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Effects of nitrogen levels, harvesting time and curing on quality of shallot bulb

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Optimization of nitrogen (N) fertilization levels, harvesting stages and curing treatments are among the management practices used for onion bulbs. Field and laboratory experiments were carried out to evaluate the effects of four levels of N application, three harvest stages and two curing levels on yield, bulb quality and shelf life of local shallot cultivar. Results of the study showed that increasing in the N application rate up to 100 kg N ha^{-1} and delay of harvesting up to 100% top fall, bulb yield of shallot increased considerably. A yield increase of 149, 68 and 72% at the 50, 75 and 100% top fall at harvest on fertilized relative to unfertilized plots. While increasing N levels showed proportional increase in the bulb pungency levels, it did not impact significantly the dry matter, total soluble solids, total sugars and reducing sugars of shallot bulbs either at harvest or during storage. However, there was associated increment in percent bulb rotting and sprouting, loss in bulb diameter, bulb weight loss and unmarketability with increased N application. Harvesting at 75% top fall showed better dry matter content of bulbs, reduced percent rot, sprouting and weight loss and improved marketability of bulbs. Interaction effects of N rates and harvest stage were observed in percent bulb rotting where the highest incidence was in 150 kg N ha^{-1} and 50% top fall harvest treatments and the least in unfertilized plot harvested at 100% top fall. The result of this study has shown N application in the range of 50 - 100 kg N ha^{-1}, harvesting at 75% top fall and curing bulbs before foliage removal is a good compromise for yield and post harvest quality and shelf life of shallot bulbs under ambient storage conditions.

Key words: Shallot, bulb, nitrogen, quality, harvesting time, curing.

INTRODUCTION

Onions contribute significant nutritional value to the human diet and have medicinal properties and are primarily consumed for their unique flavor or for their ability to enhance the flavor of other foods (Randle, 2000). On a global scale, shallot (*Allium cepa var.* Aggregatum Don.) is a minor alliaceous crop. However, in many tropical countries the vegetatively propagated shallot is cultivated as an important bulb crop (Currah and Proctor, 1990). Shallot is a crop used as a main ingredient in most traditional Ethiopian cuisine. The shallot cultivated in Ethiopia is pungent red in colour, dry bulb type which is exclusively propagated by vegetative means. However, loss of bulb weight and quality are the principal problems encountered during post-harvest storage and transport of the shallot.

Post harvest loss in onion has been estimated to reach 30% in Sudan (Hayden, 1989) and 50 - 76% in Nigeria (Denton and Ojeifo, 1990). A comprehensive statistics for shallot losses is not available for Ethiopia; however, it has been estimated that farm gate post harvest losses of horticultural crops in general may reach 25 - 35% (Fekadu, 1989). Quality of onion and shallots are known to be affected by several factors such as mineral nutrition, irrigation schedule or rainfall (Chung, 1989), cultivar differences and the use of growth regulators (Hussien, 1996). Cultivar stage of bulb development, premature defoliation, skin integrity and conditions during maturation, harvesting and curing are also among factors contributing to quality of bulbs during storage (Brewster, 1994). Use of plant nutrients and time of harvesting are known to affect quality and storability of onion and shallots. While exogenous N application is known to

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increase yield of onions, many researchers found that high levels of nitrogenous fertilizer resulted in reduced onion storage life. Shallot is considered to have similar nutritional requirements and its storage life could be affected like other Alliums (Currah and Proctor, 1990; Brewster, 1994).

Onions which are closely related to shallot mature in about four months after transplanting. Neck fall is an indication of maturity. Onions for dry bulbs are ready for harvest when the bulbs are mature and 50 - 80% of the tops fall over (Brewster, 1994). If they have to be stored, harvesting has to be done after the tops have broken down but before the foliage has completely dried. During curing, the thin outer layers of the bulb are dried to form one or more complete dry skins, which act as a barrier to water loss and microbial infection. The timing of harvesting should be decided based on the considerations that relatively early harvesting favors better skin retention while later harvesting maximizes yields. Therefore, time of harvest is a compromise between maximum yield and maximum storage life and skin quality (Choudhury, 1996). Specific information relevant to shallot production and post harvest handling is limited whereas the culture, climatic and soil requirements of shallot are considered to be more or less similar to onion. The objectives of this study were to determine the effects of nitrogen levels, harvesting time and curing on local shallot cultivar bulb quality during the storage periods.

MATERIALS AND METHODS

Site description

The experiment was conducted at Haramaya University crop experiment field, which is located 42°3'E and 9°26'N, at an altitude of 1950 m above sea level. The mean annual rainfall of the site is 780 mm while average annual minimum and maximum temperatures are 8.25 and 23.4°C, respectively. The experiment was conducted on black clay soil with a pH of 7.6, organic carbon of 1.36%, organic matter content 2.3%, total nitrogen percentage 0.19% and available P of 8.1 ppm.

Experimental design and treatments

Planting of bulbs was done on August 15, 2005 using local shallot cultivar at spacing of 20 cm within rows with 40 cm between rows. When 60% of the bulbs had sprouted (22 days after planting) 50% of each level of the nitrogen (N) treatment was applied and the remaining 50% was side dressed one month later. All plots received phosphorous (P) at the rate of 92 kg ha^{-1} P_2O_5, which was side dressed at the time of planting. The plots were irrigated at an interval of five days during the dry months. Weed and pest control were applied uniformly following crop establishment (Lemma and Shimels, 2003).

First harvesting was conducted after 50% of the shallot tops had fallen while the second and third harvests were done on December 25, 2005 and January 10, 2006 at 75 and 100% top fall, respectively. For each harvesting time there was curing treatment that was applied as non cured-topped and cured with windrowing by spreading them thinly on the ground under shade for 15 days before topping.

Bulbs from the central 8 rows were harvested and used for the storage experiment. The storage time started on December 1, 2005 and extended up April 10, 2006. Bulbs were stored in naturally ventilated house constructed from mesh wire wall and corrugated iron sheet roofing. Daily storage air conditions were recorded within two hours interval using digital psychrometer units (Jenway-digital psychrometer 5105, U.K.). The average daily maximum and minimum temperature during the three month storage periods were 22 and 7.4°C, respectively and the average daily relative humidity was 55%.

Measurements

Fresh bulb weight

Fresh weight (kg) of bulbs were taken immediately after harvesting and cutting the tops for bulbs that was not subjected to curing treatment and after curing for those that received curing treatment.

Skin thickness

In order to determine skin thickness 30 bulbs were randomly taken from each plot. Change in the skin thickness was measured using a digital caliper (FOWLER Sylvac 107884) in a biweekly interval and the difference between the initial and successive measures were used as a loss in skin thickness.

Dry matter

A homogenate was prepared from bulbs of each plot and 25 g of the homogenate was taken and oven dried (Wagtechn Gp/120/SS/100/DIG oven) at a temperature of 70°C for 48 h to determine dry matter content of the samples.

Pungency

The pyruvic acid level in a homogenized bulb tissue was used as measure of pungency following the procedure described by Bussard and Randle (1993).

Total soluble solids

Aliquot juice was extracted using a juice extractor and 50 ml of the slurry centrifuged for 15 min. The TSS was determined by hand refractometer (ATAGO TC-1E) by placing 1 to 2 drops of clear juice on the prism.

Sugar analysis

Reducing and total sugars were estimated by using calorimeteric method as described by Mazumdar and Majumder (2003).

Number of bulbs sprouted

Percentage of bulbs sprouted was cumulative, which was based on the number of bulbs sprouted in biweekly storage period. The incidence of sprouting was ascertained by counting the number of bulbs sprouted at the beginning and mid of each month. The sprouted bulbs were discarded after each count to avoid double counting. Bulbs that sprouted and rotted at the same time were classified as sprouting.

Table 1. The effect of nitrogen levels and harvesting time on fresh yield of shallot bulb (qt ha^{-1}).

Treatment	Nitrogen level (kg ha^{-1})			
	0	50	100	150
Harvesting time (% top fall)				
50	90.27^{g}	200.12^{de}	224.86^{c}	188.14^{e}
75	146.48^{f}	214.83^{cd}	246.47^{b}	194.65^{e}
100	157.8^{f}	245.69^{b}	271.86^{a}	224.6^{c}
SE±	0.54			
CV%	8.58			

Means followed by the same letter within a column are not significantly different at P < 0.05.

Number of rotten bulbs

The measurement of percentage bulbs rotted was cumulative and was based on the number of bulbs rotted in biweekly storage period. The incidence of rotting was determined by counting the number of bulbs rotted at the beginning and mid of each month. The rotted bulbs were discarded after each count.

Weight loss of bulbs

Weight loss was determined using samples of 30 bulbs (10 small, 10 medium and 10 large sized) randomly taken form each treatment. The difference in weight of the bulbs at the beginning and mid of each month was determined.

Percent marketability of bulbs

The marketable quality of fruits was subjectively assessed according to the procedure of Tefera et al. (2007). Descriptive quality attributes were determined subjectively by observing the level of visible mould growth, decay, shriveling of bulbs. The number of marketable bulbs was used as measure to calculate the percentage marketable bulb during storage.

RESULTS AND DISCUSSION

Fresh bulb yield

Nitrogen application by harvest stage showed significant (P < 0.05) interaction effect on fresh bulb yield of shallot (Table 1). The highest yield (271.9 qt ha^{-1}) was recorded in the plot that received 100 kg N ha^{-1} and harvested at 100% top fall which was significantly higher (P < 0.05) from all other treatment combinations. Nitrogen rates of 50 and 100 kg N ha^{-1} at 100 and 75% top fall harvest, respectively, gave the second highest yield that were significantly (P < 0.05) higher than other treatments. The least fresh bulb yield was obtained from N unfertilized (control) plot harvested at 50% top fall. In general, increasing N application up to 100 kg N $ha^{-1}$and delaying harvest resulted in an increasing trend in fresh bulb yield. Similarly, Kebede (2003) observed yield increases of about 10 - 15% in shallot with nitrogen fertilization in the range 75 - 150 kg N ha^{-1}. According to Palled and Kachapur (1988), the application of 100 kg N ha^{-1} produced 12.2 and 26.4% higher yields than 75 and 50 kg N ha^{-1}, respectively. For all treatment combinations of this study, high nitrogen resulted plants with more vegetative growth than bulb setting relative to other treatments with the experimental plot soil initial N of 0.19%. As Hassan and Ayoub (1978) suggested, nitrogen fertilization increases both vegetative and bulb growth in onions through its effect on cell activities and they attributed response of yield to N fertilization to the initial very low soil N (0.05%).

For all levels of nitrogen, delaying harvest until 100% top fall showed highest fresh yield compared to harvest at 50% top fall. It was expected that the fully matured bulbs would yield more than early and mid harvested plants because of longer duration for photosynthate accumulation, however delayed harvest could increase potential post harvest loss during storage. Studies on the effect of harvest date of onions indicate that bulb yield increases dramatically in the fourth week before 100% top-fall (Davis and Isenberg, 1978). Translocation of nutrients from the tops continues to increase the weight and dry matter content of bulbs when harvest is delayed. There was a significant reduction (P < 0.05) in fresh bulb weight due to the curing treatment. The non-cured bulbs had about 17% more yield than that of cured bulbs (Table 2). Though it is clear that during curing bulbs lose their fresh weight but such bulbs will have less post harvest loss during storage. This suggests longer shelf life for cured over non-cured bulbs (Currah and Rabinowitch, 2002).

Dry matter

Except at harvest and after forth week and tenth week of storage, there was a significant difference (P < 0.05) in dry matter content of bulbs harvested at different stage of maturity. The highest level of dry matter content at harvest was recorded at 75% top fall while the least was observed in bulbs harvested at 100% top fall and the difference persisted throughout the storage period.

Table 2. Effect of curing on fresh bulb yield of shallot.

Treatment	Fresh yield (qt ha^{-1})
Non-cured	216.9[a]
Cured	184.62[b]
SE$\pm$	0.22
CV%	8.58

Means followed by the same letter within a column are not significantly different at $P < 0.01$.

Table 3. Effect of harvest stage and curing on dry matter content (%) of shallot bulbs over storage period of three months.

Treatment	Storage periods (week)						
	0	2	4	6	8	10	12
Harvesting time (% top fall)							
50	17.31	17.58[a]	17.46	17.57[b]	17.56[a]	17.31	17.26[ab]
75	17.64	17.60[a]	17.59	18.82[a]	17.59[a]	17.52	17.52[a]
100	17.20	16.76[b]	17.52	17.43[b]	17.05[b]	17.67	16.90[b]
SE $\pm$	0.23	0.27	0.19	0.20	0.15	0.15	0.14
Significance	NS	*	NS	*	*	NS	*
Curing							
Non-cured	16.71[b]	16.88[b]	17.22[b]	17.65[b]	17.23	17.36	15.05[b]
Cured	18.05[a]	17.74[a]	17.83[a]	18.23[a]	17.57	17.64	17.40[a]
SE $\pm$	0.19	0.22	0.16	0.16	0.12	0.12	0.11
Significance	**	**	*	*	ns	ns	**
CV%	6.57	7.5	5.43	5.4	4.11	4.2	3.87

Means followed by the same letter within a column are not significantly different at $P < 0.01$ (**) and $P < 0.05$ (*); NS, non significant difference ($P < 0.05$).

Shallot plants required optimum time to accumulate photosynthate in storage bulbs. As senescence was reached, there was reduction in their dry matter content possibly due to loss through respiration or dilution effect. As Hansen and Henriksen (2001) reported, dry matter content increased during the period of bulb development while harvesting later than 80 - 90% top fall reduced dry matter content and storage ability of the bulbs. They noted that during the period from 10 to 100% top fall there was a 44% increase in total yield of fresh bulbs but the dry matter content did not change significantly up to 80% top fall after which a distinct decrease was observed. The nitrogen fertilization did not affect the dry matter content of bulbs neither at harvest nor in storage.

In the storage, a successive increase in dry matter content of bulbs was observed until six weeks and then a gradual decrease until termination of the storage treatment. For instance, for 75% top fall harvest there was 1.18% increment at six-week storage and 0.12% reduction at twelve-week storage in dry matter content compared to the dry matter content of bulbs at harvest. This result is supported by work of Hansen and Henriksen (2001) also showed slight increase in dry matter that was due to loss of moisture from the outer surface whereas the reduction corresponded well to hydrolysis of fructans and termination of the dormancy period where the bulbs began to sprout.

Pak et al. (1995) described the dry matter of shallot consisted 70 - 85% carbohydrates, mainly glucose, fructose and sucrose. They indicated that through storage, fructans were gradually hydrolyzed to fructose increasing dry matter during initial storage weeks. At the time of sprouting, sucrose was synthesized and transported to the sprout and basal plate for growth. Similarly, Hansen and Henriksen (2001) showed a decrease in dry matter content and concentration of fructans with storage.

Composition of cured and non-cured shallot bulbs showed that the treatments had highly significant ($P < 0.01$) effect on dry matter content of cured bulbs at harvest and during the first two weeks of storage (Table 3). The increase in dry matter content during curing could be mainly due to excessive moisture loss from the outer skin. Currah and Rabinowitch (2002) indicated that such loss could reach up to 5% of the total fresh weight. Even though loss of moisture could occur from bulbs during curing this loss could be compensated for the transport of

Table 4. Effect of nitrogen fertilization and harvesting time on the pyruvate content (µ.mol ml-1) of shallot bulb during three months of storage at Alemaya.

Treatment	Storage period (week)						
	0	2	4	6	8	10	12
Nitrogen (kg N ha^{-1})							
0	4.43^{b}	4.79^{b}	5.37^{b}	6.23^{c}	6.95^{c}	8.2^{c}	8.40^{c}
50	4.60^{b}	4.85^{ab}	5.45^{b}	6.47^{b}	7.17^{b}	8.52^{bc}	8.59^{bc}
100	4.86^{a}	4.97^{ab}	5.58^{ab}	6.64^{ab}	7.48^{a}	8.65^{b}	8.82^{b}
150	4.89^{a}	5.19^{a}	5.81^{a}	6.81^{a}	7.59^{a}	9.06^{a}	9.22^{a}
SE$\pm$	0.06	0.10	0.07	0.05	0.05	0.13	0.11
Significance	*	*	*	**	**	**	**
CV_a%	5.76	8.45	5.72	2.94	2.71	6.33	5.23
Harvesting time (% top fall)							
50	4.67^{b}	4.80^{b}	5.27^{b}	6.49^{b}	7.28^{b}	8.658^{a}	8.77^{b}
75	5.42^{a}	5.56^{a}	6.55^{a}	6.86^{a}	7.63^{a}	8.988^{a}	9.09^{a}
100	3.99^{c}	4.49^{b}	4.84^{c}	6.27^{c}	6.98^{c}	8.170^{b}	8.43^{c}
SE$\pm$	0.09	0.14	0.08	0.04	0.05	0.09	0.08
Significance	**	**	**	**	**	**	**
CV%	9.57	13.77	7.24	3.00	3.31	5.03	4.54

Means followed by the same letter within a column are not significantly different at *P* < 0.01 (**) and *P* < 0.05 (*); NS, non significant difference.

materials from the leaves to the storage bulbs during curing process of bulbs with their tops. After six weeks of storage there was reduction in the dry matter content where non-cured bulbs lost 1.66% and the cured ones lost 0.65% compared to their respective dry matter content at harvest. Rubatzky and Yamaguchi (1997) indicated that during storage there was a loss in dry matter and moisture as a result of translocation of carbohydrates for respiration process which is in agreement with the current result. Similarly, Benkeblia et al. (2000), found the respiration rate of onions after two months of storage to be 0.21 and 0.32 mmol kg^{-1}h^{-1} at 20°C for unsprouted and sprouted onions, respectively, which were accompanied by loss of the dry matter content of the bulbs.

Bulb pungency

Both nitrogen fertilization and harvesting time significantly (P < 0.01) influenced pyruvate contents of the bulbs across the storage periods (Table 4). The pyruvate level of bulbs increased with increase in the amount of nitrogen applied. An increased level of pyruvate with nitrogen application could be explained partly by greater synthesis and accumulation of sulphur containing amino acids that are precursors of flavor compounds and pyruvate (Randle, 2000). This result is in agreement with the findings of Randle (2000) who observed a linear increase in the amount of enzymatically produced pyruvate with N fertilization to plants grown in hydrophonic solutions.

The pyruvate level increment starting from harvesting time to the end of the third months of storage ranged from 4.43 - 8.4 µ.mol ml^{-1} in the control to 4.89 - 9.22 µ.mol ml^{-1} juice in the 150 kg N ha^{-1} treatment. Even though the bulbs may be dormant during the storage period, flavor changes were taking place continuously. This may also be attributed to the moisture loss of the bulbs and increment in the concentration of the constituents. Freeman and Whenham (1976) reported increase in enzymatically produced pyruvate for two long-storing onion cultivars in the first 210 days storage, followed by a sharp decrease to 240 days.

From harvesting time treatments maximum pyruvate level was observed at 75% top fall followed by 50% top fall harvest. As bulbs mature photosynthate is transferred from foliage leaf blades into storage leaves and then the foliage becomes senescent. Flavour changes with the stage of growth, since plants develop vegetatively and get optimum time to translocate materials to their storage tissues before complete leaf dry and fall. Immature onion bulbs produce low volatile sulphur which, increased as bulbing proceeded and then decreased as bulbs matured and become dormant (Platenius and Knott, 1961). Onion pungency also decreased as bulbing proceeded to maturity (Hamilton et al., 1998). Sunarpi and Anderson (1997) suggested that at full top senescence harvest, there was remobilization of sulphur from proteins during which there was also deficiency of nitrogen.

Table 5. The changes in total soluble solids (°brix) of bulbs subject to harvesting time and curing treatments.

Treatment	Storage period (week)						
	0	2	4	6	8	10	12
Harvesting time (% top fall) + Curing							
50 + non-cured	13.17[b]	15.28[b]	15.77[c]	15.33[c]	15.53	14.68	12.65
50 + cured	15.82[a]	15.87[b]	17.41[a]	17.43[a]	15.43	14.47	12.43
75 + non-cured	13.54[b]	15.75[b]	16.97[ab]	16.76[ab]	15.58	14.79	12.78
75 + cured	13.82[b]	15.98[b]	16.58[b]	16.38[b]	15.27	14.80	13.58
100 + non-cured	13.25[b]	15.90[b]	16.44[bc]	15.94[bc]	15.52	14.58	13.40
100 + cured	15.87[a]	16.82[a]	16.42[bc]	15.98[bc]	15.65	14.59	12.52
SE±	0.49	0.29	0.25	0.29	0.16	0.48	0.56
Significance	*	*	*	*	NS	NS	NS
CV%	11.87	6.31	5.31	6.11	3.58	11.39	15.14

Means followed by the same letter within a column are not significantly different at P < 0.05 (*) and NS, non significant.

Total soluble solids

Significant difference ($P < 0.05$) in the total soluble solids (TSS) content of bulbs subjected to harvest time and curing treatments was observed until the end of six weeks storage. At harvest lowest level of TSS appeared at 50% top fall with non-cured bulbs and the highest for 100% top fall with cured bulbs which was 13.17% and 15.87%, respectively (Table 5). The difference was due to the fact that movement of TSS from the foliage to the bulb was continuing till total fall over of the top and that bulb loss moisture by curing increase concentration of soluble solids of the bulb.

There was also a gradual increase of TSS until the fourth week of storage and then a reduction. However, starting from the eighth week of storage the TSS level among the treatments became almost similar with no significant difference. The reason for this could be as storage time increases bulb dormancy comes to an end leading to sprouting. Consequently, there will be proportional rise in respiration and carbohydrate metabolism that brings a rapid decline in TSS content of bulbs. Wheeler et al. (1998) reported that sprouting in storage was associated with lower levels of total water-soluble solids in the center of bulbs which was mostly associated with the early harvest. However, Kopsell and Randle (1997) found significant differences in soluble solids content during storage, which was cultivar dependent.

Total sugar content

Nitrogen fertilization and harvesting time treatments had no significant effect on the concentration of total sugar of shallot bulbs both at harvest and during the three months of storage. However, slight rise in total sugar was observed up to six week storage followed by a successive decrease until the end of the third month of storage (Figure 1). Dankhar and Singh (1991) also found that the total sugar of bulbs decreased during storage and the reduction was higher at lower dose of nitrogen compared to its higher dose.

Reducing sugar content

Harvesting time had no significant effect on reducing sugar content of shallot bulbs. However, there was increasing trend till six weeks' of storage and then decrease up to the end of the storage period (Figure 2). Ruthford and Whittle (1982) studied changes in the carbohydrate composition of onions during storage and reported that the main change was the hydrolysis of oligosaccharides to reducing sugars that were ultimately utilized upon respiration. Similarly, Pak et al. (1995) indicated that during storage, fructans are gradually hydrolyzed to fructose and at the time of sprouting sucrose is synthesized and transported to the sprout and basal plate for growth.

Roting bulbs

Significant ($P < 0.01$) interaction effect of nitrogen application and harvesting time was observed on percentage of bulb rotting. The highest percent of bulb rot was observed in the 150 kg N ha^{-1} and 50% top fall harvest treatment combination and the least with no nitrogen application and 100% top fall harvest which were 9.05% and 3.43% respectively (Table 6). The increase in rotting of bulbs due to increase in nitrogen could be attributed to the fact that higher rates of nitrogen encourage plants to produce bulbs with soft succulent tissues which make them susceptible to the attack by a disease caused

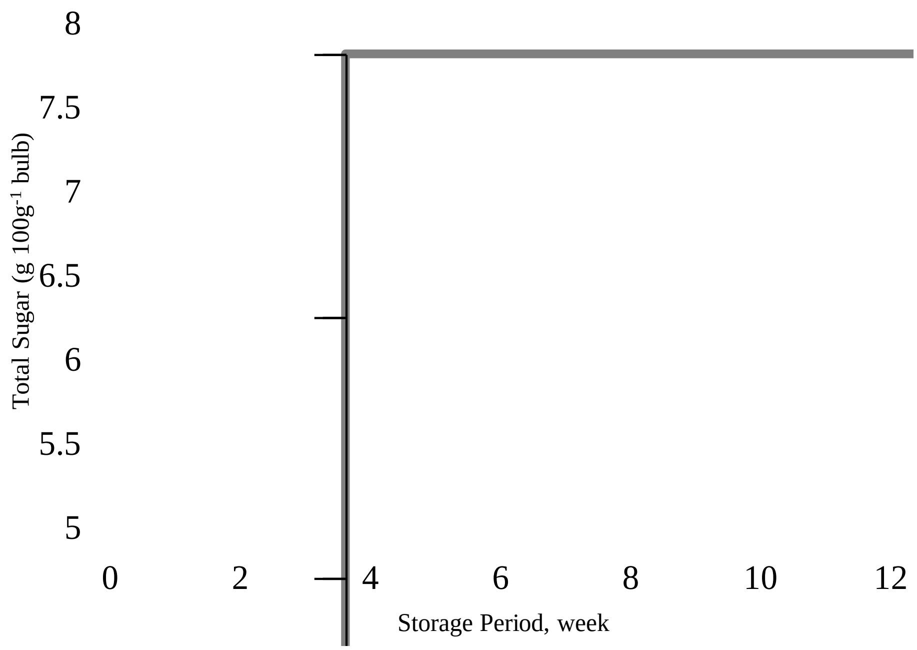

Figure 1. Total sugar content of shallot bulbs grown under different nitrogen levels and stored at ambient storage environment. -◆-, 0 kg Nitrogen ha^{-1}; -■-, 50 kg Nitrogen ha^{-1}; -×-, 100 kg Nitrogen ha^{-1} and -□-, 100 kg Nitrogen ha^{-1}.

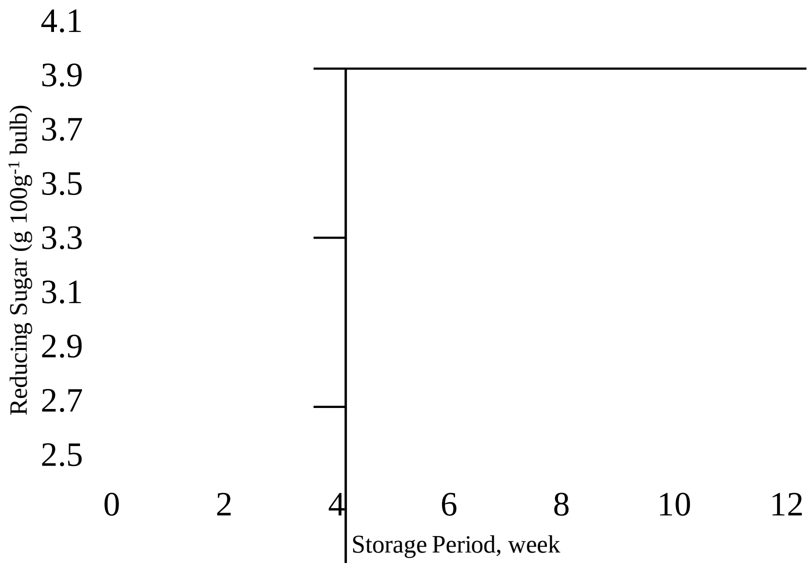

Figure 2. Reducing sugar content of shallot bulbs harvested at different stages of maturity and stored at ambient storage environment. -◇-, 50% top fall; -■-, 75% top fall and -◆-, 100% top fall.

disease caused by micro organisms and leads to production of bulbs with thick neck which are difficult to dry. The result is in agreement with the report of Dankhar and Singh (1991) which showed that rotting of bulbs was increased with increase in nitrogen fertilization. Onion bulb produced without nitrogen application was also shown to have the lowest rotting (22%) while highest rotting (36 - 54%) was recorded in bulbs produced under high dose of nitrogen (Jones and Mann, 1963). Storage losses in 37 onion cultivars in India were also found to be positively correlated with bulb protein content and negatively correlated with ash, dry matter, total soluble solids

Table 6. Interaction effect of nitrogen with harvesting time on cumulative percent rot (%) of shallot bulb at the end of third month storage.

Treatment	Nitrogen level (kg ha^{-1})			
Harvesting time (% top fall)	0	50	100	150
50	6.65^{de}	7.15^{cde}	8.25^{b}	9.05^{a}
75	4.38^{f}	6.45^{e}	7.18^{cd}	7.57^{bc}
100	3.43^{g}	3.93^{fg}	3.58^{g}	4.55^{f}
SE±		0.19		
CV%		7.53		

Means followed by the same letter within a column and row are not significantly different at *P* < 0.01.

Table 7. Interaction effect of harvesting time with curing on cumulative percent rot (%) of shallot bulb at the end of third month storage.

Treatment	Harvesting time (% top fall)		
	50	75	100
Non-cured	8.40^{a}	7.05^{b}	4.16^{d}
Cured	7.15^{b}	5.74^{c}	3.59^{e}
SE±		0.13	
CV%		7.53	

Means followed by the same letter within a column and rows are not significantly different at P < 0.01.

solids and non reducing sugar content (Gubb and Tavish, 2002).

When onions are harvested while tops are erect and fleshy, bulb yield is reduced and the potential for post harvest storage problem increases. Such bulbs have high moisture content and a relatively short shelf life. In the case with more mature onions, as the foliage dries, the neck shrinks with good closure that reduces incidence of diseases and improves storage longevity. As Sagrent et al. (2001) reported maximum storage life and least rotting in store occurred in bulbs harvested when the foliage was fully senesced.

Stored bulbs of high N level with early harvest were found to be associated with short keeping storage quality. Diseases during storage, early sprouting and shriveling, associated with high N fertilization and early harvesting were also indicated to be the main limiting factors for long keeping quality of shallots in tropical and subtropical regions (Rubatzky and Yamaguchi, 1997).

Harvest time and curing have also shown significant (P < 0.01) interaction effect on incidence of bulb rotting after three months of storage (Table 7). Interaction of 50% top fall harvest with non-cured bulbs gave the highest incidence of rotted bulbs while the least was observed in 100% top fall harvested and cured bulbs which amounted to 8.4 and 3.59%, respectively. The result also showed that at any harvesting time, non-cured bulbs were vulnerable for loss and microbial attack than cured ones. Curing appeared to have allowed the neck to dry and seal up, avoiding the avenue for entry of microorganisms in to the bulbs thereby making them less susceptible to pathogens. As Gubb and Tavish (2002) described, curing helped to develop several intact dry outer scales that limit gas exchange. In addition, Davis and Isenberg (1978) reported that curing allowed the leaves to naturally senesce and substances in the leaves that promote resistance to disease-causing fungi to be translocated down into the bulbs. Low percent rotting for cured than for non-cured bulbs could not only be from physical resistance but also biochemical changes during skin curing as shown by Takahum and Hirota (2000).

The types of organisms that caused rotting were identified to be *Penecillium* and *Yeast*. These were expected microorganisms with the prevailing temperature of 25°C in the storage. As Hayden and Maude (1997) described, *Penicillium spp*. frequently occur in the microflora of stored onions with a temperature at 1 - 5 or 20 - 25°C. Maude et al. (1991) in their study isolated eleven distinct bacterial and yeast organisms, many of them found in combination with the rotting bulbs. They concluded that under high temperatures, senescent onion tissues were likely to be invaded by a wide range of opportunistic organisms, which speed up the breakdown of the drying bulb scales.

Sprouting

Nitrogen application, harvesting time and curing showed significant (P < 0.01) interaction effect on percentage of sprouted bulbs (Table 8). The highest incidence of sprouting was found in the treatment combination of 150

Table 8. Interaction effects of nitrogen level, harvesting time and curing on cumulative percent sprout (%) of shallot bulb at the end of third month storage.

Treatment	Nitrogen (kg N ha^{-1})			
Harvesting time (% top fall) + Curing	0	50	100	150
50 + non-cured	6.400^{g-i}	8.833^{ef}	12.83^{cd}	16.73^{a}
50 + cured	7.000^{f-i}	6.333^{g-j}	8.100^{fg}	13.87^{bc}
75 + non-cured	4.833^{i-k}	4.067^{j-m}	5.533^{h-k}	10.90^{de}
75 + cured	2.367^{m}	2.467^{lm}	3.900^{k-m}	7.400^{f-h}
100 + non-cured	6.000^{g-k}	6.600^{f-i}	10.63^{de}	15.23^{ab}
100 + cured	3.700^{k-m}	4.767^{i-l}	7.200^{f-h}	7.000^{f-i}
SE$\pm$		0.60		
CV%		13.68		

[1]Means followed by the same letter within a column and row are not significantly different at $P < 0.01$.

kg N ha^{-1}, 50% top fall harvest and non-cured bulbs which accounted for 16.73% sprouting while the least was observed from zero nitrogen, 75% top fall harvest and cured bulbs which was 2.37% at the end of three months storage. In agreement with this Bhalekar et al. (1987) observed that sprouting was increased with increasing nitrogen levels from 0 to 150 kg N ha^{-1}. Dankhar and Singh (1991) also reported that high dose of nitrogen produced thick-necked bulbs that increased sprouting in storage due to increased exposure to oxygen and moisture. On the other hand, bulbs that are harvested when too immature may take longer than other to dry properly for storage and if the necks are yet soft, the inner leaves may still be growing and will continue to elongate from the topped bulbs (Jones and Mann, 1963).

While curing treatment allows bulbs to develop tough skin that limit exchange of gas with the external environment and by shrinking and closing the neck so that oxygen required for shoot growth and emergence is minimized. The onset of dormancy is thought to be caused by translocation of growth inhibitory substances from the leaves to the bulbs as crops matured and cured attached with tops (Komochi, 1990). Stow (1976) also found rise in inhibitors concentration in the leaves of onions approaching maturity and showed that defoliation at this stage shortened dormancy.

In the present result, it also appears that with increased N fertilization and harvesting earlier without curing there might have been less inhibitors accumulation in bulbs and easy access for the entrance of oxygen which could, in part, have increased percentage sprouting compared with low N application and delaying harvest while bulbs cured.

Percent bulb diameter loss

Significant difference (P < 0.01) existed in percent diameter loss of bulbs (Table 10). Highest loss in bulb diameter appeared in plots that received 150 kg N ha^{-1} applications, which showed persistently higher percentage in the bulb diameter loss throughout the storage period compared to the rest treatments. Even though plants applied with nitrogen at 150 kg N ha^{-1} had bulbs with larger skin diameter, the incidence of rotting and sprouting was higher, their thick neck with succulent skin brought about the maximum physiological weight loss and skin shrinkage, possibly as a result of higher respiration. Rubatzky and Yamagunchi (1997) described that during storage translocations of carbohydrates occur via the stem plate from the outermost succulent swollen scales to inner scales. They further noted outermost succulent scale gradually desiccated, becoming a dry protective scale that helps to reduce water loss from inner succulent scales. This process can continue, resulting in an increase in the number of dry outer scales and intern, a decrease of an equal number of succulent scales, along with a concomitant decrease in bulb diameter.

The cured bulbs had more loss in skin diameter than non-cured bulbs during treatment application. However, the maintenance of skin integrity is more for cured bulbs than non-cured ones during the storage time.

Percent weight loss

There was a significant difference (P < 0.01) in weight loss (PWL) of stored bulbs due to different harvesting time (Table 9). Large PWL was seen at 50% top fall followed by 100% top fall harvest throughout the storage periods. The weight loss was associated with the resumption of higher incidence of sprouting and rotting presumably through increase in the rate of respiration. As foods are being utilized for new growth, weight losses from such early harvest are usually higher than from later harvested ones.

Throughout the storage period there was an increase in percent weight loss where this could be associated with physiological parameters that lead to higher respiration

Table 9. Effect of harvesting time and curing methods on percentage weight loss (%) of shallot bulbs in storage.

Treatment	**Storage period (weeks)**					
Harvesting time (% top fall)	**2**	**4**	**6**	**8**	**10**	**12**
50	9.7[a]	19.51[a]	29.00[a]	38.22[a]	47.43[a]	57.19[a]
75	6.7[c]	17.33[c]	24.83[c]	32.43[c]	40.77[c]	50.27[c]
100	8.5[b]	18.60[b]	27.10[b]	35.58[b]	44.45[b]	54.15[b]
SE$\pm$	0.19	0.15	0.32	0.47	0.51	0.22
Curing						
Non-cured	9.1[a]	19.07[a]	28.07[a]	36.92[a]	45.82[a]	55.46[a]
Cured	7.5[b]	17.89[b]	25.88[b]	33.89[b]	42.61[b]	52.28[b]
SE$\pm$	0.15	0.12	0.26	0.38	0.42	0.43
CV%	11.07	3.85	5.80	6.44	5.64	4.74

[1]Means followed by the same letter within a column are not significantly different at P < 0.01.

Table 10. Nitrogen level and curing effects on bulb diameter loss (%) of shallot bulb in storage.

Treatment	**Storage period (week)**					
Nitrogen (kg N ha^{-1})	**2**	**4**	**6**	**8**	**10**	**12**
0	7.82[b]	17.93[a]	27.56[a]	38.08[ab]	47.84[ab]	56.84[b]
50	7.42[b]	16.02[a]	25.65[a]	35.32[b]	44.48[b]	52.94[bc]
100	5.94[c]	12.71[c]	21.10[b]	30.34[c]	39.76[c]	49.01[c]
150	10.23[a]	18.34[a]	28.93[a]	39.61[a]	50.43[a]	61.21[a]
SE$\pm$	0.60	0.74	0.89	0.91	0.99	1.07
CV_a%	32.3	19.3	14.7	10.7	9.2	8.2
C_0	8.62[a]	17.65[a]	27.61[a]	37.82[a]	47.66[a]	56.89[a]
C_1	7.08[b]	14.85[b]	24.01[b]	33.86[b]	43.60[b]	53.12[b]
SE$\pm$	0.16	0.29	0.37	0.41	0.4	0.33
CV%	12.23	10.59	8.63	6.79	5.22	3.59

Means followed by the same letter within a column are not significantly different at P < 0.01.

rate under the ambient storage condition of this experiment (average daily 22°C maximum and 7.4°C minimum temperature and 55% RH.). Msika and Jackson (1997) described cultivar specific weight losses of between 2 and 5% per month in warm ambient storage in Zimbabwe. There was also similar report by Kospell and Randle (1997) that showed loss in dehydrator No. 3' and CV. 'Granex' 33' during the first month of storage, which was gradually increased with storage time.

A significant decrease (P < 0.01) in storage weight loss was observed in cured bulbs compared with non-cured topped bulbs (Table 9). The rate of weight loss increased with storage time in both cases. This can be explained by the fact that during curing, the thin outer layers of the bulb are dried to form one or more complete dry skins, which act as a barrier to water loss. Curing also dries the neck of the bulbs and makes them tightly closed (Gubb and Tavish, 2002). Fleshy harvested onions contain 80 - 90% water according to cultivar and water removal from the outer skins during curing causes a rapid loss of up to 5% of total weight (Currah and Rabinowitch, 2002). As bulbs are cured the metabolic activities will be kept to the minimum since bulbs are at their dormancy that keeps respiration rates low. In comparison for total weight there was 3.18% more weight loss in non-cured than cured ones at the end of the storage period (Table 9).

Percent marketability

For the levels of harvesting stages, there was no significant difference starting from harvesting time up to eighth week of storage (Table 11). However, a significant difference between treatments existed starting from eighth week of storage where 75% top fall harvest had relatively higher percent of marketable bulbs. Actually six-week storage period (Table 12) was the time when sprout and rot had started and continued until end of the three months storage period.

The interaction effect of nitrogen levels with curing also resulted in a significant difference (P < 0.01) on marketability of bulbs. For newly harvested bulbs, highest

Table 11. Harvesting time in relation to percent marketable (%) bulbs of shallot in storage.

Treatment	Storage period (weeks)						
Harvesting time (% top fall)	**0**	**2**	**4**	**6**	**8**	**10**	**12**
50	84.46	76.25	70.08	60.46	56.917[a]	53.96[ab]	46.92[ab]
75	84.67	77.33	70.96	62.00	58.083[a]	55.417[a]	48.417[a]
100	85.25	76.96	70.42	60.21	54.750[b]	51.875[b]	44.917[b]
SE±	0.48	0.46	0.47	0.62	0.75	0.63	0.61
Significance	NS	NS	NS	NS	*	**	**
CV%	2.78	2.94	3.27	4.96	6.52	5.78	6.42

Means followed by the same letter within a column are not significantly different at P < 0.01, P < 0.05(*), NS non significant (P > 0.05).

Table 12. Nitrogen level and curing effect on percent marketability (%) of shallot bulbs during storage.

Treatment	Storage period (weeks)						
Nitrogen (kg N ha^{-1}) + Curing	**0**	**2**	**4**	**6**	**8**	**10**	**12**
0 + Non- cured	79.33[e]	66.00[e]	60.44[f]	54.11[d]	50.00[d]	47.11[d]	40.11[d]
0 + Cured	72.00[f]	70.11[d]	64.89[e]	58.89[bc]	54.56[cd]	51.44[bc]	44.56[c]
50 + Non- cured	93.33[a]	75.44[c]	69.89[d]	60.33[bc]	56.56[bc]	53.56[bc]	46.22[bc]
50 + Cured	83.56[cd]	82.22[b]	76.33[b]	65.78[a]	61.44[ab]	58.67[a]	51.56[a]
100 + Non- cured	95.11[a]	79.78[b]	74.11[bc]	63.00[ab]	57.11[bc]	55.56[ab]	48.67[ab]
100 + Cured	88.56[b]	87.89[a]	81.89[a]	65.67[a]	63.11[a]	58.67[a]	51.56[a]
150 + Non- cured	85.33[c]	72.11[d]	63.67[e]	58.44[c]	54.00[cd]	51.22[c]	44.22[c]
150 + Cured	81.11[de]	81.22[b]	72.67[cd]	60.89[bc]	55.89[c]	53.78[bc]	47.11[bc]
SE±	0.79	0.75	0.77	1.00	1.23	1.04	0.10
CV%	2.78	2.94	3.27	4.96	6.52	5.78	6.42

Means followed by the same letter within a column are not significantly different at P < 0.01.

marketability was observed in 100 kg N ha^{-1} applied and non-cured ones while the least was in 0 kg N ha^{-1} applied and cured bulbs, which were 95.11 and 72%, respectively. However, at the end of the third month storage, highest percent of marketable bulbs were found in 100 kg N ha^{-1} applied and cured bulbs and the least for 0 kg N ha^{-1} with non-cured bulbs. For all levels of nitrogen, their effect was similar throughout the storage time, but curing methods had different outcomes where the beneficial effects of curing manifested during storage than at harvest time. Except at harvesting time, the higher percent of marketability was obtained from cured and topped bulbs. Irrespective of the N levels, rotting, sprouting, weight loss and bulb diameter loss all accounted for lower percent of marketability during the storage period. In non-cured bulbs, higher percentage of decay, loss of moisture, higher sprouting and possibly higher rate of respiration were causes for the reduced percent marketability of bulbs over the storage period.

CONCLUSION

For quality of shallot crop in store, both pre and post harvest management practices should be given due attention. Nitrogen fertilization, adjustment of harvesting time and bulb curing methods were the principal factors considered in this work in relation to the shallot bulb quality during harvesting time and during its shelf life over three months storage period. In general, from post harvest quality and storability point of view, harvesting time and curing are nothing except they require simply time adjustment and labour. These cultural practices are sound especially for subsistence farmers where there is ample labour within each household. If these methods could be integrated and applied, problem of market glut could be stabilized with balanced costs from stored bulbs dispatch. Therefore, the result of this study has shown that harvesting time and curing, being the simplest cultural practices have sound and promising impact for post harvest quality that could be applied for shallot production. Shallots fertilized with required nitrogen in a particular soil, lifted at 75% top fall, bulbs field cured and the foliage removed after curing appear to be simple method and good compromise to ensure post harvest shallot quality and successful storage.

REFERENCES

Benkeblia N, Varoquaus P, Gouble B and Selselet-Attou G (2000). Respiratory parameters of onion bulbs (Allium cepa) during storage. Effects of ionizing radiation and temperature. J. Sci. Food Agric., 80: 1772-1778.

Bhalekar MN, Kale PB, Kulwal LV (1987). Storage behavior of some onion varieties (Allium cepa L.) as influenced by nitrogen levels and preharvest spray of maleic hydrazide. J. Pkv. Resear., 11(1): 38-46.

Brewster JL (1996). Onions and Other Vegetable Alliums. CABI Publishing. Wallingford, UK. p 236.

Bussard ML, Randle WM (1993). Streamlining onion Pungency analysis. J. Hortic. Sci., 28: 60.

Choudhury B, Vegetables. National Book Trust, India. p. 315.

Chung B (1989). Irrigation and bulb onion quality. Acta Hortic., 247: 233-237.

Currah L, Proctor FJ (1990). Onions in Tropical Regions. Natural resources institute. Chatham, Maritime, Kent, UK. p. 232

Currah L, Rabinowitch HD (2002). Allium Crop Science, CABI publishing, p. 515

Dankhar B, Singh J (1991). Effect of Nitrogen Potash and Zinc on storage loss onion bulbs (*Allium cepa* L.). J. Veg. Sci., 18: 16-23.

Davis HR, Isenberg MR (1978). Storage Recommendation for Northern Grown Onions. Cornell University Extension Bulletin No. 148. Ithaca, New York.

Denton L, Ojeifo IM (1990) Onion production practices and their improvement in Nigeria. Onion Newsletter for the Tropics 2: 10-13.

Fekadu T (1989). Postharvest losses of fruits and vegetables in horticultural state farms. Acta Hortic., 88: 270.

Freeman GG, Whenhan RJ (1976). The nature of origin of volatile flavour components of the onion related species. Int. Flavors Food Additives, 7: 222.

Gubb IR, Tavis MSH (2002). Onion preharvest and postharvest considerations. In: H.D. Rabinowitch and L. Currah (eds.). Allim Crop science. CABI publishing, UK. pp. 237-250.

Hamilton BK, Yoo KS, Pike LM (1998). Changes in pungency of onions by soil type, sulphur nutrition and bulb maturity. J. Hortic. Sci., 74: 249-256.

Hansen SL, Henriksen K (2001). Increasing the dry matter production in bulb onions (Allium cepa L.). Denmark Department Fruit, Vegetable Food Sci., 2: 147-152.

Hassan MS, Ayoub AT (1978). Effect of nitrogen, phosphorous and potassium on yield of onion in the Sudan Gezira. Exper. Agric., 6(4): 345-350.

Hayden NJ (1989). Observations on harvesting and storing onions in northern Sudan. Onion Newslett. Trop., 1: 19-23.

Hayden NJ, Maude RB (1997). The use of integrated pre- and post-harvest strategies for the control of fungal pathogens of stored temperate onions. Acta Hortic., 433: 475-479.

Hussien J (1996). Influence of nitrogen and maleic hydrazide on the keeping quality and subsequent establishment of shallot. M.Sc thesis. pp. 11-13.

Jones HA, Mann LK (1963). Onions and their allies: Botany, cultivation and utilization. New York. p. 285.

Kebede W (2003). Shallot (Allium cepa var. ascalonicum). Responses to plant nutrients and soil moisture in a sub-humid tropical climate. J. Hortic. Sci. Biotechnol., 78(4): 549-555.

Komochi S (1990). Bulb Dormancy and Storage pp.89-91. In: Tabinowitch, H.D. and J.L. Brewster (eds.). Onions and Allied Crops. II. Botany, Physiology and Genetics. CRC Press, Boca Raton, Florida.

Kopsell DE, Randle WR (1997). Onion cultivars differ in pungency and bulb quality changes during storage. Hortic. Sci., 32: 1260-1263.

Lemma D, Shemelis A (2003). Research Experiences in Onion Production. EARO, p. 123.

Maude RB, Lyons NF, Gurd L, Abu Baker, EI-Muallem H, Bamakrama D (1991). Disease problems of onions in the Republic of Yemen. Onion Newslett. Trop., 3: 34-38.

Mazumdar BC, Majumder K (2003). Methods on physico-chemical analysis of fruits. Daya Publishing House. Delhi. India.

Msika RL, Jackson JE (1997). Onion Production and Research in Zimbabwe: Country report. In: H.D. Rabinowitch, L. Currah. Allium Crop Science. CABI Publishing, UK. pp. 241-242.

Pak C, Van der plas LHW, de Boer AD (1995). Respiration and ethylene evolution of certain fruits and vegetables in response to carbondioxide in controlled atmosphere storage. J. Food Sci. Technol., 30: 29-32.

Palled YB, Kachapur MD (1988). Chandrasekharajah AM and Prabhakar AS, Response of onion to irrigation and nitrogen. Indian J. Agron., 33(1): 22-25.

Platenius H, Knott H (1961). Factors affecting onion pungency. J. Agric. Res., 62: 371-379.

Randle WM (2000). Increasing nitrogen concentration in hydroponic solutions affects onion flavour and bulb quality. J. Amer. Soc. Hortic. Sci., 125: 254-259.

Rubatzky VE, Yamagunchi M (1997). World Vegetables; Principles, Production and Nutritive Value 2^{nd} ed. International Thomson publishing. p. 804

Ruthford PP, Whittle R (1982). The carbohydrate composition of onions during longterm cold storage. J. Hortic. Sci., 57: 349-356.

Sargent SA, Stoffella PJ, Maynard DN (2001). Harvest date affects yield and postharvest quality of non-dried short-day onion. Hort. Sci., 36: 112-115.

Stow JR (1976). The effect of defoliation on storage potential of bulbs of the onion (*Allium cepa* L.). Annals of Appl. Biol., 84: 71-79.

Sunarpi T, Anderson JW (1997). Effect of Nitrogen nutrition on remobilization of protein sulphur in the leaves of vegetative soybean and associated changes in soluble suulfur metabolite. Plant Physiol. 115: 1671-1680.

Takahum U, Hirota S (2000). Deflucosidation of quercetin glucosides to the aglycone and formation of antifungal agents by peroxidase-dependent oxidation of quercetion on browning on onion scales. J. Plant, Cell Physiol., 41: 1021-1029.

Tefera A, Seyoum TW, Woldetsdik K (2007). Effect of disinfection, packaging and storage environment on the shelf life of mango. Biosystems Engine., 96(2): 201-212.

Wheeler TR, Daymond AJ, Ellis RH, Morison JIL, Hadley P (1998). Postharvest sprouting of onion bulbs grown in different temperature and Carbondioxide environments in the UK. J. Hortic. Sci. Biotechnol., 73:750-754.