Journal of Applied Horticulture, 22(2): 164-168, 2020

DOI: 10.37855/jah.2020.v22i02.30

Journal of Applied Horticulture

ISSN: 0972-1045

Productivity and nutritional quality of radish under different planting geometry

Luu Thi Thuy[1], Im Seon Young[2], Muhammad Farooq[3]* and Dong-Jin Lee[2]

*[1]Field Crops Research Institute, Hai Duong, Vietnam. [2]Department of Crop Science and Biotechnology, Dankook University, Chungnam 3116, Republic of Korea. [3]Department of Crop Sciences, College of Agricultural and Marine Sciences, Sultan Qaboos University, Al-Khoud 123, Oman. *E-mail: farooqcp@squ.edu.om*

Abstract

The Korean radish (*Raphanus raphanistrum* subsp. sativus) cvs. BDM, CDM, HGM, HTM, JKM and SJM, and a standard Vietnamese *cv.* R13 were evaluated for adaptability, yield and quality as affected by planting geometry in Vietnam over two growing seasons. In first season, radish cultivars were planted under the planting geometries 30 × 15 cm, 30 × 30 cm, or 60 × 30 cm. The Korean radish cultivars produced better yield of good quality than the Vietnamese cultivar. The Korean and Vietnamese cultivars had better root yield with the planting geometries of 30 × 15 cm and 60 × 30 cm, respectively. The Korean radish cultivars SJM, JKM and BDM, performed well in Vietnam, in terms of yield and quality than the Vietnamese cultivar. Therefore, Korean radish cultivars may be grown in Vietnam.

Key words: Cultivars, growth, quality, *Raphanus sativus*, planting geometry, yield

Introduction

Radish (*Raphanus sativus* L.) is a cool season, fast growing, root vegetable crop. The short growing season allows it to be grown in rotations and/or in companion cropping systems. Although it is a cool season crop, it can be cultivated out of its normal growing season (Kang *et al.*, 2015). Total annual production of radish in the world is about 7 million tonnes, representing about 2% of all vegetables (Kopta and Pokluda, 2013).

Radish is cultivated both for its roots and leaves. Its immature green pods are also used as vegetable in South and South-East Asia (Bonnema *et al.*, 2011; Jatoi *et al.*, 2011). Roots and leaves of radish are rich source of riboflavin, folate, ascorbate, vitamin A, B6 and C, and possesses anti-mutagenic, anti-cancer and antimicrobial potential (Esaki and Onozaki, 1982; Hashem and Saleh, 1999; Kapoor, 2000; Gutierrez and Perez, 2004).

In South Korea, radish is cultivated on about 10% of total vegetable area. Its demand is continuously increasing. Several factors including labor shortage and low marginal rate of return are restricting further expansion (Kang *et al.*, 2015). Growing radish cultivars of Korean origin overseas and then importing them to Korea is a pragmatic alternative. Vietnam with a diverse set of climates, offers an attractive option. Before initiating commercial production of radish cultivars of Korean origin, the production potential and quality appraisal in the new environment is needed. There is a large morphological variation in cultivated radish in different parts of the world (Ahmad *et al.*, 2003), and the market preference of each geographic region could strongly influence the morphological selection of roots, resulting in extremely variable radish root shape and color.

Cultivar appraisal, in new environments, include the optimization of planting date, planting geometries and spacing (Parvez *et al.*, 2004; Dhaliwal, 2008). Planting density has a strong influence on the growth, and yield formation of radish (Sharma *et al.*, 2013). Sub- and supra-optimal planting density may decrease the quality and yield of the crop (Maboko and Plooy, 2009). Sub-optimum plant population cause substantial reduction in crop yield (Minami *et al.*, 1998) as individual plant may yield more under wider spacing but overall yield is less due to low plant density (Bhople *et al.*, 1998; Parvez *et al.*, 2004). Optimum plant density helps in efficient use of resources (light, water and nutrients), and reduces competition between plants for these resources (Kahsay *et al.*, 2014).

To best of our knowledge, radish cultivars of Korean origin have never been evaluated in Vietnam, under different planting geometries, for yield and quality. This study was, therefore, conducted to evaluate growth, yield and quality performance of high yielding radish cultivars of Korean origin as affected by planting geometry in Vietnam.

Materials and methods

Site and soil: This study was conducted at the Experimental Station, Field Crops Research Institute, Hai Duong, Vietnam (20° 53' 40.35" N 106° 17' 4.18" E) during the 2012-2013 and 2013-2014 growing seasons. The temperature ranged from 15.0 to 22.8 °C during the first season and from 15.3 to 25.5 °C during the second season. Average relative humidity was higher during the 2012-2013 growing season (Table 1). The soil was loam in texture with pH (7.3, 7.5), P_2O_5 (114.6, 357.5 mg kg^{-1}), NO_3^- (7.0, 1.7 mg kg^{-1}), NH_4^+ (4.2, 11.4 mg kg^{-1}) and K^+ (106.0, 44.8 mg kg^{-1}) during the first and second growing seasons, respectively.

Plant material: Seed of the Korean radish cultivars BDM, CDM, HGM, HTM, JKM and SJM were obtained from the Kitazawa Seed Company; while seed of the control *cv.* R13 was purchased from the local seed market in Hai Duong, Vietnam. The *cv.* R13 was introduced from China and is popularly cultivated in Vietnam.

Experimental detail: During first growing season, all radish cultivars were planted on 15 November, 2012 under the planting geometries 30 × 15 cm, 30 × 30 cm or 60 × 30 cm. The experiment was conducted in randomized complete block design in factorial arrangement with net plot size of 14.6 m × 1.5 m and was replicated three times.

During the second growing season, based on the results of first season experiment, *cv.* R13 was planted at a geometry of 30 × 30 cm while all Korean cultivars were planted on 13 October 2013 at a planting geometry of 30 × 15 cm. The second year experiment was conducted in randomized complete block design with net plot size of 14.6 × 1.5 m and was replicated three times.

Crop husbandry: After weeding and removal of all plant residues from previous crops, the soil was tilled and raised beds were constructed with a power cultivator. Seed were sown, 2 per hill, at a depth of 0.4 cm, on beds. Fertilizer was applied at 135 N-105 P_2O_5-120 $K_2O \cdot ha^{-1}$. Fully decomposed manure was also applied at 2 $Mg \cdot ha^{-1}$. Plants were thinned to 1 per hill at the 3-leaf stage. After thinning, the soil was turned up to cover the root. Irrigation was applied as per crop requirement. Korean cultivars were harvested on 23 Feb. 2013 and 21 Jan. 2014; *cv.* R13 was harvested on 4 Jan. 2013 and 2 Dec. 2013 during first and second growing seasons, respectively.

Observations: A sub-sample of 5 randomly selected plants in each plot was harvested. Root color was recorded visually. Plant height, from the leaf base to top leaf tip was measured. Leaves were separated from roots to record leaf and root weights. Root length was measured with a ruler from the root collar to the root apical meristem. Root diameter was measured from the middle of the root with a digital Vernier caliper (Mitutoyo 500-196-20, Tokyo, Japan). The whole plot was harvested, leaves were separated from roots, roots were washed to determine total root yield. The brix level was measured using a hand-held refractometer (model ATC-1E, ATAGO, Tokyo, Japan) at 20 °C. Root and leaf ascorbic acid was determined by the 2, 6-dichlorophenol-indophenol method (Anonymous, 2000). Root and leaf samples were extracted with metaphosphoric acid, and the determination of ascorbic acid was done based on its reaction with 2,6-dichloroindophenol dye. Mineral contents (potassium, calcium, magnesium and sodium) were determined by electrophoretic methods using a double capillary analyzer IONOSEP 2002 (Recman, Ostrava, Czech Repub-lic) following Blatny *et al.* (1997).

Statistical analysis: Data were subjected to analysis of variance using CO-Stat (CoHort, Berkeley, CA). The least significant difference (LSD) test was applied for the mean separation (Steel *et al.*, 1997).

Results

During first growing season, growth, yield and related parameters, of different tested radish cultivars, were significantly ($P \leq 0.05$) affected by planting geometry (Table 2). Tested radish cultivars also differed significantly ($P \leq 0.05$) for growth parameters and yield. Interaction of planting geometry treatments and tested radish cultivars was also significant ($P \leq 0.05$) for growth and yield related parameters (Table 2). Maximum plant height (289 mm) was recorded with planting geometry of 30 × 15 cm in cultivar JKM, which was followed by the cultivars SJM and BDM with the same planting geometry. Whereas, minimum plant height (176 mm) was recorded in cultivar HTM with planting geometry of 60 × 30 cm (Table 2). Similarly, maximum leaf weight (307 g) and root length (250.6 mm) was recorded with planting geometry of 60 × 30 cm in cultivar JKM and SJM, respectively; whereas cultivar CDM had minimum leaf weight (62.1 g) and root length (107.8 mm) with planting geometry of 30 × 15 cm (Table 2). Likewise, maximum root diameter (218.8 mm) and root weight (1301.6 g) were recorded with planting geometry of 60 × 30 cm in cultivar HGM and R13, respectively, whereas cultivar R13 had minimum root diameter (45.1 mm) and root weight (192.7 g) with planting geometry of 30 cm × 15 cm (Table 3). Cultivar BDM had maximum root yield (78.5 t ha^{-1}) with planting geometry of 30 × 15 cm, which was similar with cultivar SJM (76.9 t ha^{-1}) at the same planting geometry. However, cultivar R13 had lowest yield (12.8 t ha^{-1}) with planting geometry of 30 × 30 cm (Table 2).

During second growing season, tested radish cultivars differed significantly ($P \leq 0.05$) for growth, yield and related parameters (Table 3). Maximum plant height and leaf weight were noted in cultivar BDM, which was similar with cultivar JKM; whereas minimum plant height was recorded in cultivar CDM, which was similar with cultivar HTM. However, minimum leaf weight was recorded in cultivar R13, which was followed by cultivars HGM and SJM. Maximum root length was recorded in cultivars HTM, which was similar with cultivar JKM, while minimum root length was noted in cultivar BDM (Table 3). Likewise, maximum root diameter was noted in cultivar JKM, which was followed by cultivars HTM, HGM, CDM and SJM; while minimum root diameter was recorded in cultivar R13. All tested Korean radish cultivars, except cultivar BDM for root yield, had more root

Table 1. The mean value of weather parameters recorded during the growing seasons

Month / Year	Temperature (°C)		Relative humidity (%)		Total rainfall (mm)		Sunshine (h)	
	Mean	10 yr. avg.	Mean	10 yr. avg	Mean	10 yr. avg.	Mean	10 yr. avg.
Nov 2012	22.8	>1.6	83	>3	84.4	>30.8	101.0	<46.6
Dec 2012	18.6	>0.8	82	>2	30.5	>10.1	36.0	<85.6
Jan 2013	15.0	<1.3	83	>1	10.6	<14.2	12.7	<59.3
Feb 2013	19.7	>2.4	87	>1	14.2	<8.8	33.5	<10.4
Oct 2013	25.5	>0.5	76	<7	25.5	<103.8	148.6	<21.3
Nov 2013	22.4	>1.2	77	<3	48.2	<5.4	69.6	<78.0
Dec 2013	15.3	<2.5	76	<4	21.9	<1.5	181.0	>59.4
Jan 2014	17.0	>0.7	79	<3	2.0	<22.8	123.8	>51.8

Table 2. Effect of plant spacing on plant height, yield related traits and root yield of different radish cultivars

Plant spacing (PS)	Radish cultivars (RC)							Mean (PS)
	BDM	CDM	HGM	HTM	JKM	SJM	R13	
Plant height (mm)								
30 cm × 15 cm	276ab	209d-g	257a-c	234cd	289a	283ab	244bcd	254.9A
30 cm × 30 cm	244b-d	194fg	218def	214def	254a-c	249a-d	229c-f	228.8B
60 cm × 30 cm	203efg	223c-f	205efg	176g	235cd	204efg	229c-f	210.5B
Mean (RC)	240.9AB	206.1ABC	226.5ABC	207.9ABC	259.4A	245.3A	233.8ABC	
LSD value (P=0.05)	PS = 21.8; RC = 33.3; PS × RC = 35.4							
Leaf weight (g)								
30 cm × 15 cm	168.8 c-m	62.1u	112.4n-s	106.9n-s	184.7c-k	133.1l-r	114.0n-s	126.0B
30 cm × 30 cm	162.5c-o	134.9l-r	146.9g-o	154.9e-p	278.9b	164.7c-m	136.1l-r	168.4AB
60 cm × 30 cm	186.8c-k	83.7st	176.1 c-l	165.9c-m	330.7a	181.1c-l	169.6 c-m	184.8A
Mean (RC)	172.7BCD	093.6G	145.2B-F	142.6 B-F	264.8A	159.6B-F	139.9B-F	
LSD value (P=0.05)	PS = 44.8; RC = 29.3; PS × RC = 28.2							
Root length (mm)								
30 cm × 15 cm	121.9m-u	107.8m-u	129.7l-t	124.8m-u	125.9m-u	135.2l-t	181.4b-e	132.4C
30 cm × 30 cm	126.2m-u	139.0l-t	154.8e-m	147.1i-p	156.3e-m	159.6d-l	179.6b-e	151.8B
60 cm × 30 cm	145.5k-q	135.1l-t	153.0g-o	154.5g-o	170.8b-j	250.6a	164.1d-l	167.7A
Mean (RC)	131.2B-G	127.3B-G	145.9B-G	142.1B-G	151.0B-F	153.0B-F	203.9A	
LSD value (P=0.05)	PS = 14.7; RC = 22.4; PS × RC = 19.5							
Root diameter (mm)								
30 cm × 15 cm	91.7e-s	96.6e-s	87.0j-u	93.5e-s	72.1j-u	93.9e-s	45.1j-u	82.8B
30 cm × 30 cm	94.1e-s	135.5b-p	107.5c-r	104.4c-r	120.6b-q	110.6c-r	45.8j-u	102.6AB
60 cm × 30 cm	110.6c-r	97.8e-s	218.8a	118.1b-q	94.8e-s	58.9j-u	117.1c-r	116.6A
Mean (RC)	98.8AB	110AB	137.7A	105.3AB	95.8AB	107.2AB	49.9C	
LSD value (P=0.05)	PS = 27.5; RC = 41.9; PS × RC = 45.2							
Root weight (g)								
30 cm × 15 cm	620.7j-q	479.2k-r	525.3k-r	556.7k-r	392.7n-s	607.9j-q	192.7t	482.2C
30 cm × 30 cm	714.7h-n	684.0i-o	843.2e-j	833.3e-j	627.3j-q	1058.9a-e	201.9n-s	709.1B
60 cm × 30 cm	1094.2a-e	753.6f-m	1154.8a-e	1037.7a-e	945.7a-g	468.1k-r	1301.6a	965.1A
Mean (RC)	809.8 AB	638.9 AB	841.1 AB	809.2 AB	655.3 AB	989.5A	287.6C	
LSD value (P=0.05)	PS = 160.6; RC = 245.3; PS × RC = 175.6							
Root yield (t ha^{-1})								
30 cm × 15 cm	78.5a	60.6a-f	66.4a-d	70.4ab	49.7c-k	76.9a	24.4 m-q	61.0A
30 cm × 30 cm	45.2e-m	43.3e-m	53.3b-i	52.7b-i	39.7f-n	67.0a-d	12.8 m-q	44.8B
60 cm × 30 cm	34.6i-o	23.8m-q	36.5i-o	32.8i-o	29.9j-p	14.8m-q	41.2e-m	30.5C
Mean (RC)	52.8 AB	42.6 AB	52.1 AB	52.0 AB	39.7 AB	61.7A	17.3C	
LSD value (P=0.05)	PS = 9.1; RC = 13.9; PS × RC = 15.7							

Values sharing the same case letter, for a parameter, do not differ significantly at $P \leq 0.05$.

Table 3. Plant height, yield related traits and root yield of radish cultivars during 2013-2014

Cultivars	Plant height (mm)	Leaf weight (g)	Root length (mm)	Root diameter (mm)	Root weight (g)	Root yield (t ha^{-1})
BDM	196a	226.0a	143.3c	083.0b	0658.5e	052.0bc
CDM	141b	150.0b	170.3b	124.0a	1417.5b	069.1b
HGM	161ab	111.6bc	172.3b	130.3a	0897.4d	072.1b
HTM	146b	208.2ab	197.1a	136.9a	1925.0a	081.8b
JKM	196a	219.3a	198.0a	140.6a	0989.1d	059.9bc
SJM	165ab	125.9bc	175.0b	120.6a	1248.8c	105.6a
R13	164ab	077.6c	170.3b	044.3c	0186.4f	038.1c
LSD value (P=0.05)	41.5	60.67	20.35	29.55	122.55	23.90

Values sharing the same letter, in a column, do not differ significantly at $P \leq 0.05$.

weight and root yield than the cultivar R13. Maximum root weight was recorded in cultivar HTM, which was followed by cultivar CDM; while minimum root weight was noted in cultivar R13. Maximum root yield was recorded in cultivar SJM, which was followed by cultivars HTM and HGM; while minimum root yield was noted in cultivar R13 (Table 3).

Underground part of radish root usually has white color; however, cultivar R13 had white color of whole root. Conversely, Korean cultivars had above ground part of green color (JKM–dark green + white color; HGU, SJM, HTM, BDM, SDM–green color) (Table 4). All tested Korean cultivars, except cultivar HTM, had better root brix level, and leaf and root ascorbic acid than the cultivar R13 (Table 4).

Table 4. Root color, root brix level, and root and leaf ascorbic acid of radish cultivars during 2013-2014

Cultivars	Root color	Root brix level	Root ascorbic acid (mg kg^{-1} DW)	Leaf ascorbic acid (mg kg^{-1} DW)
BDM	Green + White	5.3a	53a	281c
CDM	Green + White	5.3a	53a	293b
HGM	Green + White	5.2a	52a	296b
HTM	Green + White	4.8b	48b	301b
JKM	Dark green + White	5.4a	54a	321a
SJM	Green + White	5.1a	51a	288c
R13	White	4.7b	47b	180d

Means sharing the same letter, in a column, do not differ significantly at $P \leq 0.05$.

There was no difference in other Korean cultivars for root brix level and leaf ascorbic acid; however, maximum leaf ascorbic acid concentration was recorded in cultivar JKM (Table 4). Likewise, all tested Korean cultivars had higher potassium, calcium and magnesium contents than the cultivar R13 (Table 5). In this regard, highest root potassium, calcium and magnesium contents were noted in cultivar JKM that was followed by cultivar HTM. However, all the tested cultivars didn't differ for root sodium contents (Table 5).

Table 5. Root mineral contents in the radish cultivars during 2013-2014.

Cultivars	K (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	Na (mg kg^{-1})
BDM	2593e	149bc	93b	209
CDM	2706c	155b	96ab	203
HGM	2739b	157b	94b	202
HTM	2778b	159b	98a	201
JKM	2962a	170a	101a	203
SJM	2658d	152b	98a	205
R13	1861f	121d	90bc	202

Means sharing the same letter, in a column, do not differ significantly at $P \leq 0.05$. ns = non-significant

Discussion

Radish cultivars of Korean origin, in particular cultivars SJM, JKM and BDM, performed quite well in terms of yield and quality, even better than the popular control cultivar R13, in Vietnam (Tables 2-5). Growth, yield and related traits, and quality of radish cultivars of Korean origin was better than the standard Vietnam cultivar. This indicates that if grown commercially these radish cultivars of Korean origin may capture the Korean vegetable market.

During first growing season, all Korean cultivars performed better with planting geometry of 30 cm × 15 cm; whereas the performance of standard cultivar 'R13'was better with planting geometry of 30 × 30 cm (Table 2). Raising radish with optimum planting geometry helped fetching good yield of better quality. Because, plant spacing affects the growth of root crops by creating competition for nutrients, water and light among the plants crop (Maboko and Plooy, 2009). Lowering the plant density improved the quality of root quality by increasing root weight and biomass (Bhople *et al.*, 1998; Parvez *et al.*, 2004). Plants having higher density had smaller leaf weight, but had higher plant height and yield. Plants grown in close spacing have high inter or intra competition for the uptake of nutrients resulting in reduced growth of plant and associated roots (Haas, 1983), which is possible reason for lower leaf weight, root length, root diameter and root weight, as has been observed in this study. However, increase in plant spacing provides favorable environment, reduces competition for light and nutrients, resulting in improved growth of root, because plants roots find enough space to move freely for the acquisition of nutrients and water (Satyaveer, 1994). Moreover, plants grown under wide spacing show good growth because less completion exist in plants for nutrient uptake and other resources (Sharma *et al.*, 2013). Plants grown under wider space produced higher leaf weight (Maboko and Plooy, 2009). Conversely, plants grown in close spacing performed better due to proficient utilization of light, water and nutrients, and had better growth. Increase in planting density (close spacing) is directly proportioned to increase in plant height. Increase in plant height may be attributed to better utilization of photosynthetically active radiation (Tetio-Kaho and Gardner, 1988). Radish grown under closed spacing produced better yield than the plants grown under wider space (Warade *et al.*, 2004) as has been observed in this study. Increase in yield is due to efficient uptake and utilization of nutrients by radish plants (Bilekudari *et al.*, 2005). Increase in yield under close plant spacing may contribute to increased or optimum plant density per unit area (Malik *et al.*, 1999). Crop yield was reduced under wider plant spacing due to less plant density per unit area and less plant population than the optimum (Warade *et al.*, 2004).

Root yield during second growing season was better than the first growing season (Tables 2, 3) owing to bright and sunny days, longer sunshine duration, less relative humidity, and relatively mild temperature (Table 1). Root color not only attracts the consumers and enhance its consumption, but it also depicts the nutritional quality of radish. Most often, underground part of radish has white color; however, cultivar R13 has white color of the whole root. Nonetheless, Korean cultivars had above ground part of green color and underground part of white color, which was associated with high root brix level, and leaf and root ascorbic acid concentration (Table 4). Interestingly, quality of cultivar JKM, as indicated by root brix level, root and leaf ascorbic acid concentration, and root potassium, calcium and magnesium contents was better than rest of the Korean cultivars. Root color of cultivar JKM was dark green + white compared with rest of the tested Korean cultivars having green + white color (Table 4).

Ascorbic acid is one of the most important natural antioxidants. Antioxidants of plant-derived origin can elicit a number of *in vivo* effects such as promotion of increased synthesis of endogenous antioxidant defenses or themselves acting directly as antioxidants (Aruoma, 1999). For instance, intake of antioxidants, such as ascorbic acid, in the natural form help reducing the risk of coronary heart disease and cancer (Marchioli *et al.*, 2001).

In conclusion, planting geometry affected growth, yield and quality of different radish cultivars of Korean origin. Plants having higher density had smaller leaf weight, but had higher plant height and yield. All radish cultivars of Korean origin, specifically cultivars, SJM, JKM and BDM performed well under Vietnam conditions, in terms of yield and quality than the standard Vietnam cultivar R13. Radish cultivars of Korean origin may thus be commercially planted in Vietnam for export to Korean vegetable market.

Acknowledgements

Financial support was provided by Dankook University in 2014.

References

Ahmad, F., S. Ahmed and S. Mehmood, 2003. Performance of radish cultivars at Juglate, Northern Areas, Pakistan. *Sarhad J. Agri.*, 19: 489-491.

Anonymous. 2000. *Official Methods of Analysis*. 17th edition. Association of Official Agricultural Chemists, Washington, DC.

Aruoma, O.I. 1999. Free radicals, antioxidants and international nutrition. *Asia Pacific J. Clin. Nutri.*, 8: 53-63.

Blatny, P., F. Kvasnicka, R. Loucka and H. Safarova, 1997. Determination of ammonium, calcium, magnesium, and potassium in silage by capillary isotachophoresis. *J. Agric. Food Chem.*, 45: 3554-3558.

Bhople, S.R., S.G. Bharad, V.N. Dod and S.V. Gholap, 1998. Effect of nitrogen and phosphorus on growth and yield of radish (*Radish sativus* L.) *cv.* Pusa Chetki. *Orissa J. Hort.*, 26: 34-36.

Bilekudari, M.K., V.K. Deshpande and M. Shekhargouda, 2005. Effect of spacing and fertilizer levels on growth, seed yield and quality of radish. *Karnataka J. Agric. Sci.*, 18: 338-342.

Bonnema, G., D.P. Del Carpio and J. Zhao, 2011. Diversity analysis and molecular taxonomy of Brassica vegetable crops. In: *Genetics, Genomics and Breeding of Vegetable Brassicas*, J. Sadowski and C. Kole (eds.). p. 81-124. Science Publishers, New York.

Dhaliwal, M.S. and J.S. Klair, 2008. Sowing date affects development and root yield of radish. *Inter. J. Vegetable Sci.*, 13: 75-93.

Esaki, H. and H. Onozaki, 1982. Antimicrobial action of pungent principles in radish root. *J. Japan Soc. Nutri. Food Sci.*, 35: 207-211.

Gutiérrez, R.M.P. and R.L. Perez, 2004. *Raphanus sativus* (radish): their chemistry and biology. *Scientific World J.*, 4: 811-837.

Haas, P.W. 1983. *The Effects of Plant Density on Agronomic Qualities of Four Species of Grain Amaranth*. Rodale Research Center Report RRC/C-81-8. Rodale Press, Emmaus, PA.

Hashem, F.A. and M.M. Saleh, 1999. Antimicrobial components of some Cruciferae plants. *Phytotherapy Res.*, 13: 329-332.

Jatoi, S.A., A. Javaid, M. Iqbal, O.U. Sayal, M.S. Masood and S.U. Siddiqui, 2011. Genetic diversity in radish germplasm for morphological traits and seed storage proteins. *Pakistan J. Bot.*, 43: 2507-2512.

Kahsay, Y., D. Belew and F. Abay, 2014. Effects of intra - row spacing on plant growth and yield of onion varieties (*Allium cepa* L.) at Aksum, Northern Ethiopia. *Afri. J. Agric. Res.*, 9: 931-940.

Kang, E.S., S.M. Ha, S.R. Cheong, M.W. Seo, S.H. Park, Y.B. Kwack, K.J. Choi and W.B. Chae, 2015. Optimum double-row spacing in the autumn cultivation of radish (*Raphanus sativus* L.). *Korean J. Environ. Agri.*, 34: 204-209.

Kapoor, L.D. 2000. *Handbook of Ayurvedic Medicinal Plants*. CRC Press, Boca Raton, FL.

Kopta, T. and R. Pokluda, 2013. Yields, quality and nutritional parameters of radish (*Raphanus sativus*) cultivars when grown organically in the Czech Republic. *Horti. Sci.,* 40: 16-21.

Maboko, M.M. and C.P. Du Plooy, 2009. Effect of plant spacing on growth and yield of lettuce (*Lactuca sativa* L.) in a soilless production system. *South Afri. J. Plant Soil*, 26: 195-197.

Marchioli, R., C. Schweiger, G. Levantesi, L. Tavazzi and F. Valagussa, 2001. Antioxidant vitamins and prevention of cardiovascular disease: epidemiological and clinical trial data. *Lipids*, 36: 53-63.

Malik, Y.S., B.K. Nehra and N. Singh, 1999. Effect of steckling planting dates and spacing on seed yield of radish (*Raphanus sativus* L.) *cv.* Pusa Chetki. *Vegetable Sci.*, 26: 149-151.

Minami, K., A. Cardoso, F. Costa and F.R. Duarte, 1998. Effect of spacing on radish yield. *Bragantia*, 57: 169-173.

Pervez, M.A., C.M. Ayub, B.A. Saleem, N.A. Virk and N. Mahmood, 2004. Effect of nitrogen levels and spacing on growth and yield of radish (*Raphanus sativus* L.). *Inter. J. Agri. Biol.*, 6: 504-506.

Satyaveer, S., B.K. Nehra and Y.S. Malik, 1994. Carrot seed yield and quality as influenced by different order umbels under varying nitrogen, plant density and geometry. *Crop Res.*, 8: 543-548.

Sharma, U.G., N.J. Vihol and J.C. Chavda, 2013. Influence of plant density and nutrient management on growth, yield and quality of radish (*Raphanus sativus* L.) *cv.* ‘Pusachetki. *Asian J. Hort.*, 8: 671-676.

Steel, R.G.D., J.H. Torrie and D.A. Dicky, 1997. *Principles and Procedures of Statistics, A Biometrical Approach*. 3rd edition. McGraw Hill, New York.

Tetio-Kaho, F. and F.P. Gardner, 1988. Response of maize to plant population density. Canopy development, light relationships, and vegetable growth. *Agron. J.*, 80: 930-935.

Warade, A. D., V.S. Gonge, L.V. Kulwal and J. Girl, 2004. Effect of time of planting and spacing on seed yield and quality of radish var. Pusa Chetki. *Agric. Sci. Digest,* 24: 21-23.

Received: December, 2019; Revised: January, 2020; Accepted: February, 2020