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Seed yield of onion (*Allium cepa* L.) as affected by bulb size and intra-row spacing

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'Bombay Red' is one of the most widely used onion cultivars in Ethiopia. Seed production of this cultivar is expanding among farmers. However, various constraints are reported for the low seed productivity of this cultivar, out of which inappropriate uses of bulb size and intra-row spacing are the most important ones. Therefore, a field experiment was conducted at Bati Futo watershed, Meskan Wereda, Southern Ethiopia under supplemental irrigation in 2012 to find out optimum bulb size and intra-row spacing for quality and economically feasible seed production of the cultivar. The crop was grown in factorial combinations of four different bulb sizes (3-4.0,4.1-5.0, 5.1-6.0 and 6.1-7.0 cm) and four intra-row spacings (10, 15, 20 and 25 cm) in a randomized complete block design with three replications. The results revealed that significantly highest value of days to 50% bolting (27 and 28 days), days to 50% flowering (75 and 81 days), days to 50% maturity (123 and 124 days), number of leaves per plant (37 and 36), biomass (130 and 146 g/plant), flower stalk height (84 and 74 cm), flower stalk diameter (1.62 and 1.75 cm), umbel diameter (5.52 and 5.82 cm), number of umbels per plant (11 and 10), number of umbels per plot (854 and 1016), 1000-seed weight (4.50 and 4.35 g) and seed germination percentage (92 and 91 %) were obtained from bulbs of 6.1 to 7 cm size and 25 cm intra-row spacing, respectively. However, the maximum (2.05 and 1.80) leaf area index was obtained at 6.1 to 7 cm bulb size and 20 cm spacing, respectively. The interaction effects of bulb size and intra-row spacing on number of seeds per umbel, weight of seeds per umbel, seed yield per plant and seed yield per hectare were significant. Significantly higher seed yield (920 to 995 kg/ha) was obtained at the larger bulb size (5.1 to 7 cm) grown at 20 and 25 cm spacing. The highest net field benefits of 245,678 Ethiopian Birr ha^{-1} was obtained from a bulb of 5.1-6.0 cm sizes grown at 20 cm spacing. Hence, for quality and economically feasible seed yield of onion, the treatment combination of 5.1 to 6.0 cm bulb size and 20 cm spacing is recommended to the farmers at Bati Futo watershed.

Key words: Bulb size, intra-row spacing, onion seed production.

INTRODUCTION

Onion (*Allium cepa* L.) is a major bulbous vegetable which ranks second only to tomato in terms of total annual world production (Ambulker et al., 1995). Total area under onion cultivation in Ethiopia during *Meher* season was estimated to be about 30,478.35 ha with a total production of 328, 000 t in the year of 2011/12 (CSA, 2012).

Commonly, the economically important onion group is mostly grown from seeds (Brewster, 1994). However, seed supply from domestic production in Ethiopia is inadequate and therefore, vegetable growers mainly depend on imported seeds that have mostly poor germination percentage, uniformity and susceptibility to diseases (Lemma, 1998).

Onion seed production might be increased by increasing the area with good variety and changing the existing management practices. Khokhar et al. (2001) noted that planting of bulbs of suitable size increased onion seed yield. Larger bulb size (5.5 to 7.0 cm diameter) produced seed yield significantly higher than small sized bulbs (Ali et al., 1998). Asaduzzaman et al. (2012b) also reported that larger sized bulb (20±1 g) and wider spacing (25 × 20 cm) resulted in higher seed yield per plant (3.78 g). Bulb size and plant spacing are the two key factors in producing quality of onion seeds (Mirshekari and Mobasher, 2006).

In Ethiopia, the previous study was conducted in limited bulb categories and spacing and it has been done over 20 years besides the fact that the production have not benefited the seed quality. Farmers in Butajira area simply used this recommendation for Bombay Red cultivar that was made on the rift valley area for Adama Red. The present study was, therefore, undertaken to find out the optimum mother bulb size and intra-row spacing needed to achieve the best quality and economically feasible yield and quality of onion seed for the area.

MATERIALS AND METHODS

The study was conducted on the farmers' field at Bati Futo watershed, Meskan Woreda, Guraghie Administrative Zone of the South Nations Nationalities and Peoples Regional State using supplemental irrigation from January to June, 2012. The site is located south west of Addis Ababa in the coordinates of 08°06.422"N latitude and 038°24.909"E longitude with an altitude of 1936 m above sea level. The land was having sandy loam textured soil with pH of 6.5. Four different bulb size (3-4.0, 4.1-5.0, 5.1-6.0 and 6.1-7.0 cm) and four intra-row spacings (10, 15, 20 and 25 cm) were considered as treatments in the experiment. The experiment was laid out in a randomized complete block design with three replications. A uniform plot size of 2 x 5.6 m was used for each plot. In each plot, there were seven double rows (50 x 30 cm) and eight plants per row with a total of 112 plants per plot. Onion cultivar 'Bombay Red' was used as a test crop. It is the most widely grown cultivar under irrigation in the area due to its earliness, high yielding potential of bulb and seeds.

The land was prepared by ploughing properly. The entire quantity of DAP (200 $kgha^{-1}$) were applied at planting, whereas urea (150 $kgha^{-1}$) was applied in two equal splits at planting and 45 days after planting. Cultural practices, such as weeding, irrigation, mulching and chemical application were done as and when necessary. Five plants from each plot were selected randomly at 50% bolting, flowering and maturity for growth, yield, yield components and quality parameters.

The parameter under study were days to 50% bolting, days to 50% flowering, days to 50% maturity, number of leaves per plant, leaf area index, biomass, number of umbels per plant, number of flower stalks per plot, flower stalk height (cm), flower stalk diameter (cm), umbel diameter (cm), number of seeds per umbel, weight of seed per umbel (g), seed yield per plant (g), seed yield per ha (kg), 1000-seeds weight and seed germination percentage. Five plants were selected at random from each plot for recording growth attributes whereas the three central rows were considered for yield and quality parameters. The results were analyzed by using analysis of variance techniques (SAS, 2002) and mean separation was made based on LSD at 5% level of significance. Simple partial budget analysis was made for economic analysis of optimum bulb size with appropriate intra-row spacing. The economic analysis was calculated following the formula developed by CIMMYT (1988).

RESULTS AND DISCUSSION

Effect of intra-row spacing on growth and quality of onion seed

Days to 50% bolting

Different sizes of onion mother bulb showed significant effect on growth and quality of the seeds (Table 1). Days to 50% bolting was significantly earlier (21 days) for bulbs with 3 to 4 cm size while it was significantly late (27 days) for bulbs with 6.1 to 7 cm size. The finding is similar to the results obtained by Gill et al. (1989) who obtained least number of days to complete flower stalk bolting on small bulb sizes as compared to the largest ones. The increase in number of days to 50% bolting with increase in bulb size might be due to the presence of stored food inside the larger bulbs that contributed to the vegetative growth of plants through which bolting was delayed.

Days to 50% flowering

Days to 50% flowering were lowest (61 days) for bulbs with 3 to 4 cm sizes, while it was highest (75 days) for 6.1 to 7 cm sizes. This result is in agreement with the work of Jilani (2004) who obtained the lowest and the highest number of days to flowering from small and large sized bulbs, respectively.

Days to 50% maturity

The lowest (106 days) days to 50% maturity was achieved at 3 to 4 cm bulb sizes which, however, were statistically similar with 4.1 to 5 cm bulb sizes and the highest (123 days) was obtained at the largest bulb size.

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Table 1. Effect of bulb size on growth and quality of onion seeds

Bulb size (cm)	DB	DF	DM	NLP	LAI	BM (g/plant)	FSH (cm)	FSD (cm)	UD (cm)	NUP	NUPO	TSW (g)	SGP (%)
3-4	21[d]	61[d]	106[c]	29[d]	0.61[c]	70[c]	56[d]	1.21[b]	4.25[d]	6[d]	495[c]	3.50[d]	84[d]
4.1-5	23[c]	66[c]	108[c]	32[c]	1[b]	97[b]	61[c]	1.29[b]	5.10[c]	7[c]	536[b]	3.78[c]	86[c]
5.1-6	26[b]	71[b]	118[b]	34[b]	1.73[a]	117[a]	72[b]	1.53[a]	5.26[b]	9[b]	827[a]	4.10[b]	89[b]
6.1-7	27[a]	75[a]	123[a]	37[a]	2[a]	130[a]	84[a]	1.62[a]	5.52[a]	11[a]	854[a]	4.50[a]	92[a]
LSD (5%)	0.80	2.59	2.92	1.49	0.33	18.44	1.64	0.25	0.12	0.62	110.62	0.19	1.11
CV (%)	3.93	4.56	3.08	5.40	29.42	21.40	2.89	20.84	2.93	8.74	19.58	5.63	1.51

The letter DB, DF, DM, NLP, LAI, BM, FSH, FSD, UD, NUP, NUPO, TSW and SGP stands for dates of 50% bolting, dates of 50% flowering, dates of 50% maturity, number of leaves per plant, leaf area index, biomass, flowers talk height, flowers talk diameter, umbel diameter, number of umbel per plant, number of umbel per plot, thousand seed weight and seed germination percentage, respectively. Means followed by different letters in the same column are significantly different from each other at 5% level of significance.

The result is in line with the work of Khokhar et al. (2001) who noted that large sized bulbs delayed the maturity of onion seeds.

Number of leaves per plant

The lowest (29) and highest (37) mean number of leaves per plant was recorded from bulbs with 3 to 4 and 6.1 to 7.0 cm size, respectively. The finding is similar to the results obtained by Hussain et al. (2001) and Mosleh ud-Deen (2008) who reported that large sized bulbs produced greater number of leaves per plant. This might be due to the fact that larger sized bulbs contain more reserve foods that can support the production of more initial leaves as compared to the small sized bulbs (Asaduzzaman et al., 2012b).

Leaf area index

Increasing bulb size from 3 to 6 cm significantly increased leaf area index (LAI) but further increase had no significant effect. Bulbs with 6.1 to 7 cm sizes produced 236% higher LAI than the smallest (3 to 4 cm) bulb size treatments (Table 1).

Biomass

The lowest (70 g plant^{-1}) plant biomass was obtained with bulbs of 3 to 4 cm sizes and it was highest (130 g plant^{-1}) for bulbs with 6.1 to 7 cm sizes which, however, were statistically similar with bulbs of 5.1 to 6 cm sizes. This might be due to the presence of food reserves inside the largest bulb size that contributed to the growing plant and it would have maximum biomass as compared to the smallest bulb sizes.

Flower stalk height

The lowest mean flower stalk height (56 cm) was recorded with the smallest (3 to 4 cm) bulb sizes while the highest (84 cm) was recorded with the largest bulb size (6.1 to 7 cm). This finding is similar to the results obtained by Sidhu et al. (1996) and Mosleh ud-Deen (2008) who showed that flower stalk height of onion was found to vary with bulb size. This might be due to the presence of more stored foods inside large bulbs which contributed for the emergence of more flower stalks.

Flower stalk diameter

Significantly lowest (1.21 cm) mean flower stalk diameter was observed at 3 to 4 cm bulb size but the higher ones (1.62 cm) were produced by bulbs with 6.1 to 7 cm, however, it was not significantly different from 5.1 to 6 cm. This is in line with the findings of Shaikh et al. (2002) and Ashrafuzzaman et al. (2009) who obtained maximum flower stalk diameter from large sized bulbs.

Umbel diameter

The lowest and highest mean umbel diameters of 4.25 and 5.52 cm were obtained from bulbs with 3 to 4 and 6.1 to 7 cm sizes, respectively. These results are in line with the work of Ali et al. (1998) and Ashrafuzzaman et al. (2009), Khodadadi (2012) and Asaduzzaman et al. (2012b) who reported that large sized bulbs have more stored foods that are supplied to the emerged flower stalks and it significantly increased umbel diameter.

Number of umbels per plant

The mean number of umbels per plant was lowest (6) for bulbs with 3 to 4 cm sizes, while it was highest (11) for bulbs with 6.1 to 7 cm sizes. The finding is in line with the work of Geetharani and Ponnuswamy (2007) and Ashrafuzzaman et al. (2009) on onion plants. Large bulbs may contain higher food reserves and be responsible for the higher number of flowering stalks per plant.

Table 2. Effect of intra-row spacing on growth and quality of onion seeds

Intra-row spacing (cm)	DB	DF	DM	NLP	LAI	BM (g/plant)	FSH (cm)	FSD (cm)	UD (cm)	NUP	NUPO	TSW (g)	SGP (%)
10	21[d]	58[d]	105[d]	29[d]	1.04[c]	69[c]	62[d]	1.20[c]	4.23[d]	6.74[d]	423[c]	3.58[d]	85[d]
15	23[c]	64[c]	111[c]	32[c]	1.05[c]	83[c]	67[c]	1.23[c]	4.47[c]	7.94[c]	475[c]	3.85[c]	87[c]
20	25[b]	69[b]	116[b]	35[b]	1.80[a]	115[b]	70[b]	1.49[b]	5.61[b]	9.06[b]	795[b]	4.09[b]	89[b]
25	28[a]	81[a]	124[a]	36[a]	1.47[ab]	146[a]	74[a]	1.75[a]	5.82[a]	10.04[a]	1016[a]	4.35[a]	91[a]
LSD (5%)	0.80	2.59	2.92	1.49	0.33	18.44	1.64	0.25	0.12	0.62	110.62	0.19	1.11
CV (%)	3.93	4.56	3.08	5.40	29.42	21.40	2.89	20.84	2.93	8.74	19.58	5.63	1.51

The letter DB, DF, DM, NLP, LAI, BM, FSH, FSD, UD, NUP, NUPO, TSW and SGP stands for dates of 50% bolting, dates of 50% flowering, dates of 50% maturity, number of leaves per plant, leaf area index, biomass, flowers talk height, flowers talk diameter, umbel diameter, number of umbel per plant, number of umbel per plot, thousand seed weight and seed germination percentage, respectively. Means followed by different letters in the same column are significantly different from each other at 5% level of significance.

Number of umbels per plot

The mean number of umbels per plot was lowest (495) for bulbs with 3 to 4 cm sizes, while it was highest (854) for bulbs with 6.1 to 7 cm sizes. The increase in number of umbels per plot due to increase in bulb size might be due to the increase in number of umbels per plant (Ashrafuzzaman et al., 2009; Mollah et al., 1997).

1000-seed weight

The lowest (3.5 g) and the highest (4.5 g) 1000-seed weights were achieved using bulbs of 3 to 4 and 6.1 to 7 cm sizes, respectively. The finding is in line with the work of Khodadadi (2012) who noted that large size bulbs resulted in maximum weight of 1000-seeds as compared to the smaller ones. High food reserves present in the large bulbs might supply nutrients properly to the seeds, resulting in the highest weight of 1000-seed weight.

Seed germination percentage

Mean seed germination percentage was lowest (84%) for bulbs with 3 to 4 cm sizes while it was highest (92%) for bulbs with 6.1 to 7 cm sizes. The finding is similar to the results of Muktadir et al. (2001) and Asaduzzaman et al. (2012b) who obtained the highest seed germination percentage from larger sized bulbs.

Effect of intra-row spacing on growth and quality of onion seed

Days to 50% bolting

The lowest (21 days) and the highest (28 days) number of days to 50% bolting were achieved at intra-row spacing of 10 and 25 cm, respectively. The finding confirms the results obtained by Navab et al. (1998) which showed that wider plant spacing had significantly delayed flowering of onion. The increase in number of days to 50% bolting with increase in intra-row spacing might probably be due to the availability of resources at wider plant spacing and this might increase the vegetative growth of the plant and bolting time was delayed.

Days to 50% flowering

The lowest (58 days) and the highest (81 days) number of days to 50% flowering were achieved at 10 and 25 cm intra-row spacing, respectively. It increased with increase in intra-row spacing reaching maximum at 25 cm. This result is similar with the work of Aminpour and Mortzavi (2004) who reported that wider plant spacing delayed flowering of onion due to the absence of competition risk as compared to the closer spacing.

Days to 50% maturity

The lowest (105 days) and the highest (124 days) number of days to 50% maturity were recorded at 10 and 25 cm intra-row spacing, respectively. In line with the current result, Mirshekari et al. (2008) also observed that wider intra-row spacing significantly delayed the maturity of onion seeds as compared to narrow plant spacing.

Number of leaves per plant

Number of leaves per plant was lowest (29) for 10 cm intra-row spacing, while it was highest (36) for 25 cm intra-row spacing; the other intra-row spacing treatments scored in between the two (Table 2). The finding is similar to the results obtained by Anisuzzaman et al. (2009) who found that increase in the number of leaves per plant was directly related to the number of flower stalks per plant. The result is in accordance with the findings of Jilani et al. (2010) and Asaduzzaman et al. (2012b) who also reported increased number of leaves per plant with increase in intra-row spacing. Similarly, Hussain et al. (2001) reported that number of green leaves per plant increased with increase in intra-row spacing which might be due to the presence of less competition among plants in wider plant spacing for space, moisture, nutrients and light.

Leaf area index

The lowest (1.04) LAI was achieved at 10 cm spacing which, however, was statistically similar with 15 cm spacings. The highest (1.80) LAI was recorded on 20 cm spacing and further increase in intra-row spacing had decreased LAI by 22.45%. The lowest LAI at closer spacing might be due to the fact that at closer spacing, competition among plants and disease severity is very high. Similarly, Lemma and Shimelis (2003) also showed that the lowest plant density in onion crop increased the risk of attack by fungal diseases such as purple bloch caused by *Alternaria porri*.

Biomass

The lowest (69 g plant^{-1}) plant biomass was achieved at 10 cm spacing which, however, was statistically at par with 15 cm spacing and the highest (146 g plant^{-1}) plant biomass were recorded on 25 cm spacing (Table 2). This finding is in accordance with the work of Zamil et al. (2010) who reported increase in plant biomass with widest intra-row spacing due to less competition among plants for nutrients.

Flower stalk height

The lowest and highest mean flower stalk heights of 62 and 74 cm were recorded using 10 and 25 cm intra-row spacing, respectively; all the other spacing treatments were performed in between the two (Table 2). This might be due to higher competition at closer spacing resulting in shorter flower stalk height. The result is in accordance with the findings of Khan et al. (2003). Also, as explained by Asaduzzaman et al. (2012a), wider intra-row spacing produces more green leaves due to the free access of soil nutrients which promotes the length of the flowering stalks.

Flower stalk diameter

The lowest mean flower stalk diameter (1.20 cm) was achieved using 10 cm intra-row spacing which, however, was statistically similar to 15 cm spacing; the highest mean flower stalk diameter (1.75 cm) was recorded using 25 cm spacing (Table 2). The finding is similar to the results of Pandey et al. (1994) who obtained larger flower stalk diameter from wider intra-row spacing. The difference in flower stalk diameter might be due to competition associated with closely spaced plants that resulted in lower flower stalk diameter (Mahadeen, 2004).

Umbel diameter

The lowest and highest mean umbel diameters of 4.23 and 5.82 cm were recorded at 10 and 25 cm intra-row spacing, respectively; the other spacing treatments were performed in between (Table 2). The finding is in accordance with the work of Pandey et al. (1994) and Asaduzzaman et al. (2012b). This might be due to the greater access of nutrients (especially nitrogen) and water, producing large sized umbels at wider plant spacing.

Number of umbels per plant

The lowest (7) and highest (10) mean number of umbels per plant were achieved at 10 and 25 cm intra-row spacing, respectively; the other spacing treatments were performed in between the two (Table 2). The finding is in agreement with the work of Navab et al. (1998) who showed that wider plant spacing resulted in large number of umbels per plant. Plants at the widest spacing produced more number of leaves probably due to less competition for nutrients, light, space, and moisture. Later on, these leaves accumulated photosynthates and ultimately encouraged producing more number of umbels (Asaduzzaman et al., 2012a). Singh and Sachan (1999) also found the highest number of umbels per plant from the widest spacing.

Number of umbels per plot

The lowest (423) number of umbels per plot was achieved at 10 cm spacing which, however, was also statistically at par with 15 cm spacing. The highest mean number of umbels per plot (1016) was recorded using 25 cm intra-row spacing (Table 2). The finding is similar to the result obtained by Miccolis et al. (1995) and Navab et al. (1998) which showed that wider plant spacing produced large number of umbels per plant, thereby increasing the number of umbels per plot. Bulb size and intra-row spacing were also significant

1000-seed weight

1000-seed weight was lowest (3.58 g) for 10 cm spacing,

Table 3. Interaction effects of bulb size and intra-row spacing on number of seeds per umbel.

Bulb size (cm)	Intra-row spacing (cm)				
	10	15	20	25	Mean
3-4	331[f]	376[f]	420[f]	461[ef]	397
4.1-5	382[f]	471[ef]	696[cd]	720[cd]	567
5.1-6	604[de]	794[c]	1190[ab]	1270[a]	965
6.1-7	485[ef]	730[cd]	1061[b]	1325[a]	900
Mean	450.50	592.75	841.75	944	707.25
LSD (5%) = 169.47					
CV (%) = 14.37					

Means followed by different letters in the same column are significantly different from each other at 5% level of significance.

while it was highest (4.35 g) for 25 cm spacing; the other spacing treatments was performed in between the two (Table 2). The findings are similar to the results of Daljeet et al. (1990) who obtained highest 1000-seed weight from wider plant spacing. The increase in 1000-seed weight with increased intra-row spacing might be due to the fact that wider spacing supplied more food materials to the growing seeds as compared to the closest spacing.

Seed germination percentage

The lowest (85%) and the highest (91%) mean seed germination percentage was recorded at 10 and 25 cm intra-row spacing, respectively (Table 2). This result is in conformity with the work of Asaduzzaman et al. (2012b) who reported that wider intra-row spacing had a significant effect on seed germination percentage.

Interaction effects of bulb size and intra-row spacing on seed yield of onion

Number of seeds per umbel

The interaction between bulb size and intra-row spacing on mean number of seeds per umbel was highly significant ($p \leq 0.001$). Mean number of seeds per umbel increased with increase in bulb size and intra-row spacing; however, the magnitude of the increase varied in relation to both bulb size and spacing (Table 3). At 10 cm intra-row spacing, increasing bulb size from 3 to 6 cm increased number of seeds per umbel by 15.26 and 58.32%, whereas further increase in bulb size resulted in a 24.54% decrease. At 25 cm spacing, increasing bulb size from 3-7 cm enhanced the mean number of seeds per umbel by 56.18, 76.39 and 4.33% (Table 3). Similarly, using bulbs with 3-4 cm sizes, increasing intra-row spacing from 10 to 25 cm, enhanced the mean number of seeds per umbel by 13.60, 11.70 and 9.76%. Similar results are evident at the other bulb size and intra-row spacing treatment combinations (Table 3).

The above findings showed that the number of seeds per umbel is determined by bulb size and spacing. The result is in accordance with the findings of Badawi et al. (2009) and Asaduzzaman et al. (2012a) who stated that larger bulb sizes and wider plant spacing resulted in increased number of seeds per umbel.

Weight of seeds per umbel

The interaction effects of bulb size and intra-row spacing on average weight of seeds per umbel in onion plant was highly significant ($p \leq 0.001$). Mean weight of seeds per umbel increased with increase in bulb size and intra-row spacing; but, the extent of its increase in relation to both bulb size and spacing was different (Figure 1). At 10 cm intra-row spacing, increasing bulb size from 3 to 6 cm increased weight of seeds per umbel by 13.85 and 112.84%, while further increase in bulb size resulted in a 33.47% decrease. At 25 cm spacing, increasing bulb size from 3-7 cm increased the average weight of seed per umbel by 39.25, 105.02 and 1.69% (Figure 1). Likewise, at 3-4 cm bulb size, increasing intra-row spacing from 10 to 25 cm increased mean weight of seeds per umbel by 25.38, 8.77 and 4.91%. Similar results are evident at the other bulb size and intra-row spacing combinations (Figure 1).

It is evident from the data presented above that the weight of seeds per umbel was determined by bulb size and intra-row spacing. The findings are similar to the results of Begum et al. (1998) and Asaduzzaman et al. (2012a) who obtained the highest weight of seeds per umbel from larger sized bulbs grown at wider intra-row spacing. This might be due to the fact that larger bulbs contain higher food reserves which produced higher number of flowers and seeded fruits per umbel; wider spacing had also more available nutrient and less competition risks for the emergence of seeded florets.

Seed yield per plant

The mean total seed yield per pant recorded in the present study ranged from 3.36 to 12.84 g (Figure 2). The interaction effects of bulb size and intra-row spacing on mean total seed yield per plant was highly significant ($p \leq 0.001$) (Appendix Table 3). Mean total seed yield per plant–increased with increase in bulb size and intra-row spacing; however, the magnitude was different in relation to both bulb size and spacing (Figure 2). At 10 cm spacing, increasing bulb size from 3 to 6 cm increased seed yield per plant of onion by 30.56 and 95.89%, while further increase in bulb size resulted in a 40.20% decrease. At 25 cm spacing, increasing bulb size from 3-7 cm increased the average weight of seeds per umbel

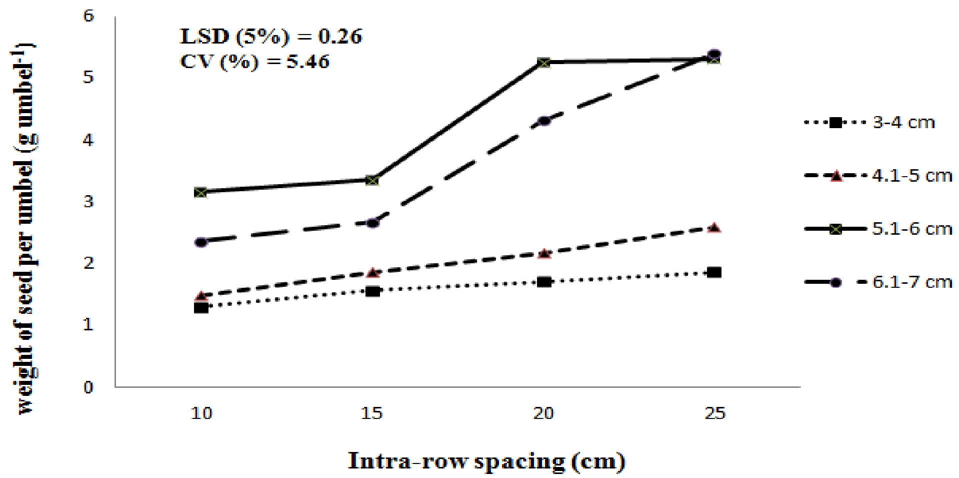

Figure 1. Interaction effects of bulb size and intra-row spacing on weight of seeds per umbel (g umbel^{-1}).

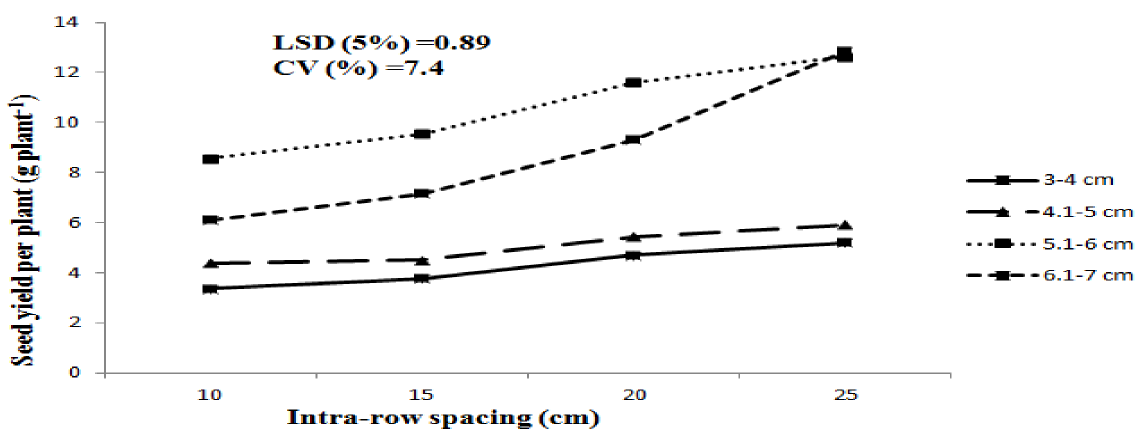

Figure 2. Interaction effects of bulb size and intra-row spacing on seed yield per plant (g plant^{-1})

by 13.87, 113.71 and 1.66% (Figure 2). Similarly, at 3-4 cm bulb size, increasing intra-row spacing from 10 to 25 cm, mean seeds per plant was increased by 12.20, 24.93 and 10.19%. Similar results are evident at the other bulb size and intra-row spacing combinations (Figure 2).

The interaction result showed that seed yield per plant of onion is determined by bulb size and intra-row spacing. The results are in line with the findings of Lemma and Shimelis (2003) and Mahadeen (2004) who obtained significantly higher seed yield per plant of onion on large sized bulbs and wider intra-row spacing. Similarly, Amin and Rahim (1995) and Asaduzzaman et al. (2012a) reported that wider intra-row spacing and larger sized bulbs had significantly increased seed yield per plant of onion. The low seed yield per plant under closer spacing is due to the increased level of competition for moisture and nutrients required for plant growth available in the area.

Seed yield per hectare

The interaction between bulb size and intra-row spacing on mean seed yield was highly significant ($p \leq 0.001$). Mean seed yield per hectare increased with increase in bulb size and intra-row spacing; however, the magnitude was different across the treatment combinations (Table 4). At 10 cm intra-row spacing, increasing bulb size from 3 to 6 cm increased seed yield of onion by 34.74 and 52.22%, whereas further increase resulted in a 53.45% decrease. At 25 cm spacing, increasing bulb size from 3 to 7 cm increased seed yield per ha by 60.86, 152.92 and 6.23% (Table 4). Similar results are evident at the other bulb size and intra-row spacing combinations.

The above finding showed that seed yield of onion is determined by bulb size and spacing. The result is in accordance with the findings of Verma et al. (1994) and Dudhat et al. (2010) who studied the effects of bulb size

Table 4. Interaction effects of bulb size and intra-row spacing on seed yield per hectare (kg/ha).

Bulb size (cm)	Intra-row spacing (cm)				
	10	15	20	25	Mean
3.0-4.0	250[fg]	350[defg]	370[efg]	230[g]	280
4.1-5.0	337[defg]	420[cde]	472[cd]	372[def]	400
5.1-6.0	516[c]	753[b]	988[a]	937[a]	799
6.1-7.0	240[fg]	725[b]	920[a]	995[a]	720
Mean	335.75	562	687.50	633.50	549.75
LSD (5%) = 136.17					
CV (%) = 14.85					

Means followed by different letters in the same column are significantly different from each other at 5% level of significance.

Table 5. Partial budget analysis for seed production of onion as affected by bulb size and intra-row spacing.

Treatments	Total variable cost(Birr)	Change in total variable cost (Birr)	Gross field benefit (Birr)	Net field benefit (Birr)	Change in net field benefit(Birr)	Marginal rate of return (%)
B1S4	38459		82919	44460		
B1S3	48088	9629	133330	85241	40781	424
B2S3	80088	32000	169906	89817	4576	14
B3S4	109659	29571	337345	227686	137869	466
B3S3	111088	1429	355766	245678	17992	1259

B1, B2 and B3 stands for bulb size (3-4.0, 4.1-5.0 and 5.1-6.0 cm diameter) whereas S3 and S4 stands for intra-row spacing of 20 and 25 cm, respectively.

and intra-row spacing on seed yield of onion. This may be due to the fact that large sized bulbs had more reserve foods and produce more spouting initial seed stalks; wider plant spacing also avoids disease and competition risks among the emerged flower stalks.

Economic analysis

The maximum MRR of 1259% was obtained when the treatment combination was shifted from B1S1 to B3S3 and the highest (245,678 ETB ha^{-1}) net field benefit was also recorded on this treatment combination of B3S3 (5.1-6 cm and 20 cm spacing). Moreover, treatment combination of B3S3 gave maximum seed yield (988 kg ha^{-1}) of onion (Table 5). Further increase of the treatment combination led to incurring additional variable costs without a concomitant increase in benefit and also below the minimum acceptable promising treatment combination (B3S4), maximum variable cost is incurred without gaining income by the farmers. As per the recommendation of CIMMYT (1988), the minimum acceptable MRR for farmer is 100%. Therefore, the treatment combination of 5.1-6 cm bulb size and 20 cm spacing which had the highest seed yield (988 kg ha^{-1}) and the highest net benefit (245,678 ETB ha^{-1}) together with an acceptable MRR might be taken as profitable option and can be tentatively recommended for the study area.

Conclusion

Largest bulb size (6.1 to 7.0 cm) resulted in significantly highest days to 50% bolting (27 days), days to 50% flowering (75 days), days to 50% maturity (123 days), number of leaves per plant (37), LAI (2.05), biomass (130 g), flower stalk height (84 cm), flower stalk diameter (1.62 cm), umbel diameter (5.52 cm), number of umbels per plant (11), number of umbels per plot (854), 1000-seed weight (4.50 g) and seed germination percentage (92%)

The widest intra-row spacing (25 cm) resulted in significantly highest days to 50% bolting (28 days), days to 50% flowering (81 days), days to 50% maturity (124 days), number of leaves per plant (36), biomass (146 g), flower stalk height (74 cm), flower stalk diameter (1.75 cm), umbel diameter (5.82 cm), number of umbels per plant (10), number of umbels per plot (1016), 1000-seed weight (4.35 g) and seed germination percentage (91%) in relation to the closest spacing (10 cm). However, LAI was maximum (1.80) at 20 cm spacing.

The interaction effects of bulb size and intra-row spacing revealed that, the highest number of seeds per umbel (1270 to 1325) and seed yield per plant (12.63 to

12.84 g) was obtained from 5.1 to 7 cm bulb size grown at 25 cm spacing. However, the highest (5.26 to 5.40 and 5.40 g) weight of seeds per umbel was from 5.1-6 cm bulbs on 20 to 25 cm spacing and from 6.1-7 cm bulbs on 25 cm spacing, and seed yield per ha was also maximum (920 to 995 kg ha^{-1}) from 5.1-7.0 cm bulb sizes grown at 20 to 25 cm spacing.

Partial budget analysis showed that the combination of 5.1-6.0 cm bulb size and 20 cm intra-row spacing resulted in higher seed yield (988 kg ha^{-1}) with a maximum net field benefit of 245,678 Ethiopian birr ha^{-1} which was obtained from an acceptable MRR of 1,259%. Based on the result of this study, it can be concluded that bulbs of 5.1 to 6.0 cm and 20 cm intra-row spacing combination are more economically feasible, and recommended for seed yield of Bombay Red onion cultivar in the study area.

Conflict of interest

The authors have not declared any conflict of interest

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