

Full Length Research Paper

An investigation on the influence of intra-row spacing and variety on yield and shelf life of onion

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A field experiment was conducted to investigate the influence of intra-row spacing and, variety on yield and shelf life of onion. The study was conducted between August 2010 and April 2011 at Aksum area (Laelay Maichew District). Three different intra-row spacings (5, 7.5 and 10 cm) were evaluated using 4 varieties of onion ('Adama' Red, 'Bombay' Red, 'Melkam' and 'Nasik' Red) using randomized complete block design replicated 4 times. Data on yield and shelf life parameters were recorded and subjected to analysis of variance using SAS 9.2 software. The result showed the post harvest deterioration as measured by percentage of marketable loss, total soluble sugars in ^{oBrix} and dry matter content (DMC) was less on 'Nasik' Red variety. The largest bulb size, produced by the larger intra-row spacing, showed highest rotting percentage compared to the smaller ones. Average bulb weight loss during storage also was higher at the intra-row spacing of 5 cm than 7.5 cm. Moreover, the result revealed that 'Melkam' and 'Bombay' Red varieties were superior in yield and an intra-row spacing of 7.5 cm can gave good yield bulbs while 'Nasik' Red had best storage quality and 'Melkam' and 'Adama' Red are moderate.

Key words: Quality, yield, storage, onions, dry matter content.

INTRODUCTION

Onion (*Allium cepa* L.) belongs to the genus *Allium* of the family Alliaceae. Onion is by far the most important of the bulb crops cultivated commercially in nearly most parts of the world. The crop is grown for consumption both in the green state as well as in mature bulbs. Onions exhibit particular diversity in the eastern Mediterranean countries, through Turkmenia, Tajikstan to Pakistan and India, which are the most important sources of genetic

diversity and believed to be center of origin (Brewster, 2008). *Alliums* are typically plants of open, sunny, dry sites in fairly arid climates, however many species are also found in the steppes, dry mountain slopes, rocky or stony open sites, or summer dry, open, scrubby vegetation.

Onion is considerably important in the daily Ethiopian diet. All the plant parts are edible, but the bulbs and the lower stem sections are the most popular as seasonings or as vegetables in stews (MoARD, 2009). It is one of the richest sources of flavonoids in the human diet and flavonoid consumption has been associated with a reduced risk of cancer, heart disease and diabetes, anti bacterial, antiviral, anti-allergenic and anti-inflammatory.

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One onion quality parameter, the percentage of single-center bulbs, has become important to meet demands of both processing and fresh market buyers (Brewster and Rabinowitch, 1990). According to the report of Ethiopian

Statistics Agency (CSA) (2011) the area coverage of onion was 22,035.80 ha in Ethiopia and 528 ha in Tigray region in one season.

So far, research in the country was mainly focused on the identification of superior cultivars of onions and adopting improved management practices. Different cultural practices and growing environments are known to influence yield and quality of dry bulbs. Spacing has effect on different varieties as their root and leaf growth habits differ. Geremew et al. (2010) recommended intra row spacing of 4 cm for '*Nasik*' Red and '*Adama*' Red varieties, and 6 cm for '*Bombay*' Red variety, both of which gave highest marketable yield and reduced unmarketable bulb yield in central rift valley areas of Ethiopia. Higher yield and better control over bulb size could be obtained if plants are grown at optimum density. Kantona et al. (2003) concluded that, varieties as well as planting densities significantly affected the onion bulb yield. The author observed that Bulb neck diameter, mean bulb weight and plant height decreased as population density increased. Total bulb yield increases significantly as population density increases. Number of marketable bulbs increases significantly with higher planting density.

The status of vegetable production in the country yet needs further improvement. Despite an enormous potential and a favorable environmental advantage in the country, vegetable production and productivity is relatively underdeveloped. The majority of private farms in the countryside are using traditional practices to grow crops and require much benefit from the research results, including inputs like improved seeds. The major constraints of the vegetable sector in the country include: Lack of high-yielding and multiple pest and disease resistant cultivars with specific attributes for growth adapted to the different agro-ecological zones, proper agronomic practices, appropriate pest and disease control techniques, proper post harvest handling, suitable marketing and transportation systems, sufficient quantity of seed supply and good orientation of people to make them aware of the nutritive and economic advantages of these crops (Fekadu and Dandena, 2006).

To improve onion production, the agricultural research system of the country has made efforts to generate improved varieties. '*Bombay*' Red and '*Adama*' Red varieties are widely grown in Ethiopia (EARO, 2004). However, these varieties are not distributed to all or most growing areas of the country and are not tested in different agro-ecologies particularly in the study area. Although some production technologies are developed in the country, it is very difficult to give general recommendation that can be applicable to the different agro ecological zones. To optimize onion productivity, full

package of information is required (Gupta et al., 1994; Lemma and Shimeles, 2003). Plant population needs to be optimized. The optimum use of spacing or plant population has dual advantages (Geremew et al., 2010). It avoids strong competition between plants for growth factors such as water, nutrient and light. In addition optimum plant population enables efficient use of available cropland without wastage.

Aksum-Adwa area is one of the potential areas for onion production in Ethiopia (EHDA, 2011). Though Bombay Red and *Adama* Varieties are approved and being used (AxARC, 2009), there are no packages of recommendation with regard to crop management practices. Market problem and poor cropping pattern are also major problems in the study areas. Onion is the first in area coverage, but the yield is 107 q/ha, which is very less, compared to the national average (1.87 tones/ha) (Mintesinot et al., 2005). Lack of proper agronomic practice used by farmers is one of the major problems in onion production (AxARC, 2009). This is because there had been no agronomic or varietal trial done for onion so far. The nationally recommended spacing between plants of onion has been 10 cm, which was made based on the research done in central rift valley of the country some years back. Nevertheless, in the real situation, the practice, which is adopted by farmers, is a bit far (narrower or wider) from the recommendation.

In Ethiopia, up to 30% of vegetable harvests are reported to be lost due to poor post harvest handling. Hence, the vegetable production value chains should include production of disease resistant varieties, agronomic practices, and post harvest handling capacity for bulking, increased shelf life, new product development and delivery systems to markets (Fekadu and Dandena, 2006). Thus, post harvest losses can be minimized not only by post harvest management, but also by pre harvest management like use of improved variety and proper cultural practices. Onion is one of the horticultural crops being exported to Djibouti, Somalia and Sudan. In most areas of the country, appropriate technologies are lacking to overcome the loss over the transportation and marketing chain (EHDA, 2011). The present study was therefore, undertaken to investigate the effects of different intra-row spacing on the growth, yield, quality and shelf life of onion varieties with the following specific objectives:

- i) To determine the best plant spacing for better shelf life of some onion varieties
- ii) To study the interaction effect of intra-row spacing and onion varieties on shelf life

MATERIALS AND METHODS

Description of the study site

The study was conducted in August 2010 to April 2011 at Aksum area (Laelay maichew district), Central Zone of Tigray National

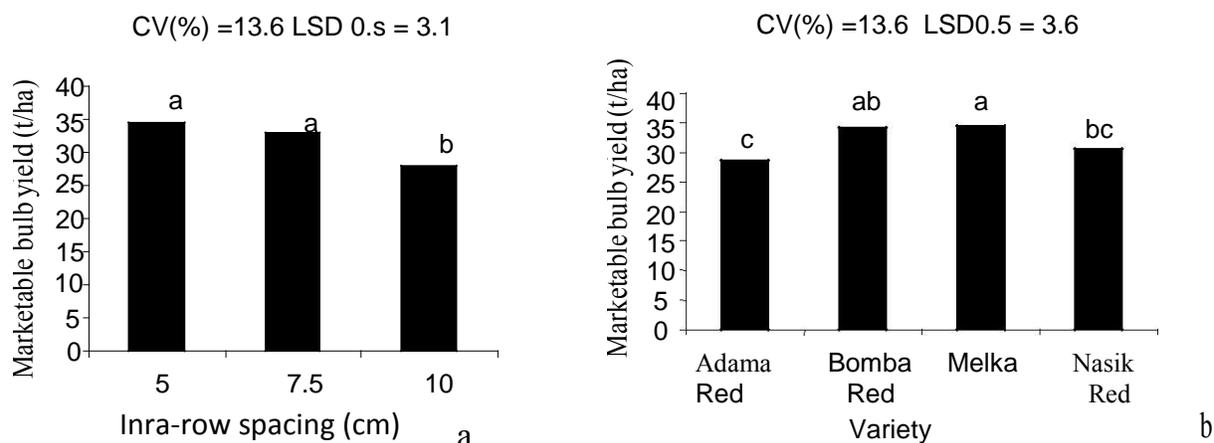


Figure 1. Effect of intra-row spacing (a) and variety (b) and variety on marketable bulb yield (ton/ha) of onion.

Regional State, 245 km away from Mekelle towards the North west. The experimental site lies between latitude of 14° 07' 00" and 14° 09' 20" N, and 38° 38' 00" and 38° 49' 09" E longitude, and elevation of 2080 meter above sea level. The soil is, classified as loamy clay vertisol. The rainy season of the area is monomial and receives 700 mm average rainfall per annum. The rainy period is June to September. The annual minimum and maximum monthly temperature ranges from 11 to 15.1°C, respectively.

Experimental treatment and design

The experiment consisted of factorial combination of two factors viz; intra-row spacing (5, 7.5 and 10 cm) having 90, 67 and 45 plants/m² respectively and variety ('Adama' Red, 'Bombay' Red, 'Melkam' and 'Nasik' Red) laid out in 3 × 4 factorial randomized complete block design (RCBD) replicated four times. Each plot had a size 2*3 m and spacing of plots and rows 100 m and 20 cm, respectively. There were totally 48 plots.

Experimental management

Cultural management practices other than intra-row spacing were done according to the national recommendations. Seeds were sown for nursery rising and transplanted after 50 days from sowing. Di-ammonium phosphate (DAP) (100 kg/ha) fertilizer was applied during the last land preparation and Nitrogen (100 kg urea/ha) urea was split applied during planting and 6 weeks after transplanting. Weeds were controlled mechanically (by hand weeding). Onion thrips was observed and treated with phenotrotine chemical. During maturity when 2/3 of the leaves become yellow in color, bulb was harvested and cured for 5 days (EIAR, 2007). Sample bulbs were taken from each plot for bulb characteristics measurement and stored in aerated plastic sacks to evaluate shelf life. The storage time was on the month of March to April at which the average monthly temperature were 20.14° and 20.28°C, respectively and relative humidity of 37 and 36.4%, respectively (Aksum Metrology Station, 2011).

Data collection and analysis

Data were collected according to the standard procedures

described by IPGRI (2001). Data on bulb weight and size were taken in two weeks interval for two months. Data on marketable bulb yield, percentage of rotten bulbs, bulb weight loss, bulb diameter loss, bulb length loss, marketable loss, Total soluble sugars (TSS) content in oBrix and Dry matter content (DMC) were collected and were subjected to the Analysis of Variance (ANOVA) using SAS version 9.2 Computer software (SAS Institute Inc., 2008). Whenever the treatment was significant least significance differences (LSD) was used for mean separation at $p = 0.05$.

RESULTS AND DISCUSSION

Marketable bulb yield

A highly significant ($p < 0.001$) differences were observed among the levels of intra-row spacing and onion varieties on the marketable bulb yield (t/ha). As intra-row spacing increased from 5 to 10 cm, marketable bulb yield in tons/hectare decreased from 34.49 to 28.1. Among the intra-row spacing, a statistically similar result was obtained from 5 and 7.5 cm intra-row spacing, which scored the highest marketable yield in tons per hectare, 34.49 and 32.97, respectively (Figure 1). Intra-row spacing of 10 cm showed the lowest (28.1 t/ha). Generally, a trend of increasing gross marketable yield together with plant density was observed. Plant density has an impact on marketable bulb size and the higher the plant density the smaller the marketable size Seck and Baldeh (2009). Kantona et al. (2003) also reported that as plant density increased, number of marketable bulbs increased significantly.

The highest marketable bulb yield (34.36 t/ha) was recorded by 'Melkam' Variety. However, it was not significantly different from 'Bombay' Red variety. The lowest marketable yield (28.45 t/ha) was recorded on 'Adama' Red variety, but not significantly different from 'Nasik' Red (Figure 1). In agreement to the present results, Jilani et al. (2009) reported similar observation. A cultivar performs differently under different agro- climatic

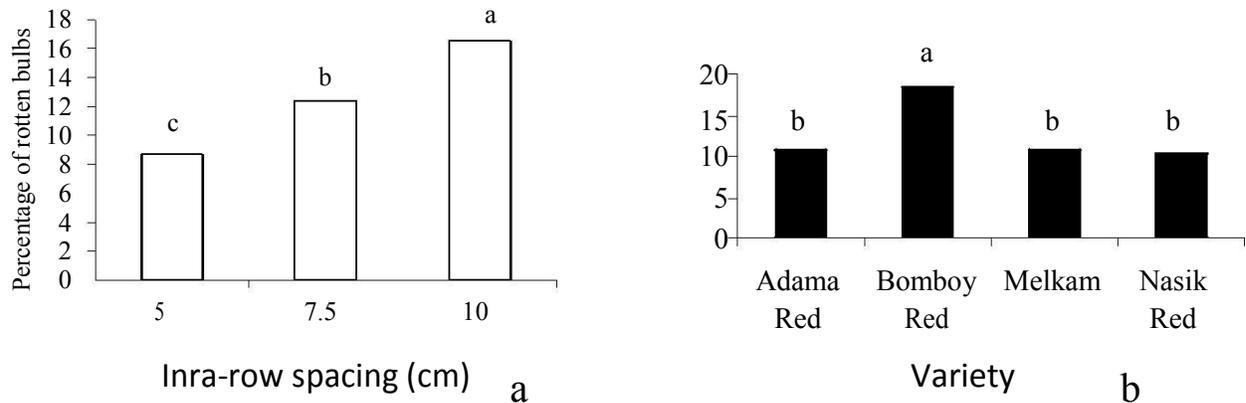


Figure 2. Effect of intra-row spacing (a) and variety (b) on percentage of rotten bulbs of onion. Means followed by the same letter are not significantly different at $p < 5\%$ as established by LSD-test (LSD=2.71 and 3.13, respectively).

conditions and various cultivars of the same species grown even at the same environment often yield differently (Jilani and Ghaffoor, 2003).

Shelf life of onion bulb

The results on evaluation of the shelf life of onion and deterioration rate at different weeks indicated that there were variations among the weeks in level of deterioration or changes of the bulb like bulb weight loss, bulb diameter loss and bulb length loss. There was progressive increase of loss as the number of week increased. The result indicated that the significant effect of number of weeks (storage period) on various response parameters. Moreover, the effects of the intra-row spacing and varieties on the post harvest parameters are discussed below.

Storage rots (%)

The main effect of varieties and intra-row spacing had significant ($p < 0.001$) effect on the percentage of rotten bulbs measured at the end of 8 weeks storage period. Maximum percentage of rotten bulbs (16.54) was observed at 10 cm intra-row spacing, while lowest percentage of rotten bulbs (8.70%) was seen at 5 cm (Figure 2). The increased tendency of large bulbs to rotting could have commercial importance in onion storage and transportation. Increase in rotting of bulbs due to increase in spacing may be attributed to the fact that higher spacing encourage plants to produce large bulbs with soft succulent tissues which make them susceptible to the attack of disease causing micro organisms and produce bulbs with thick neck which render them difficult to dry. The loss due to rotting is also increased with bulb size may be due to the infection rate among bulbs is high and the loss of individual large bulbs

is more considerable to decrease yield (Rajcumar, 1997). Periodic assessments done by Ward (1979) investigated that the number of rotted bulbs increased with increasing bulb size. Cho et al. (2010) justified that, larger onions are more susceptible to bruising, disease and other damage than smaller bulbs also support this finding. The cause of rotting was observed neck rot.

'Bombay' Red showed highest (18.51%) and significant difference from the others regarding percentage of rotten bulbs. There was no statistically significant difference among 'Melkam', 'Adama' Red and 'Nasik' Red varieties (Figure 2). This may be associated with the large bulb size percentage of these varieties had and the low DMC observed on 'Bombay' Red. In agreement to this finding, Cho et al. (2010) reported similar result. Storage life could be also association with dry matter (DM) content. This result is in accordance to the report of Rafika et al. (2006) who observed that DM was negatively correlated with the level of rotten bulbs. The author further explained that, this variability characterized the ability to store of cultivars.

The probable cause of rotting was fungal pathogens because, symptoms which look like neck-rot and basal rot were observed. Lee et al. (2001) noticed that, larger bulbs had higher incidences of bulb rots. The authors further identified that major causal pathogens associated with basal and neck rot diseases were *Fusarium oxysporum* and *Aspergillus sp. or Botrytis allii*, respectively, of which basal rot was most prevalent and damaging during storage. The higher incidence of rotting in large bulbs may be probably associated with higher water content.

Percent of bulb weight loss

Percentage of bulb weight loss of onion was not affected by intra-row spacing, while there was a significant ($p < 0.01$) difference due to different varieties throughout the

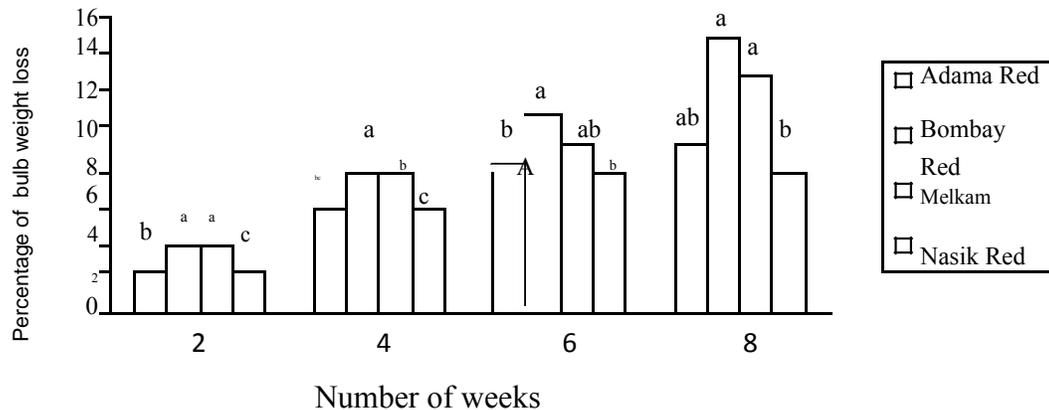


Figure 3. Effect of variety on percentage of bulb weight loss of onion, Means connected by the same letter are not significant different at $P < 5\%$ according to LSD-test (LSD = 0.05, 0.84, 1.76, 2, 26 and 3.61 for weeks 2, 4, 6 and 8, respectively).

storage period (weeks). However, almost at all the weeks, the loss of the widest spacing (10 cm) and the least spacing (5 cm) were found to be greater than that of the middle one (7.5 cm) (Figure 3). 'Bombay' Red and 'Melkam' varieties showed significantly highest percent of bulb weight loss (Figure 3). In agreement to this finding, Msika and Jackson (1997) described cultivar specific weight losses of between 2 and 5% per month in warm ambient storage in Zimbabwe. They indicated that the loss increment occurred from second week to end of third month storage time. They described the relatively low initial rate to loss of water through the skin and by low-level of respiration of dormant bulbs that was followed by a change to a steeper slope, indicating more rapid weight loss, due to high respiration rate and senescence of older fleshy scales.

The higher weight loss at wider and closest intra-row spacing might be probably because wide planting distance produced the large size of bulb, the large size of bulb contains highest water and have more surface area per unit of bulb and then per kg and there by highest rate of transpiration. Sing and Sing (2003) reported that, large size of bulb exhibited the highest weight loss compared to smaller size of bulbs. The size, color, flavor and keeping quality of onions could be determined by the variety (Mar, 1994). Storage quality is also reported that the negatively correlated with certain bulb morphological traits such as bulb diameter and neck diameter (Rivera et al., 2005). Medium size bulbs (50 to 60 g) are suitable for long-term storage. Storing a mixture of sizes of bulbs facilitates longer shelf life. With the size of the bulbs, storability varies and closer spacing produces smaller size bulbs (<http://www.goviya.lk/agri>). In this study, the storage weight loss throughout all weeks increased where this could possibly be associated with physiological parameters that lead to higher respiration rate. AVRDC (2000), reported that the loss in weight can be highest in large size bulbs and followed by small size

bulbs and medium size bulbs. Rajcumar (1997) indicated that, weight loss was associated with the resumption of higher incidence of sprouting, rotting and percentage of diameter loss most likely through increase in the rate of respiration.

Percent bulb diameter loss

There was no significant difference on the percentage of diameter loss due to spacing and their interaction with variety and weeks. However, there was very significant ($p < 0.001$) difference in the percentage of bulb diameter loss among varieties during the storage period. 'Bombay' Red and 'Melkam' varieties showed significantly higher difference throughout the storage period (Figure 4). This high diameter loss is also probably associated with the large size bulbs in which 'Bombay' Red and 'Melkam' varieties had. The character of diameter loss may be probably due to moisture loss and respiration loss. In accordance to the current result, Lancaster et al. (2001) reported that, some onion varieties became more elongated during storage time.

Percentage of marketable bulb loss

The percentage of marketable bulbs loss after two months of storage was significantly ($p < 0.001$) affected by the intra-row spacing and variety. The highest loss (34.75%) was recorded at the 5 cm intra-row spacing followed by the 10 cm intra-row spacing (31.29%) while, the lowest (26.24%) percentage of marketable bulb loss was recorded at the 7.5 cm intra-row spacing (Figure 5).

'Bombay' Red variety had higher significant difference in marketable bulb loss (Figure 5). According to a report from AVRDC (2000), storage losses varied among the cultivars and ranged from 14.5 to 97.5% over a trial

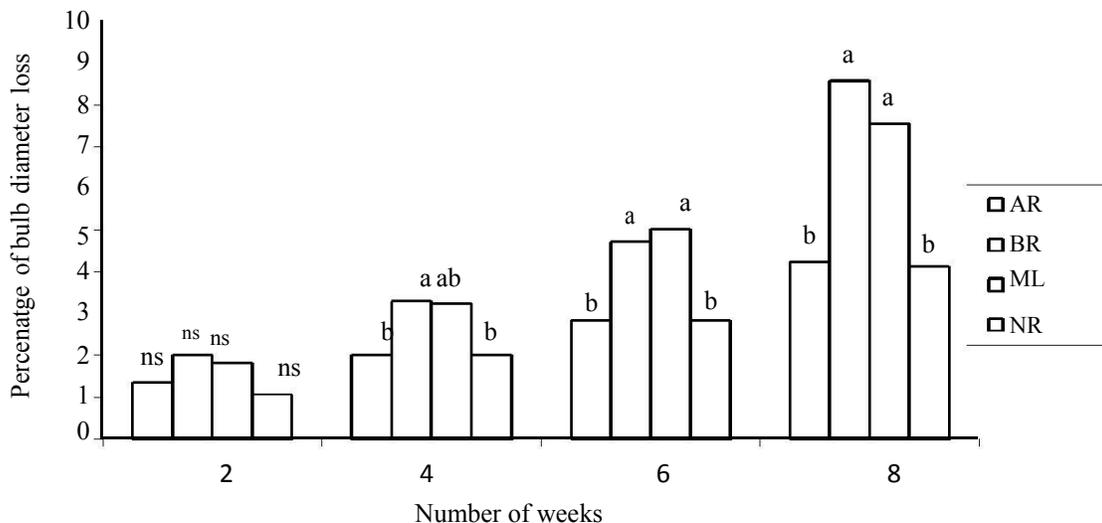


Figure 4. Effect of varieties on percentage bulb diameter loss at different weeks interval. Means connected by the same letter are not significant different at $P < 5\%$ according to LSD-test (LSD = ns, 1.29, 1.8, and 1.8 for week 2, 4, 6 and 8, respectively). AR=Adama Red, BR = Bombay Red, ML= Melkam and NR = Nasik Red).

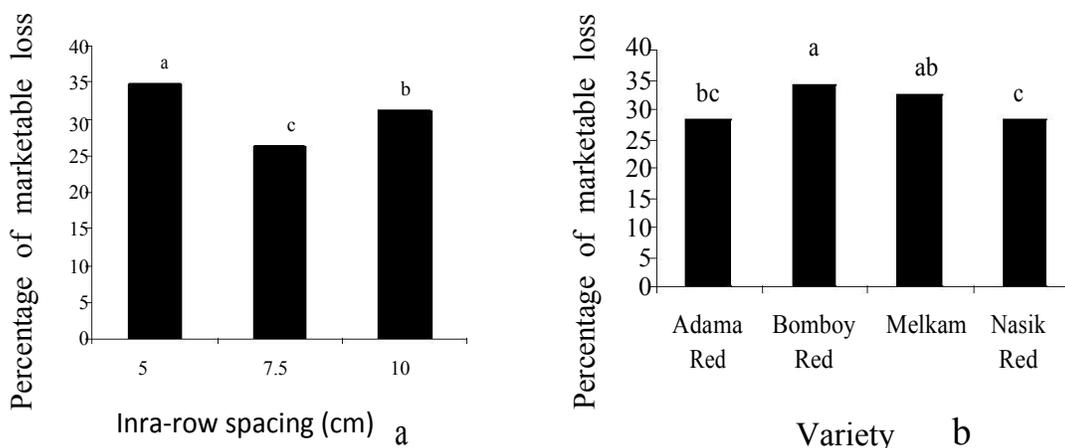


Figure 5. Effect of intra-row spacing (a) and varieties (b) on percentage marketable bulb loss at the end of 8 weeks storage, Means connected by the same letter are not significantly different at $P < 5\%$ established by LSD-test (LSD = 3.44 and 5.55, respectively).

period of 16 weeks and significant difference in storage loss was observed in relation to bulb sizes. This might be because wide planting distance produced the large size of bulb, the large size of bulb contains more water and have more surface area and there by highest rate of transpiration. Storage quality is also reported to be negatively correlated with certain bulb morphological traits such as bulb and neck diameter (Martinez et al., 2005). Due to wider spacing, the large sized set could get better nutrition and hence exhibited highest growth and development. The highest growth and development expressed more diameter and bigger size of bulbs. The bigger sizes of bulbs have highest juice and more weight loss in ambient storage (Sing and Sing, 2003).

Duration of dormancy and therefore storage potential clearly depends on genotype and it can be improved through breeding. Long storage potential is correlated with high bulb DMC, high pungency and the formation of several thick skins (Currah and Proctor, 1990; Brewster, 2008). Onions, garlic and dried produce are best suited to low humidity in storage. Pungent types of onions have high soluble solids and will store longer than mild or “sweet” onions, which are rarely stored for more than one month (Kitinoja and Kader, 2004). Overall, the marketable bulb loss in this study was associated with bulb size and dimensions, which were influenced by intra-row spacing and variety.

The percentage of marketable bulb loss had significant

Table 1. Pearson correlation coefficients among average bulb weight and loss parameters.

Parameter	ABW	BDI	BLI	BWI	TSSf	DMCf	PRB	PML
ABW	1	0.28	0.02	-0.04	-0.03 ^s	0.23	0.4**	0.16
BDI		1	0.1	0.6***	-0.27	-0.57***	0.55***	0.49**
BLI			1	-0.15	0.36	-0.24	0.16	-0.12
BWI				1	-0.25	-0.3*	0.38**	0.46**
TSSf					1	0.52*	-0.1	-0.47**
DMCf						1	-0.59***	-0.34*
PRB							1	0.46*

ABW, BDI, BLI, BWI, TSSf, DMCf, PRB and PML= average bulb weight, bulb diameter loss, bulb length loss, bulb weight loss, final total soluble sugars content, final dry mater content, percentage of rotten bulbs and percentage of marketable loss respectively. ns, *, **, and *** indicates non significant, significant difference at probability levels of 5, 1 and 0.1%, respectively.

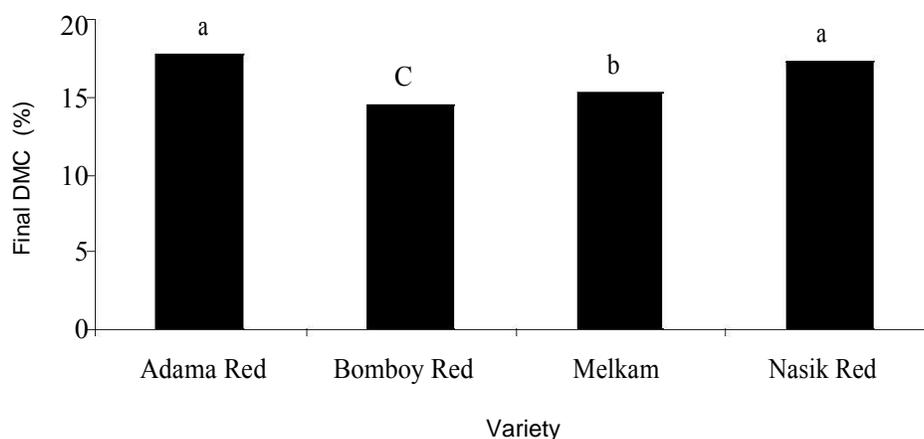


Figure 6. Differences of onion varieties in the final DMC (percentage) of bulb after storage of two months. Means connected by the same letter are not statistically significant different at <5% established by LSD-test (LSD = 1.6).

and positive correlation with bulb diameter loss (0.49**), bulb weight loss ($r = 0.46^*$) and percentage of rotten bulbs ($r = 0.46^{**}$). Thus, rotting, weight loss and bulb diameter loss all accounted for amplified percent of marketable bulb loss during the storage period. Meanwhile percentage of marketable loss had significant negative correlation with total soluble sugar content ($r = -0.47^{**}$) and bulb DMC ($r = -0.34^*$). Onions having high DMC and TSS cured and stored better than milder ones (Hector, 1991). Many factors can influence the storage life of onion. Under all conditions, onion continually loss water and DM, but the more serious losses arose from rotting and sprouting. Among the factors, which are critical for successful onion storage, are choice of cultivars and method of cultivation. The medium, large and bulked bulbs stored longer than the small and extra large bulbs (AVRDC, 2000). Currah and Proctor (1990) concluded that, onion varieties having high DMC lead to lower yield, but it improves the storability of onion cultivars having high DMC. Nabi et al. (2010) also concluded that, variation among varieties in marketable

loss might be probably linked with DM and moisture contents of the bulbs (Table 1).

Dry matter content (DMC) (%)

There was no any significant difference among the different intra-row spacings on DMC after bulb storage. But there was significant ($p < 0.001$) difference among the varieties on DM content of the bulb after storage of two months. 'Adama' Red and 'Nasik' Red having DMC (%) of 17.67 and 17.27, respectively showed higher and significant difference from 'Melkam' and 'Bombay' Red which had DMC (%) of 15.23 and 14.41, respectively (Figure 6). Different investigations support the present result. Pavlovic et al. (2011) reported that, significant variability was found for DMC in bulbs during two years of research. The author suggested that high percentage of genetic variability in total phenotype variability has been confirmed by high heritability.

AVRDC (2000) also reported that, DM and TSS

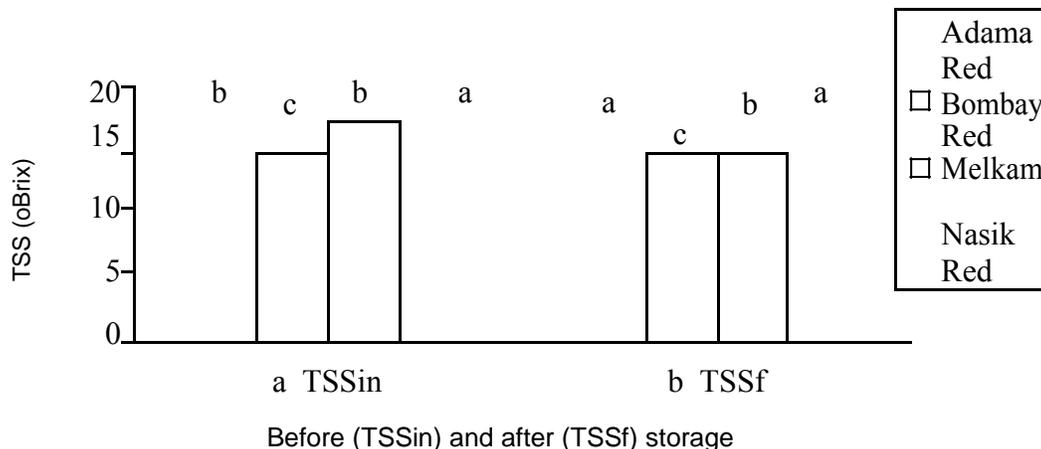


Figure 7. Differences of onion varieties in the TSS content (oBrix) of bulb before storage (a) and after storage (b). Means on the same group (TSSin and TSSf) connected by the same letter are not statistically significant different at $P < 0.05$ as established by LSD-test (LSd = 4.1 and 4.5 respectively).

contents were determined for 24 of onion entries: DM content ranged from 4.40 to 11.30% and the TSS in oBrix value from 5.30 to 10.60. Correlation coefficients between storage loss of onion bulbs and their DM and TSS contents at harvest suggest that high DM or TSS content is associated with lower storage losses ($r = -0.73$ with DM, $r = -0.81$ with TSS; $P < 0.001$) and less rotting in storage ($r = -0.74$ with DM, $r = -0.84$ with TSS; $P < 0.001$). DM or TSS content may therefore be an indicator of good storability.

The current finding is also in accord with investigations of Foskett and Peterson (1994) briefed those good storage onions and shallots are characterized by high DMC. Among cultivars of bulb onions DMC consisting mostly of fiber and sugars is an important quality factor determining bulb use, such as high DM onions required for dehydration. The relationship between bulb DMC and composition of non-structural carbohydrates has an important implication for physiology of carbohydrate accumulation in the onion bulb. Storage losses in 37 onion cultivars in India were also found to be negatively correlated with ash, potassium, DM, total soluble solids and non-reducing sugar content (Gubb and Tavis, 2002). Genetically controlled factors that may influence storage performance include DMC, pungency, skin color, skin number and quality, and length of natural dormancy of the particular onion variety (Salunkhe, 1998).

Total soluble solids

There was no significant ($p < 0.05$) effect of the intra-row spacing and of the interaction. The TSS content after the storage period was significantly ($p < 0.001$) affected by variety. Varieties 'Adama' Red and 'Nasik' Red showed higher and significant difference from the other and

'Melkam' variety showed higher and significant difference from 'Bombay' Red. The varieties 'Adama' Red and 'Melkam' had no significant difference before storage while 'Adama' Red showed higher and significant difference from 'Melkam' after storage (Figure 7); this implied that the TSS of 'Melkam' decreased more than that of 'Adama' Red. Consecutively it indicated that, the susceptibility of 'Melkam' variety to biochemical change more than of 'Adama' Red variety which may be associated with negative effect of relatively larger bulb size in 'Melkam' variety.

Moreover, Rajcumar (1997) reported that cultivars with low total soluble solids met with high storage losses. The sugar concentration is associated with dormancy and storage life of onion, occurring as decrease in glucose, fructose and fructan (Cho et al., 2010). Kopsell and Randle (1997), found the significant differences in total soluble solids content during storage, which was cultivar dependent. They found a quadratic decline during maturation and storage in short day cultivars while in intermediate cultivars they found a linear decrease over time.

The physico-chemical composition of bulbs particularly the DM, TSS in oBrix, total soluble solids, reducing and non-reducing sugars had direct relation on storage quality (Kukanoor, 2005). Wheeler et al. (1998) reported that rapid sprouting in storage was associated with lower levels of total water-soluble solids in the center of bulbs. The reason for this could be as storage time increases bulb dormancy ends leading to sprouting. Consequently, there will be proportional rise in respiration and carbohydrate metabolism that brings a rapid decline in TSS content (oBrix) of bulbs.

Changes in sugar composition might be used as an indicator of the degree of dormancy of bulbs in biochemical terms. In onions, fructose level at harvest

has been suggested as an indicator of storage potential (Ruthford and Whittle, 1984). Total sugar content during storage considered as an index of keeping quality. Changes in the carbohydrate composition of onions during storage were reported where the main change was the hydrolysis of oligosaccharides to reducing sugars. Suzuki and Cutcliffe (1989) reported that, onion cultivars with a short storage life contained relatively higher moisture content, a high concentration of monosaccharides and a low concentration of fructans at harvest.

The lower final total soluble sugar content (TSSf) content containing 'Bombay' Red variety and moderate total soluble sugar containing 'Melkam' variety had higher yield and large bulb size. This confirmed that total soluble solids content in onions appeared to be negatively correlated with both bulb yields and storage losses. The greater amount of DM and TSS contents of the bulbs may help to have less moisture content in the bulb. Thus, due to the less amount of moisture the weight loss may also be very limited. Low total soluble solids content implies high percentage of water in onion contributing to larger bulbs and higher yields (Rajcumar, 1997).

Conclusion

Onion is one of the most popular and the most cultivated vegetables in Ethiopia in general and in Tigray region in particular. Farmers in the study area produce onion as a cash crop using non-uniform plant spacing based on the existing indigenous knowledge. The study was conducted to investigate best plant spacing for highest growth, yield, better quality and shelf life of onion varieties and to recommend best variety adaptable to the specific area and best plant spacing that give best growth, yield and bulb quality and shelf life.

The experiment was conducted from August 2010 to April 2011 under irrigated condition at Aksum area, L/maichew district, Central Zone of Tigray National Regional State. The experiment was done at three intra-row spacings (Factor 1): S1 (5 × 20), S2 (7.5 × 20) and S3 (10 × 20) cm equivalent to densities of 90, 67 and 45 plants/m², respectively, and four onion varieties (Factor 2): 'Adama' Red, 'Bombay' red, 'Melkam', 'Nasik' Red. A 3 × 4 factorial experiment was laid out in RCBD with four replications. Data were collected on growth; yield parameters, yield, bulb quality and shelf life.

Results of the study showed that, the main effects of intra-row spacing, varieties as well as their interactions had considerable influence on different parameters. The highest percentage of small size bulbs (23.76% and 15.45%) was produced by the treatment combination of 'Adama' Red at 5 cm spacing and 'Bombay' Red at 5 cm spacing respectively. While the minimum percentage of small size bulbs (4.4 and 6.9) was found in the combination of 'Melkam' at 10 cm and 'Adama' Red at 10 cm spacing respectively. The highest percentage of large

size bulbs (20.71) was recorded in 'Melkam' variety, while the lowest percentage of large bulbs (11.1) was obtained in 'Nasik' Red variety. The finding suggested that it is better to use intra-row spacing greater than 5 cm to minimize more small bulbs as this is might not mostly preferred for market. Besides, the ultimate goal of onion production is profitability through yield enhancement; the result revealed that 'Melkam' and 'Bombay' Red varieties appeared to be superior for yield and earliness at the study area although it needs repeated research for complete recommendation.

The highest percentage of bulb DMC (13.47) was recorded on 'Nasik' Red variety, while the lowest percentage (10.6) was recorded on 'Bombay' Red variety. The highest TSS in oBrix, was found at the late matured varieties 'Nasik' Red (17.57). While the lowest TSS in oBrix was found at the early varieties 'Bombay' Red (15.29) followed by 'Melkam' (16.54). Hence, for fresh consumption the milder ones with lesser TSS in oBrix value are better to use since they have better yield and adaptability advantages at the dry land condition of Tigray in general and Aksum area in particular.

With regard to the shelf life of onion bulbs measured by percentage of loss due to rotting, bulb weight loss probably due to respiration and transpiration, DCM, total soluble sugars content and loss of marketable bulbs, there was significant variation due to the varieties and due to intra-row spacing. There was no interaction effect between intra-row spacing and variety in all parameters. Generally, the wider spacing's bulb was found to be more deteriorating than the middle intra-row spacing in most parameters. The smallest spacing's bulb was also more deteriorating than that of the middle one. Thus, large bulbs could be easily affected by rotting and weight loss and the small bulbs very affected by weight loss. The high yielder 'Melkam' and 'Bombay' Red varieties were earlier in maturity, but 'Bombay' Red deteriorated more measured in most shelf life (post harvest) parameters while 'Melkam' was medium. The high bulb weight loss and marketable also were associated with low TSS content (oBrix) and low bulb DMC. From these findings it can be concluded that 'Bombay' Red variety had high yielder in addition to earliness in the study area that can be usefully for direct consumption/marketing and need careful storage and transportation management (storage period and condition) when needed to store and transport long distance. 'Melkam' variety had better yield and good storage quality relative to the others. 'Nasik' Red and 'Adama' Red varieties found to be superior for quality as measured by TSS content, DMC and storability. Moreover, intra-row spacing of 7.5 can give good yield and better quality of bulbs for market and storage.

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