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Bulb Quality and Storability of Onion (*Allium cepa* L.) as Affected by Varieties and Intra-Row Spacing in Antsokia Gemza, Ethiopia

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ABSTRACT

This experiment was conducted in Antsokia Gemza district, Ethiopia in 2017/18 to evaluate the effect of intra-row spacing on bulb quality and storability of onion varieties. A 4×4 factorial experiment with four different varieties (Adama Red, Bombay Red, Melkam and Shendi) and four levels of intra-row spacing (5.00, 7.50, 10.00 and 12.50 cm) was laid on randomized complete block design with three replications. Data were collected on bulb quality attributes and storability and subjected to Analysis of Variance (ANOVA) using statistical analysis system (SAS) computer software 9.1. The mean separation test was done by list significant difference (LSD) test at 5% probability level. Simple linear correlation analyses between and among the different parameters were made using Pearson Correlation Coefficient. Accordingly, most of the parameters were significantly affected by intra-row spacing and variety. Variety Melkam exhibited the highest bulb diameter, bulb length, bulb dry matter content and bulb fresh weight. Melkam and Adama Red were with the lowest weight loss in storage while Bombay Red and Shendi scored the highest weight loss in storage. Most of the bulb quality parameters were significantly highest at the widest intra-row spacing of 10.00 and 12.50 cm. However, there was no significant variation between 7.50 and 10.00 cm intra-row spacing on average bulb weight which is considered as the most important bulb quality parameter for the producers from the market point of view. Weight loss was higher at the widest intra-row spacing for all varieties. Based on the findings of this study, it can be concluded that the bulb quality and storability of onion in Antsokia Gemza district can be optimized through cultivating variety Melkam at intra-row spacing of 7.5 cm.

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Introduction

Onion (*Allium cepa* L.) is one of the most important vegetable crops that are commercially grown in most parts of the world. It ranks second after tomato among vegetable crops produced in the world (FAO, 2017). It probably originated from Central Asia between Turkmenistan and Afghanistan where some of its relatives are still grown in the wild (Grubben and Denton, 2004; Bagali et al., 2012).

It is estimated that over 3.6 million ha of onions are grown annually around the world. On a worldwide scale, around 98.9 million metric tons of onions are produced per year (FAO, 2017). China is by far the top onion producing country in the world, accounting for approximately 25% of the world's onion production, followed by India, USA, Egypt, Iran, Russia, Turkey, Pakistan, Brazil, Bangladesh and South Korea.

Onion is a very important food and cash crop in Ethiopia predominantly grown by small holder farmers under small scale irrigation (Makombe et al., 2011). It occupies economically important place among vegetables in the country. Its area coverage increased by 29.63% from 2014/15 to 2015/16 mainly due to its high profitability per unit area and ease of production, and the increases in small scale irrigation areas. The total area coverage and annual production of onion in Ethiopia in 2015 was estimated to be 29.5 thousand ha and 265 thousand tons, respectively (CSA, 2016). In 2017, Ethiopia imported a net weight of 47.4 thousand tons of fresh or chilled onion and shallots from Sudan and exported around 16.5 thousand tons to Djibouti, Somalia and United States (ERCA, 2017). In Antsokia Gemza district, onion and tomato are among the predominately cultivated vegetable crops under irrigation.

In 2017, about 2,250 ha of irrigated land had been covered by onion (AGWARDO, 2017).

In the past few decades, several screening and variety trials on a number of introduced onion varieties were carried out at Melkassa and other Agricultural Research Center. Consequently, few onion varieties, namely Rosy, Caramelo F1, Sweet Caroline, Red passion F1, Sivan, Jamber F1, Red king, Nafis Red, Neptune, Nasik Red, Adama Red, Red Creole, Bombay Red and Melkam, have been released for production (MARC, 2015). However, only three varieties, namely Adama Red, Bombay Red and Neptune are being supplied by seed retailers.

Optimum spacing and population density play important roles in contributing to high yield and better bulb quality. Because dense planting population will not get proper light for photosynthesis and may lead to high level of disease incidence while very small population will also reduce yield per unit area due to decreasing in light interception per unit area and excess vegetative growth (Pookpakdi and Pataradilok, 1993). The ideal spacing and plant population are those that maximize yield and quality without unduly increasing costs. As a rule, all crops tend to increase yield per unit area as plant population is increased, however up to a certain limit. Beyond this limit, the yield may not increase further and may even drop. The appropriate spacing for onion generally differs with differences in environment and variety (Rabinowitch and Brewster, 1990).

According to Awas et al. (2010) reported that control of plant spacing is one of the cultural practices to control bulb size, shape and yield. These authors also recommended intra-row spacing of 4 cm for Nasik Red and Adama Red and 6 cm for Bombay Red in Adami Tulu, Ethiopia. Zeleke and Derso (2015) also reported that spacing of 40 cm between double rows on a ridge, 20 cm between rows on the bed and 5-7 cm between plants is suitable for small scale hand operated production system.

However, all the studies are specific with regard to location and are relatively old and excluded the performance of varieties and population densities in potential onion growing areas like Antsokia Gemza district. In the study area, even most growers use narrower intra-row spacing, which is less than nationally recommended one. Therefore, to optimize quality onion productivity, site specific research based full package of information is required. Hence, this research was conducted to evaluate the effects of intra row spacing on bulb quality and storability of onion varieties in Antsokia Gemza district, Ethiopia.

Materials and Methods

Description of the Study Site

The field experiment was conducted at Atiko sub-district of Antsokia Gemza District, North Shoa Zone, Eastern Amhara, Ethiopia, from November 2017 to April 2018 under furrow irrigation. The experimental site is located 310 km north east of Addis Ababa. It has an altitude of 1400m.a.s.l. and a bimodal unevenly distributed average annual rainfall of 900-1000 mm and the minimum and maximum temperature of 20°C and 29°C, respectively. The pH of soil is 5.7-6.1 and it is fine sandy clay loam (AGWARDO, 2017). The area experiences less amount and erratic rainfall that stretches from March to June with the main rainy season from July to early September. In the area, rain fed agriculture is difficult due to moisture stress and drought, so using irrigation in dry season and supplementary irrigation in summer (meher) season is required to get good yield and quality bulbs.

Description of the Experimental Materials

Four nationally released onion varieties (Table 1) were collected from Melkassa and Humera Agricultural Research Centers for this study. These varieties differ in their bulb size (60-100 g), skin color (dark red, medium red and light red), leaf arrangement (erect and medium erect) and days to maturity (90-130 days).

Treatments and Experimental Design

A 4 × 4 factorial experiment with four onion varieties (Bombay Red, Adama Red, Melkam and Shendi) and four levels of intra-row spacing (5, 7.5, 10 and 12.5 cm) was carried out in Randomized Complete Block Design (RCBD) with three replications. The plot size was 2.4 m × 1.5 m (3.6 m^2) with 1 m spacing between blocks and 0.5 m between plots. Only the central rows were used for data collection. The plant density ranged from a minimum of 144 plants per plot (12.5 cm spacing) to a maximum of 360 plants per plot (5 cm spacing).

Nursery and Field Management

Seedlings of each variety were raised on 1 m x 5 m well prepared seed bed. The seeds were placed at the spacing of 10 cm between rows. All other nursery management practices such as mulching, watering, application of fertilizers, chemicals and weeding were applied as per recommendation for raising vigorous and healthy seedling of the crop. Seedlings were equally managed in nursery until transplanted to the main experimental area after 50 days.

Table 1. Characteristics of onion varieties used in the experiment

Characteristics	Adama Red	Bombay Red	Melkam	Shendi
Leaf color	Medium Green	Dark Green	Dark Green	Medium Green
Leaf arrangement	Erect	Medium Erect	Erect	Medium Erect
Bulb size (g)	60-80	85-100	70-90	70-90
Bulb shape	Flat Globe	Flat Globe	High Globe	High Globe
Bulb skin color	Dark Red	Light Red	Medium Red	Light Red
Bulb flesh color	Redish White	Redish White	Redish White	Reddish White
Maturity (days)	110-130	Less than 120	110-130	90-110
Altitude (m)	700-2000	700-2000	700-2000	570-1500
Yield (tone/ha)	9-15	13-16	9-15	13-16
Source of varieties	MARC	MARC	MARC	HARC

Source: EARO (2004) and HARC (2018)

Before transplanting, the experimental field was ploughed and harrowed. Large clods were broken down in order to bring the soil to fine tilth, and then 48 plots were prepared in which 16 plots were allocated in each replication. Moreover, ridges and rows were marked in each plot. One day before transplanting of seedlings, the nursery beds were irrigated for the safe uprooting of onion. Then, the seedlings were transplanted in well prepared and irrigated experimental field. During transplanting, only healthy, vigorous and uniform seedlings were transplanted and gap filling of the dead seedling was done within a week after transplanting.

Application of water was performed using furrow irrigation method. Four days irrigation interval was maintained for the first four weeks and then it was extended five to seven days interval until 15 days to harvest. Phosphorus was applied as Di Ammonium Phosphate (DAP) at the rate of 200 kg ha^{-1} at the time of transplanting and nitrogen was applied in the form of urea at the rate of 150 kg ha^{-1}. Half of urea was applied at the time of transplanting, while the remaining was applied after four weeks of transplanting for all plots (EARO, 2004; SARC, 2008; Anisuzzaman et al., 2009).

The weeding was done with hand hoe and by hand-pulling whenever necessary throughout the experimental period to keep the crop free from weeds, for better soil aeration and to break the crust. Pest (Onion trips), leaf miner and disease (Purple blotch) were kept under control by applying Selecron (720 EC) (0.5 l ha^{-1}), Dimethoate (0.5 l ha^{-1}) and Mancozeb 80 WP (3 kg ha^{-1}), respectively. These chemicals were applied in an interval of 3-5 days. Other agronomic practices were applied as per recommended for onion production.

Data Collection

Data related to bulb quality and storage life parameters were collected from 10 randomly selected bulbs from the net plot area. The harvested onion bulbs were cured for five days by wind rowing on the ground before topping. The procedure applied to collect the data is presented as follows.

Bulb diameter (cm): It was measured at right angles to the longitudinal axis at the widest circumference of the bulb in each plot using vernier caliper at harvest and the average was calculated.

Bulb length (cm): It is the vertical average length of the matured bulbs in each plot which was measured by vernier caliper.

Bulb neck thickness (cm): It was measured at the narrowest point at the junction of bulb and leaf sheath using a vernier caliper.

Average bulb weight (g): The average weight of bulbs of plants which were harvested from net plot was calculated as the mean fresh bulb weight after curing.

Bulb dry matter content (%): from each plot, 200 g of fresh and chopped bulbs were dried in oven at 75°C for 48 hours to a constant weight to determine the dry matter content (DMC %). It was calculated by using the formula:

$$\text{DMC(\%)} = \frac{\text{Sample oven dry weight(g)}}{\text{Sample fresh weight (g)}} \times 100$$

TSS (total soluble solid): bulbs were cut horizontally through the center using sharp knife to collect the samples for determination of total soluble solid. The samples were then crushed gently in separate containers and drops of the juice were placed in a hand refractometer.

Bulb weight loss: Cumulative loss in weight was recorded at interval of two weeks for two months, keeping ten pre tagged bulbs from each plot spread on floor at ambient condition. It was calculated as per the following formula.

$$\text{\% weight loss} = \frac{\text{Wi-Wf}}{\text{Wi}} \times 100$$

Where: W_i = initial weight, W_f= final weight

Data Analysis

The data was subjected to Analysis of Variance (ANOVA) using SAS computer software 9 (SAS, 2008) and the mean separation test was done by Least Significant Difference (LSD) test at 5% significance level. Simple linear correlation analyses among the different parameters were carried out using Pearson’s correlation coefficient.

Result and Discussion

Bulb Diameter (cm)

The difference in bulb diameter per plant among varieties was highly significant ($P<0.01$) and very highly significant ($P<0.001$) among intra-row spacing while there was no significant interaction among the two main factors (Table 1).

According to Table 2, Melkam had the highest mean bulb diameter (5.31 cm) probably because it had highest plant height that resulted in higher photosynthetic area which help the variety accumulate food and turn out in higher bulb diameter. Melkam was followed by Bombay Red (5.22 cm) which was statistically similar with Adama Red (5.04 cm). The smallest mean diameter was measured from Shendi (4.99 cm) and Adama Red. This result agrees with the finding of Jambo (2015) who reported that Melkam variety had larger bulb diameter than Bombay Red and Adama Red.

The mean bulb diameter increased as intra-row spacing increased. Onion grown at 5 cm intra-row spacing had the lowest mean bulb diameter (4.89 cm) while the widest intra-row spacing (12.5 cm) had the highest mean bulb diameter (5.4 cm) (Table 2).

The increase in bulb diameter with an increase in intra-row spacing can be attributed to reduced competition for nutrients and moisture at wider spacing. Onion plants grown at 5 cm intra-row spacing had fewest mean number of leaves which may explain why they have lower mean bulb diameter. The increases in bulb diameter as the intra-row spacing increases was also supported by Dawar et al. (2007) who indicated that onion grown at wider plant spacing had significantly bulb diameter while this yield component reduced at closer spacing due to less availability of soil nutrients, water and light etc.

Bulb Neck Thickness

The finding of this study revealed that intra-row spacing had significant ($P<0.05$) effect on bulb neck thickness. The interaction between these two factors did not have any effect on neck thickness (Table 1).

Table 2. Effect of variety and intra-row spacing on bulb diameter (BD), bulb neck thickness (BNT), bulb length (BL) and average bulb weight (ABW) of onion

Treatment	BD (cm)	BNT (cm)	BL (cm)	ABW (g)
Variety				
Adama Red	5.04[bc]	1.34	4.73[b]	70.20[b]
Bombay Red	5.22[ba]	1.30	4.67[b]	78.14[a]
Melkam	5.31[a]	1.35	5.00[a]	80.98[a]
Shendi	4.99[c]	1.31	4.93[a]	75.81[ab]
LSD (5%)	0.19	ns	0.18	5.78
Intra-row (cm)				
5.00	4.89[b]	1.26[b]	4.71[b]	68.68[c]
7.50	5.03[b]	1.31[ab]	4.79[ab]	75.03[b]
10.00	5.24[a]	1.35[ab]	4.86[ab]	78.54[ab]
12.50	5.40[a]	1.38[a]	4.97[a]	82.87[a]
LSD (5%)	0.19	0.09	0.18	5.78
Mean	5.14	1.32	4.83	76.28
CV (%)	4.52	8.28	4.45	9.1

ns = non-significant; Means with the same letter(s) within a column are not significantly different according to LSD test at 5% level of significance

Slightly higher bulb neck thickness was observed from Melkam (1.35 cm) and Adama Red (1.34 cm) than Bombay Red (1.3 cm). The numerical difference occurred, because the trait was influenced by growing area and the interaction of cultivar and environment. In addition, slightly thicker bulb neck (1.38 cm) was observed in plants spaced in 12.5 cm than plants spaced at the narrower intra-row spacing. On the other hand, the lowest neck thickness (1.26 cm) was observed with 5 cm intra-row spacing (Table 2).

The general trend in this study showed that the neck thickness increased as the intra-row spacing increased from 5 to 12.5 cm (Table 2). The present study is in agreement with the report of Dawar et al. (2007) who reported that onion grown at wider plant spacing had significantly increased of bulb neck thickness while at closer spacing this yield component was reduced.

Bulb Length

The effect of variety on bulb length was very highly significant ($P<0.001$) and intra-row spacing had significant ($P<0.05$) effect on bulb length; however their interaction did not show a significant variation (Table 1).

Considering mean performance of varieties, Melkam and Shendi gave the longest bulb length (5.00 cm and 4.93 cm, respectively) while variety Bombay Red (4.67 cm) and Adama Red (4.73 cm) had the shortest bulb length (Table 2).

Contrary to this study, Demisie and Tolessa (2018) reported that Adama Red gave the longest (5.85 cm) bulb length while variety Melkam had the shortest (5.09 cm) bulb length. The trait could be influenced by growing area and the interaction of cultivar and environment.

Bulb length increased as intra-row spacing increased (Table 2). The highest bulb length (4.97 cm) was recorded at the widest intra-row spacing while the narrowest intra-row spacing resulted in the lowest (4.71 cm) bulb length. This could be attributed to reduced limitations of growth factors at wider spacing that allows the bulbs to have more assimilates available for storage and thus resulted in higher bulb length. Asres (2017) also reported that higher bulb length (6.02 cm) was observed in wider spacing (15 cm) followed by those planted at 12.5 cm while significantly smaller bulb length (5.48 cm) was obtained from closer spacing (7.5 cm), which was also statistically similar to those planted at 10 cm spacing.

Average Bulb Weight (g)

According to the analysis of variation, variety had highly significant effect ($P<0.01$) on bulb fresh weight and intra-row spacing had very highly significant ($P<0.001$) effect on same parameter (Table 1). However, there was no significant interaction effect between varieties and intra-row spacing.

Melkam had significantly higher mean bulb fresh weight (80.98 g) than Adama Red (70.2 g) (Table 2). In concurrence to the present study, Kahsay et al. (2013) reported that Melkam had the highest bulb weight (75.77 g) as compared to Adama Red, Bombay Red and Nasik Red. Jambo (2015) also reported that Melkam had the highest fresh bulb weight (68.33 g) which exceeded Bombay Red and Adama Red by 11 and 29%, respectively.

The fresh weight of the bulb increased by 21% as the intra-row spacing increased from 5 cm to 12.5 cm (Table 2). The highest bulb diameter recorded from the widest intra-row spacing, probably as a result of availability of more resources at this spacing, may contribute to the increase in bulb fresh weight. In agreement with this study, Jambo (2015) reported that mean fresh bulb weight increased as intra-row spacing increased from 4 to 10 cm by about 47%.

Bulb Dry Matter Content

The effect of variety on bulb dry matter content was very highly significant ($P<0.001$) and the interactions between variety and intra-row spacing was significant ($P<0.05$) (Table 2).

Varieties were responded differently at different intra-row spacing. On plots with an intra-row spacing of 5, 7.5 and 10 cm, bulb dry matter content of Adama Red, Melkam and Shendi were not statistically different, however significantly higher than that of Bombay Red. At intra-row spacing of 12.5 cm, bulb dry matter content of Bombay Red was statistically similar with that of Melkam and Shendi (Table 3). The lowest bulb dry matter content (BDMC) from Bombay Red may be associated with its rapid bulbing property. This result is similar with the report of Kahsay et al. (2013) who confirmed that lowest dry matter content is recorded from Bombay Red.

On the other hand, intra-row spacing was also had different effects on different onion varieties. Significantly highest BDMC of Bombay red was recorded from the wider intra-row spacing (12.5 cm) while there was no statistically significant difference among all intra-row spacing using Adama Red, Melkam and Shendi. The highest BDMC of Bombay Red at the widest intra-row spacing may due to less competition for light and mineral which may enhance growth and synthesis of more photoassimilates to be translocated in to bulbs.

Total Soluble Solid

Both variety and intra-row spacing had very highly significant effect on total soluble solid of onion bulbs. The interaction between the main factors had significantly ($P<0.05$) influenced the total soluble solid of the onion bulbs (Table 1).

The effect of varieties on total soluble solid (TSS) varied as the intra-row spacing varies. At the narrowest intra-row spacing (5 cm) and widest intra-row spacing (12.5 cm) statistically similar and significantly highest TSS was recorded from Adama Red, Melkam and Shendi while significantly the lowest TSS was recorded from Bombay Red. At 7.5 cm intra-row spacing, significantly highest TSS was recorded from Adama Red and Melkam while significantly the lowest TSS was recorded from Bombay Red. At 10 cm intra-row spacing, significantly highest TSS was obtained from Melkam compared to Shendi and there was no significant difference among Adama Red, Bombay Red and Shendi (Table 3).

Similarly, the effect of intra-row spacing on TSS varied on the different varieties of onion. Using Adama Red, although there was no statistically significant difference among 5, 7.5 and 12.5 cm intra-row spacing, the highest TSS (13.53 °Brix) was recorded from the narrowest intra-row spacing (5 cm). Using Bombay Red, although there was no statistically significant difference among 5, 7.5, and 12.5 cm intra-row spacing, the lowest TSS was obtained from the widest intra-row spacing (12.5 cm). Melkam produced significantly highest TSS of 13.33 °Brix at the narrowest intra-row spacing (5 cm) compared to 12.5 cm. Using Shendi, significantly highest TSS was recorded from the narrowest intra-row spacing than the other intra-row spacing (Table 3).

Even though the trend was not consistent due to interaction effects, the highest TSS was recorded from Adama Red and Melkam while the lowest one is from Bombay Red. Similar to this result, Kahsay et al. (2013) also reported that Adama Red and Melkam had highest TSS.

Table 3. Interaction effect of variety and intra-row spacing on bulb dry matter content (%) of onion

Intra-row spacing (cm)	Total soluble solid (°brix)					Dry matter content (%)				
	5.00	7.50	10.00	12.50	Mean	5.00	7.50	10.00	12.5	Mean
Varieties										
Adama Red	13.53[a]	12.60[ab]	11.57[bcd]	12.17[abc]	12.47	17.08[ab]	16.66[ab]	17.33[ab]	17.8[a]	17.22
Bombay Red	9.80[ef]	10.67[def]	10.87[cde]	9.47[f]	10.20	14.00[c]	14.00[c]	14.08[c]	16.30[b]	14.60
Melkam	12.93[ab]	12.17[abc]	12.17[abc]	11.07[cde]	12.09	16.61[ab]	17.80[a]	17.66[a]	16.86[ab]	17.23
Shendi	13.33[a]	11.83[bcd]	10.67[def]	11.07[cde]	11.73	16.16[b]	16.55[ab]	16.65[ab]	16.11[b]	16.37
Mean	12.40	11.82	11.32	10.95		15.96	16.25	16.43	16.77	
	LSD(5%)=1.37, CV (%) = 7.08					LSD(5%)=1.29 CV (%) = 4.74				

Means with the same letter(s) within columns and rows are not significantly different according to LSD test at 5% level of significance

Table 4. Interaction effect of variety and intra-row spacing on weight loss (%) at second and fourth week of storage

Intra-row Spacing (cm)	Second week					Fourth week				
	5	7.5	10	12.5	Mean	5	7.5	10	12.5	Mean
Varieties										
Adama Red	1.65[g]	2.69[ef]	2.13[fg]	5.89[a]	3.09	4.93[ef]	5.73[efd]	4.81[f]	5.91[cdef]	5.35
Bombay Red	3.24[cde]	3.19[de]	4.11[b]	3.97[bc]	3.63	7.96[ab]	7.02[bcd]	7.97[ab]	8.77[a]	7.93
Melkam	2.92[de]	2.90[de]	3.37[cde]	3.09[de]	3.07	5.24[ef]	5.45[ef]	4.75[f]	5.13[ef]	5.14
Shendi	3.41[bcde]	2.92[de]	3.15[de]	3.55[bcd]	3.26	5.47[ef]	6.13[cde]	8.66[a]	7.17[bc]	6.86
Mean	2.81	2.93	3.19	4.13		5.9	6.08	6.55	6.75	
	CV (%) = 13.31; LSD (5%) = 0.72					CV (%) =12.47; LSD (5%) = 1.31				

Means with the same letter(s) within columns and rows are not significantly different according to LSD test at 5% level of significance

Table 5. Interaction effect of variety and intra-row spacing on weight loss (%) at sixth and eighth week of storage

Intra-row Spacing (cm)	Sixth week					Eighth week				
	5	7.5	10	12.5	Mean	5	7.5	10	12.5	Mean
Varieties										
Adama Red	9.15[f]	10.67[cdef]	10.69[cdef]	11.68[bcd]	10.55	13.99[ef]	14.90[edf]	15.63[bcde]	16.64[bcd]	15.29
Bombay Red	10.23[def]	12.08[b]c	12.66[b]	15.61[a]	12.65	14.73[def]	16.14[bcde]	17.77[b]	21.92[a]	17.64
Melkam	9.73[ef]	10.73[cdef]	9.72[ef]	10.10[def]	10.07	13.96[ef]	13.96[ef]	12.87f	12.83[f]	13.41
Shendi	10.79[cde]	11.54[bcd]	12.11[bc]	12.81[b]	11.81	15.67[bcde]	15.24[cdef]	16.86[bcd]	17.37[bc]	16.29
Mean	9.98	11.26	11.3	12.55		14.59	15.06	15.78	17.19	
	CV (%) = 8.75;LSD (5%) = 1.64					CV (%) =9.37; LSD (5%) = 2.45				

Means with the same letter(s) within columns and rows are not significantly different according to LSD test at 5% level of significance

With respect to intra-row spacing, the highest TSS was obtained at the narrowest intra-row spacing while the lowest TSS was recorded from wider intra-row spacing. This might due to dilution of TSS as larger bulbs grown at wider spacing have higher volume and more water content. This result is in agreement with the report of ARDC (2008) and Mallor et al. (2011) who reported that higher bulb size resulted in lower TSS.

Bulb Weight Loss

Variety had very highly significant effect (P<0.001) on the percent of bulb weight loss of onion in the fourth, sixth and eighth weeks of storage. The effect of intra-row spacing on this quality parameter was also very highly significant (P<0.001) in all weeks of bulb storage, except the fourth week. The interaction effect between variety and intra-row spacing was very highly significant (P<0.001) at the second week, highly significant (P<0.01) at the fourth and eighth weeks and significant (P<0.05) at the sixth week (Table 1).

During the storage period, Bombay Red experienced the highest weight loss while the mean weight loss for Melkam was the lowest (Table 4 and 5). An increase in the percent of weight loss in all varieties was observed with an increment in the storage period of the bulb due to increase in water loss. In the second week, Adama Red experienced the highest weight loss (5.89%) with 12.5 cm intra-row spacing followed by Bombay Red (4.11%) with intra-row spacing of 10 cm. Adama Red had the lowest weight loss (1.65, 2.69 and 2.13%) with 5, 7.5 and 10 cm intra-row spacing followed by Melkam (2.90%) with 7.5 cm spacing. The loss of weight in the fourth week of storage was highest (8.77 and 8.66%) for Bombay Red and Shendi with 12.5 and 10 cm spacing, respectively while Adama Red and Melkam had the lowest loss of weight (4.81 and 4.75%, respectively). At the sixth and eighth weeks of storage, the loss of weight was highest (15.61 and 21.92, respectively) for Bombay Red with 12.5 cm intra-row spacing, however it was least (9.72 and 12.83%) for Melkam with intra-row spacing of 10 and 12.5 cm, respectively. In addition, the least weight loss (9.15%) was recorded for Adama Red at 5 cm spacing at the sixth week of bulb storage. Kahsay et al. (2013) also reported that Bombay Red variety showed significantly highest percent of bulb weight loss.

The highest weight loss was recorded at the widest spacing due to high loss of water from bulbs with higher surface area to volume ratio. Asres (2017) reported that higher weight loss during the 12^{th} week of storage was observed in wider spacing (15 cm) than in bulbs from narrower spacing treatments. Sing and Sing (2003) also reported that larger size bulbs exhibited the highest weight loss compared to smaller sized bulbs.

Correlation Analysis

According to Table 2, total soluble solid negatively and significantly correlated with bulb diameter (r=-0.635**) and weight loss (r=-0.565**). Positive and highly significant correlation was recorded between neck thickness and bulb diameter (r=0.662**), bulb length (r=0.621**) as well as mean bulb fresh weight (r=-0.657**). Bulb diameter had positive and significant, highly significant and very highly significant correlation with bulb length (r=0.524*) and mean bulb fresh weight (r=0.896***). Total soluble solid had positive and significant correlation with bulb dry matter content (r=0.527*). The relationship between bulb dry matter content and weight loss during the fourth week of storage had been negative and highly significant (r=-0.609**).

Conclusion

In this study, most of the quality parameters have been maximized by using Melkam variety with the widest intra-row spacing of 10 and 12.5 cm. However, the total bulb yield will be reduced at the widest intra-row spacing due to low population density. The average bulb weight which is considered as the most important parameter for producers from the marketability point of view did not show significant variation between 7.5 cm and 10.00 cm intra-row spacing. Therefore, quality bulb production can be optimized using variety Melkam and 7.5 cm intra-row spacing and can be recommended to Antsokia Gemza district and other areas with similar agro-ecology.

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