						
Mino Early	4.99 a	4.61 a	616.67 a	614.50 a	146.94 a	143.62 a
Forty Days	4.80 a	4.32 a	606.89 a	595.00 a	144.03 b	142.69 b
F 2: PS × RS						
30 × 45 cm	4.14 c	3.78 c	511.50 d	478.50 d	131.67 f	128.78 f
30 × 60 cm	4.61 bc	4.02 c	547.17 d	522.33 cd	137.49 e	134.80 e
30 × 75 cm	4.73 bc	4.15 bc	590.17 c	550.17 c	143.66 d	140.90 d
45 × 45 cm	4.97 ab	4.50 abc	631.67 bc	644.00 b	149 44 c	146.56 c
45 × 60 cm	5.33 ab	5.07 ab	649.00 b	698.17 a	153.86 b	150.71 b
45 × 75 cm	5.62 a	5.27 a	741.17 a	735.33 a	156.80 a	157.19 a
Interactions:	NS	NS	NS	NS	NS	NS
Variety × Plant Spacing						

NS= Non-significant at 5% probability level

Table 4. Effect of cultivars and spacing on seeds per silique and seed yield of radish seed crop.

	No of seeds per Silique		**Seed Yield per plant (g)**		**Seed Yield per plot (g)**	
Factors	**2013-14**	**2014-15**	**2013-14**	**2014-15**	**2013-14**	**2014-15**
F 1: variety						
Mino Early	4.69 a	4.80 a	54.31 a	52.62 a	1297.9 a	1380.2 a
Forty Days	4.62 a	4.53 a	52.36 a	49.52 a	1288.3 a	1375.4 a
F 2: PS × RS						
30 × 45 cm	3.70 d	3.96 b	42.33 c	39.77 d	1353.1 a	1409.8 a
30 × 60 cm	4.26 c	4.44 ab	43.55 bc	43.27 cd	1334.8 ab	1401.2 b
30 × 75 cm	4.66 bc	4.50 ab	48.88 b	50.03 bc	1305.4 abc	1380.2 c
45 × 45 cm	4.75 bc	4.52 ab	59.28 a	54.07 ab	1276.9 bcd	1379.7 c
45 × 60 cm	5.15 ab	5.17 a	61.61 a	58.90 a	1263.5 cd	1375.8 d
45 × 75 cm	5.40 a	5.42 a	64.33 a	60.38 a	1224.8 d	1338.0 e
Interactions:	NS	NS	NS	NS	NS	NS
Variety × Plant Spacing						

NS= Non-significant at 5% probability level

Table 5. Effect of cultivars and spacing on radish seed quality.

	Seed germination %		Vigor index		1000 seed weight (g)	
Factors	**2013-14**	**2014-15**	**2013-14**	**2014-15**	**2013-14**	**2014-15**
F 1: variety						
Mino Early	94.32 a	93.79 a	1344.0 a	1302.4 a	10.96 a	10.33 a
Forty Days	93.56 a	93.24 a	1336.1 a	1316.1 a	10.89 a	10.19 a
F 2: PS × RS						
30 × 45 cm	93.36 a	93.15 a	1295.1 bc	1265.8 a	9.06 c	8.77 d
30 × 60 cm	92.73 a	93.40 a	1291.2 bc	1270.4 a	10.07 bc	9.56 cd
30 × 75 cm	94.78 a	93.95 a	1264.1 c	1265.6 a	10.35 bc	9.79 cd
45 × 45 cm	93.48 a	93.70 a	1370.5 ab	1368.4 a	11.03 ab	10.40 bc
45 × 60 cm	94.58 a	93.58 a	1392.2 a	1320.0 a	12.44 a	11.27 ab
45 × 75 cm	94.70 a	93.33 a	1427.0 a	1374.2 a	12.60 a	11.76 a
Interactions: Variety × Plant Spacing	NS	NS	NS	NS	NS	NS

NS= Non-significant at 5% probability level

Table 6. Effect of cultivars and spacing on NPK contents of radish seeds.

	Nitrogen content (%)		Phosphorous content (ppm)		Potassium content (ppm)	
Factors	**2013-14**	**2014-15**	**2013-14**	**2014-15**	**2013-14**	**2014-15**
F 1: variety						
Mino Early	0.90 a	0.92 a	55.44 a	55.72 a	11.16 a	10.94 a
Forty Days	0.87 a	0.87 a	52.17 a	53.11 a	10.61 a	10.63 a
F 2: PS × RS						
30 × 45 cm	0.61 c	0.63 d	41.83 c	46.50 d	7.57 b	7.83 b
30 × 60 cm	0.72 bc	0.72 cd	47.00 bc	50.17 cd	9.80 ab	9.83 ab
30 × 75 cm	0.73 bc	0.78 c	50.00 b	52.33 bcd	10.67 ab	11.00 a
45 × 45 cm	1.00 ab	0.94 b	58.33 a	55.50 abc	11.69 a	11.70 a
45 × 60 cm	1.07 ab	1.10 a	61.33 a	59.50 ab	12.39 a	12.12 a
45 × 75 cm	1.20 a	1.20 a	64.33 a	62.50 a	13.20 a	12.21 a
Interactions: Variety × Plant Spacing	NS	NS	NS	NS	NS	NS

NS= Non-significant at 5% probability level

recorded at widest spacing compared with narrowest spacing. In contrast to seed yield per plant, seed yield per plot was highest at 30 × 45 cm spacing and exhibited 10.4 and 5.3% reduction at widest spacing compared with the closest spacing (Table 5). Seed yield per plot was same in both varieties during both years. Plant spacing and varieties had non-significant effect on germination of seed produced during both years. But, 1000-seed weight was significantly higher at 45 × 75 cm than at 30 × 45 cm during both years (Table 5). Moreover, vigor index of seeds obtained from 45 × 75 cm spaced plants was 10.1 and 8.5% higher than spaced 30 × 45 cm apart, during 1st and 2nd years, respectively (Table 5). There was no significant difference in 1000-seed weight and vigor index of the two varieties studied.

Impact of plant spacing on seed quality was assessed in terms of seed NPK contents. Seed NPK contents of the two varieties did not differ significantly during both years. However, seed NPK contacts were significantly varied due to plant spacing (Table 6). It can be observed from the results that seed NPK contents enhanced with increase in plant spacing. Highest increase (90.4 and 96.7%) with increase in plant spacing was observed in seed nitrogen contents during both years. Seed phosphorus contents at widest spacing were 53.7 and 34.4% higher than closest plant spacing during 1st and 2nd year or study, respectively. Seeds from plants spaced 45 × 75 cm apart contained 74.3 and 55.9% more potassium than plants spaced 30 × 45 cm apart.

DISCUSSION

It is a common observation that plant height increases with reduction in plant spacing due to increase in plant population (Oliveira *et al*., 2011). But plants were taller at wider spacing in this study, which can be attributed to reduction in plant growth in dense plant spacing due to high level of competition (Getachew *et al*., 2013; Leon *et al*., 2013). Radish seed plant canopy is open till start of pod setting, after which plant height is not significantly increased, and therefore does not show etiolation as observed in dense canopy plants (Oliveira *et al*., 2011). Because of open canopy, plants produced more number of branches with increased lengths. Such widely spaced plants were also strong enough with sturdy stems and therefore, exhibited significantly less lodging than closely spaced plants with weak stems. These results are in line with the findings of Bilgili *et al*. (2003) who reported enhanced stem thickness, more branches per plant and less lodging at wider spacing in forage turnip.

Row spacing modifies plant architecture, photosynthetic competence of leaves and dry matter partitioning in several field crops (Hussain *et al*., 2012; Kuai *et al*., 2015). Accordingly, number of siliques, their length and weight as well as seeds per silique of a radish seed crop was also positively influenced by wide row and plant spacing due additional amount of absorbed nutrition. However, values of these parameters started to decrease at dense spacing because crops grown in too narrow rows may result in severe inter-row competition. Enhanced number of seeds at wider spacing due to less competition than dense spacing was also reported by Dass *et al*. (2016) in rice.

Thousand seed weight was higher from widely spaced plants compared with closely spaced plants plots possibly because of better uptake of nutrients and improved photosynthetic efficiency of plants (Kuai *et al*., 2015). Ashraf *et al*. (2016) noticed increase in 1000-grain weight of rice at wider spacing than closer spacing. Seed yield per plant was higher for widely spaced plants but seed yield per plot was higher for closely spaced plants because of more plants per plot than the plots having widely spaced plants. Bilgili *et al*. (2003) also recorded higher seed yield in closely spaced plots than at wider spacing in forage turnip. Similarly, Oliveira *et al*. (2011) reported that seed yield of fodder radish increased with increase in plant population due to close plant spacing, which affirms our results.

Plant spacing did not influence seed germination but seed vigour of widely spaced was significantly better than closely spaced plants. These results agree to the findings of Oliveira *et al*. (2011) who stated that spacing did not affect germination but improved vigour. This difference can be due to better nutrient availability to widely spaced plants which produced seeds of higher vigour than closely spaced plants, the later possibly suffered from nutrient competition (Kamboj and Sharma, 2015). To confirm this hypothesis, we analyzed NPK contents of seeds obtained from plants sown at different spacing. Higher NPK contents were recorded in seeds collected from plants grown at wider spacing than plants grown at closer spacing.

***Conclusion*:** Seed obtained from widely spaced (45 × 75 cm) radish plants was better in almost all aspects than the seed collected from closely spaced (30 × 45 cm) plants, except seed yield per plot that was higher for the later one. However, this difference in seed yield per plot was only 10.47 and 5.36%. So, seed companies and radish growers can grow radish seed crop at 45 × 75 cm spacing for obtaining high yield of good quality seed.

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