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Postharvest Quality and Shelf life of Garlic Bulb as Influenced by Storage Season, Soil Type and Different Compound Fertilizers

Diriba-Shiferaw G.[1]*, Kebede Woldetsadik[1], Nigussie-Dechassa R.[1], Getachew Tabor[2], and J.J. Sharma[1]

[1]School of Plant Sciences, Haramaya University, P. O. Box 138, Dire Dawa, Ethiopia.

[2] Ethiopian Institute of Agricultural Research, Debre Zeit Agricultural Research Centre, Debre Zeit, Ethiopia

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Abstract

The experiment was conducted twice during rainy (2011/12) and dry (2012/13) seasons at Debre Zeit Agricultural Research Centre, Ethiopia, to evaluate effects of pre-harvest fertilizer application, soil type and storage season on postharvest quality and storability of garlic bulb. The treatments comprised twelve different fertilizer types and doses i.e. control, recommended N and P (92 and 40 kg ha^{-1}), three rates of Azofertil (100, 200 and 300 $kgha^{-1}$), four rates of Basic (100, 200, 400 and 600 $kgha^{-1}$) and three rates of D-coder (100, 200 and 400 $kgha^{-1}$) evaluated in two soil types (Andosol and Vertisol) and replicated thrice using Complete Randomized Block Design. Two storage seasons (dry and Rainy) were used for bulbs storage. Significant variations in storability and quality of bulbs were recorded to the fertilizers, soil type and storage season. Higher rates of fertilizers improved storability and quality of bulb whereas higher weight and diameter losses were observed in bulbs from control plot and plots treated with lower levels of each fertilizer. Garlic grown on Andosol and subsequent storage during the rainy season recorded better bulb qualities with long storability. D-coder at the rates of 200 and 400 $kgha^{-1}$, followed by Azofertil at 200 and 300 $kgha^{-1}$, recorded higher percent of dry matter, total soluble solids and pungency of bulbs and lower percent in weight and diameter losses. Thus application of these fertilizers on Andosol is a better compromise for post harvest quality and shelf life of garlic bulbs under ambient storage conditions.

Keywords

Garlic bulb
Compound fertilizer
Bulb quality
Shelf-life
soil types
Storage season

INTRODUCTION

In Ethiopia, the Allium groups (onion, garlic and shallot) are important bulb crops produced for home consumption as well as sources of income to many peasant farmers in many parts of the country (Metasebia and Shimelis, 1998; Getachew and Asfaw, 2000). Garlic (*Allium sativum* L.) is the most widely used bulb crop next to onion and has a wide range of climatic and soil adaptation in Ethiopia (Lemma and Herath, 1994). It contributes significant nutritional value to the human diet and has medicinal properties for cardiovascular diseases; it is primarily consumed for its unique flavour and ability to enhance the flavour of other foods (Randle, 2000).

Worldwide, postharvest losses in fruits and vegetables range from 24-40% (Raja and Khokhar, 1993) or even greater reaching up to 50% in developing tropical countries (Iqbal, 1996). A comprehensive statistics for such losses is not available for Ethiopia; however, it has been estimated that the postharvest losses of horticultural crops in general may reach up to 25-35% in the state farms and in the peasant sector (Fekadu, 1989). Quality of bulb crops can be affected by mineral nutrition, irrigation schedule or rainfall (Chung, 1989), cultivar differences and the use of growth factors (Hussien, 1996). Stage of bulb development, premature defoliation, skin integrity and conditions during growth, maturation, harvesting, curing and storage are the main factors contributing to quality of bulbs in postharvest storage (Brewster, 1994).

The principal aims of bulb crops storage are to maintain the 'quality capital' present at harvest and to satisfy consumer demand for extended availability of bulbs of satisfactory quality (Gubb and Tavis, 2002). Therefore, increasing garlic yield and improving bulb quality are the desired attributes for growers, traders as well as consumers. Appropriate pre-and post-harvest treatments are required so that quality factors such as dry matter content, sugars, pungency, total soluble solids, skin integrity, skin colour and un-sprouted bulbs can be kept at their optimum level in storage until they reach consumers or market.

Use of plant nutrients, time of harvesting, and curing process after harvest are also known to affect quality and storability of garlic. Nitrogen, phosphorus, sulphur and potassium are the principal plant nutrients required in much greater quantities and are important component of proteins, enzymes, sugars and vitamins in plants. N is a central part of essential photosynthetic molecule, chlorophyll (Marschner, 1995). Plants demand for nutrients can be satisfied from a combination of soil and external fertilizers to ensure optimum growth, yields and qualities. Top dressing of nutrients are known to increase yield of bulbs however, high levels of fertilizers reduce of storage life of bulbs (Kato et al., 1987). Poor management of fertilizers could increase physiological disorders of crops after harvest due to deficiencies of some minerals and toxicity of others which will lead to negative effect on the quality of crops (Hewett, 2006).

Farmers in the study area (Debre Zeit, central Ethiopia) attempt to increase yields of their garlic crop by applying fertilizers, that contain only nitrogen and phosphorus, and some farmers by applying farmyard manure where available. However, the yield response is low due to inadequate fertilizer supply and partly low level of agronomic practices, not using fertilizers that contain other nutrients especially potassium and sulphur and some micro nutrients. Thus, different compound fertilizers that contain different nutrients in it could enhance nutrient availability and uptake, resulting in optimum vegetative growth and bulb development thereby increasing bulb yield and quality characters. However, no data was generated in the study area to substantiate the conviction that benefits can be obtained from using different compound fertilizers to compensate soil fertility for garlic productivity especially under nutrient stress soil condition. The study was conducted to evaluate effects of different rates of compound fertilizers, soil types and season of storage on postharvest quality and shelf-life of garlic bulbs.

Materials and methods

Experimental area and materials

Field experiment was conducted at the experimental farm of Debre Zeit Agricultural Research Centre ($08^0 44''$N latitude, $38^0 58''$E longitude, altitude of 1860 meter above sea level) in the central Ethiopia. The garlic variety 'Tseday' was raised for study. During growth garlic plants were treated with different compound fertilizers containing different nutrient types at different levels. The fertilizer sources included NP from DAP (20% P and 18% N) supplemented with urea (46%), Azofertil (30% N and 25% S), Basic (9% N-6% P-22% K- 10% CaO) and D-coder (14% N-20% P_2O_5-21% S- 0.1% Zn). The average of two cropping seasons of Andosol and Vertisol soils nutrients content were about 0.120 and 0.065% N, 20.36 and 15.20 ppm phosphorus, 2.13 and 1.19 Cmol(+) kg^{-1}K, and 177 and 174 ppm sulphur, respectively before planting the crop.

Bulbs were stored in a naturally ventilated diffused light store constructed from mesh wire wall and corrugated iron sheet roofing. The bulbs were thinly spread on wooden shelves. The bulbs were stored in ambient storage atmosphere having 25/28^{o}C maximum and 13/11^{0}C minimum average temperatures with 62/42% mean relative humidity during rainy season (2011/12) and dry season (2012/13), respectively.

Treatments and experimental design

The treatments consisted of storage of bulbs grown on plots fertilized with twelve fertilizer types/rates on two soil types for two seasons. The fertilizer treatments included control (non-fertilized; T_1), locally recommended NP rate (92 kg Nha^{-1} and 40 kg P ha^{-1}; T_2), three rates of Azofertil (100 (T_3), 200 (T_4) and 300 (T_5) kgha^{-1}), four rates of Basic (100 (T_6), 200 (T_7), 400 (T_8)and 600 (T_9)kgha^{-1}) and three rates of D-coder (100 (T_{10}), 200 (T_{11}) and 400 (T_{12}) kgha^{-1}). The two soil types were Andosol and Vertisol, and the growing seasons were during the off-season of 2011/12 under irrigation (first season) and during the rainy season of 2012/13 (second season). The rates of fertilizers were selected depending on their nutrients content.

Garlic bulbs were harvested from each treatment and, just after curing, sorted for similar diameter and weights of marketable size for the post harvest storage experiment under climatic conditions of Debre Zeit Agricultural Research Centre. Samples of 60 bulbs per treatment in each replication were selected from each fertilizer type/rate grown on both soils for assessing postharvest quality and shelf-life of the bulbs. Bulbs produced during dry (first) season were stored during rainy season and the one produced during rainy (second) season were stored during dry season for the postharvest study. The bulbs storage time was from July to September, 2012 for the rainy storage season and from December 2012 to February 2013 for the dry storage season. The experiment was laid out in randomized complete block design (RCBD) and replicated three times in the storage.

Data collected

The following quality and storability data were taken randomly after harvest and from stored bulbs at different time intervals for consecutive three months during the two storage seasons.

Dry matter (%): Homogenate sample of 50 g was taken and oven dried at a temperature of 65^{o}Cfor 48 hours. Then the weight was measured using digital balance and percent dry matter was calculated using a formula:

$$DW(\%) = \frac{[(DW + CW) - CW]}{[(FW + CW) - CW]} \times 100$$

Where, DW = dry weight, CW = container weight and FW = fresh weight

* *Email:* dsphd2010@gmail.com or senadiriba2012@yahoo.com

Total soluble solids (^{0}Brix):-TSS was determined using hand refractometer (Waskar et al., 1999) at a month interval. Aliquot juice was extracted using a juice extractor and 50 ml of the slurry centrifuged for 15 minutes. The TSS was determined by hand refractometer with a range of 0 to 32^0 Brix and resolutions of 0.20 Brix by placing 1 to 2 drops of clear juice on the prism, washed with distilled water and dried with tissue paper before use. The refractometer was standardized against distilled water (^{0}Brix; TSS).

Pungency (μmolml^{-1}): The content of pyruvic acid developed in homogenized bulb tissue was used as measure of pungency following the procedure of Bussard and Randle (1993) at a month interval of the storage time. A core sample was cut from garlic bulbs of each treatment and squeezed (using a juice extractor) and 0.5 ml of the juice put into a 40 ml test tube. The slurry was allowed to wait for 10 minutes. A 1.5 ml of 5% trichloroacetic acid was added to each test tube and vortexed; to each test tube, 18 ml of distilled water was added, which vortexed and capped. From the solution, 1 ml was taken and put in a 20 ml test tube and 1 ml of 2,4-Dinitrophenylhydrazine and 1 ml of distilled water was added to each test tube and vortexed. The test tubes then was placed in a water bath at 37 ^{o}C and allowed to incubate for 10 minutes after which 5 ml of 0.6 N sodium hydroxide was added to each test tube and vortexed. The samples were run on a spectrophotometer set at 420 nanometers. Standards were made using sodium pyruvate and run under the same conditions to prepare a standard curve; then pungency readings on spectrophotometer were determined using the standard curve.

Bulb weight and diameter loss (%): These were determined using the methods described by Waskar et al. (1999). The measurement was based on the difference in weight and diameter of bulbs at the beginning and at two weeks interval using20 bulbs taken randomly from each treatment replication over the storage periods. The difference between the initial weight/diameter and successive weight/diameter gave the weight and diameter losses percentages; the storability data measurements were converted to cumulative percentage losses at the successive storage weeks.

$$WL\,(\%) = \frac{Wi - Wf}{Wi} \times 100$$

Where, Wi = initial weight; Wf = final weight

Number of bulbs sprouted and rotten (%): The average numbers of bulbs sprouted and rotted were observed at two week interval over three storage months.

Data analysis

The data was subjected to analysis of variance (ANOVA) using SAS (Statistical Analysis System) version 9.0. Significant difference between the means was determined using Least Significant Differences test at 5% level of significance.

Results and discussion

Dry matter

There was significant differences in dry matter contents of garlic bulbs both after harvest (fresh weight) and at all successive months of storage due to the effects of fertilizers and seasons; but, only significant at the third month of storage due to soil types. The highest dry matter percentages at harvest and at all successive storage months were recorded from bulbs treated with D-coder at 200 kg ha^{-1}, which however did not vary statistically from values of bulbs treated with higher rates of other compound fertilizers during most part of the assessment periods (Table 1). On the other hand, lowest dry matter contents at initial stage and during the storage months were obtained from the bulbs grown on control plots. Bulbs from plots fertilized with recommended NP recorded dry matter which was significantly better than those from the control plots but at par with the lower rates of the remaining fertilizers. However, according to the report of Tekalign et al. (2012) N fertilization reduced onion bulb dry matter content and storability by enhancing sprouting and rotting percentage while P fertilization did not significantly affect bulb dry matter content.

Significant increase in dry matter content of garlic bulbs were recorded due to fertilizers applied, except for a slight decrease at the third month in the control and the two lower levels of Basic fertilizer. The increase in dry matter content during successive storage months could be mainly due to moisture losses from the outer skin over the storage period. This result is supported by work of Pak et al. (1995) and Henriksen and Hansen (2001) who showed slight increase in dry matter and accounted it to loss of moisture from the bulbs as well as to hydrolysis of fructans upon termination of the dormancy where the bulbs began to sprout. Similar results were also observed by Currah and Rabinowitch (2002) in onion and by Sebsebe et al. (2010) in shallot who indicated that such loss could reach up to 5% of the total fresh weight over a storage period of second to six week.

Similarly, the storage seasons significantly influenced the dry matter percentages of garlic bulbs where higher dry matter was recorded from bulbs stored during the rainy season than those of the dry season at all storage periods. The dry matter contents of bulbs during rainy season storage were higher by about 89%, 53%, 24% and 5% over the dry storage season at harvest- and at the first, second and third storage months, respectively (Table 1). These high dry matter contents recorded during the rainy storage season might be due to the growing season which was warmer and with ample moisture from supplemental irrigation as well as the lower ambient storage temperature than during the dry storage season as there might be high respiration rate as a result of high temperature in the later case. This indicate that garlic planted during the first season by irrigation produced heavier bulbs with higher dry matter contents through uptake of nutrients, and fertilizers having sulphur nutrient particularly produced bulbs with more dry matter. Bulbs stored during the dry season were grown under relatively cooler rainy season and had lower dry matter contents at initial stage, which however, showed slight increases with storage time due to loss of moisture from the bulbs. Similarly, Kebede et al. (2002) found higher dry matter of shallot bulbs in crops grown during warmer short rainy season of 2000 than those grown during main rainy seasons of 1999 and 2000. Reports of Rubatzky and Yamagunchi (1997) also indicated that during storage there was loss in dry matter and moisture as a result of translocation of carbohydrates for respiration process. This is in agreement with the current findings as the first stored bulbs was during summer (rainy) season with low respiration rates but at third month of the first season storage and throughout the second season storage bulbs faced high

* *Email:* dsphd2010@gmail.com or senadiriba2012@yahoo.com

temperature that might have caused high respiration, which could have reduced the dry matter contents and caused variation between the two storage seasons.

Total soluble solids

There was a highly significant difference ($P < 0.01$) in total soluble solids (TSS) content of garlic bulbs subjected to the main effects of compound fertilizers, storage seasons and soil types, except at the third month of storage due to season (Table 1). The highest TSS values of garlic bulbs with fertilizer treatments were due to application of 200 and 400 kg ha^{-1} D-coder fertilizer. Lowest TSS values, both initially and at all storage months, were recorded from the control treatment. Similarly, garlic grown on Vertisol recorded higher TSS contents than those grown on Andosol. Regarding the storage season, garlic bulbs of the dry season had higher TSS levels at initial and one month storage period and this value changed during the second month and leveled off at the third month of storage. These increments of TSS by D-coder fertilizer might be due to availability of sulphur with nitrogen which improves the dry matter production of garlic bulbs through increasing the nutrients uptake by the crop, in addition to phosphorus and zinc nutrients available in D-coder compound fertilizer, which is in line with the report of Channagoudra (2004) and Poornima (2007).

There was a gradual increase of TSS until the end of second storage month starting from the result obtained at harvest and then a slight reduction at a third month was observed due to all factors considered. The reason for the slight reduction at the third month could be as storage time increases bulb dormancy comes to an end leading to sprouting. Consequently, there might be a proportional rise in respiration and carbohydrate metabolism that brings a rapid decline in TSS content of bulbs. Also Kale (2010) and Nabi et al. (2010) reported significant increases in TSS of onion by Ammonium sulphate and Sulphate of potash than muriate of potash, urea, farm yard manure and sheep manure at all storage periods, but increased with storage time only up to 30 days. Similarly, Kebede et al. (2002) recorded greater TSS in shallot bulbs due to Ammonium nitrate and Ammonium sulphate fertilization than urea, while higher rates of N increased TSS in the main season of 1999 than the main season of 2000 cropping season. Al-Fraihat (2009) also reported that higher onion bulb TSS was due to $N_{200}S_{100}$ kg ha^{-1} application during 2005/6 than during 2004/5 production seasons. Wheeler et al. (1998) revealed that sprouting in storage was associated with lower levels of total water-soluble solids in the centre of bulbs which was mostly associated with the early harvest. However, Kopsell and Randle (1997) found significant differences in soluble solids content during storage depending on cultivar.

Bulb pungency

The compound fertilizers applied at different rates, soil types and storage seasons significantly ($P < 0.01$) influenced pyruvate contents (μ-molml^{-1}) of the garlic bulbs across the storage periods (Table 1). D-coder fertilizer applied at 400 kg ha^{-1} produced significantly highest pyruvate content (10.96, 13.37, 12.96 and 15.22 μ.molml^{-1}) during harvest and at first, second and third storage months respectively, followed by 200 kg ha^{-1} D-coder and 300 kg ha^{-1} Azofertil fertilizers over the rest treatments. But lowest pyruvate contents of bulbs were recorded in bulbs from the control plot, ranging from 3.98 μmol ml^{-1} at harvest to 8.94 μmolml^{-1} at the third month storage period. The pyruvate level of bulbs obtained from plot applied with recommended NP was significantly better than those from the non treated control but inferior to the remaining fertilizer treatments across the storage periods. Generally, Azofertil and D-coder fertilizers produced higher pyruvate contents than Basic and standard NP fertilizers. These indicate that availability of sulphur either with N or with N and P increased the pyruvate content of garlic bulbs. An increased level of pyruvate with nitrogen and sulphur application could be also explained partly by greater synthesis and accumulation of sulphur containing amino acids that are precursors of flavor compounds and pyruvate which is in agreement with the findings of Randle (2000). According to the results obtained by Ershadi et al. (2009) Ammonium sulphate was the best to access high yield with good pungency than application of urea at 200 kg Nha^{-1} level; and Nabi et al. (2010) also reported higher pungency due to sulphate of potash than muriate of potash.

Different types of fertilizers applied showed an increment in pyruvate contents with increased level of fertilizers. Generally, the pyruvate level of garlic bulbs increased starting from harvesting time to the end of the third storage month. This indicates that flavour changes took place continuously although the bulbs were dormant during the storage period. This might also be attributed to the moisture loss of the bulbs and increment in the concentration of the constituents of the bulbs during the storage periods. Sebsebe et al. (2010) obtained significant increase of shallot bulb pungency levels with N fertilization levels but insignificant on dry matter, TSS, total sugars and reducing sugars both at harvest and during storage periods.

There was also a significant difference in pyruvate content of stored garlic bulbs due to storage season and bulbs pyruvate were higher during rainy season than the dry season. This appear to relate to the high dry matter production of bulbs grown during warm season and also due to storage of bulbs during cooler summer season that preserve pyruvate of bulbs as less respiration process take place. Also soil types significantly affected the pyruvate content of bulbs during all storage periods with higher results obtained from bulbs grown on Andosol over those grown on Vertisol. This increase might be due to the higher nutrient contents of the soil before the crop was planted supplemented with externally added fertilizers and availability of the nutrients for uptake by plants as the soil is lighter and not packed as that of Vertisol (Currah and Rabinowitch, 2002). The seasonal differences in pyruvate levels indicates that flavour development is affected by the growing condition and that changes were taking place continuously during storage due to storage moisture loss of the bulbs and increment in the concentration of the constituents in the bulbs. Increasing onions and shallot pungencies during storage and decreasing total bulb sugar content was also reported by Wright and Grant (2001) and Sebsebe et al. (2010). Freeman and Whenham (1976) also reported an increase in enzymatically produced pyruvate for two long storing onion cultivars in the first 210 days storage, followed by a sharp decrease at 240 days.

Bulb weight loss

There was a significant difference ($P < 0.05$) in percent weight loss (PWL) of stored garlic bulbs all over three month storage periods due to the fertilizers applied at different rates (Table 2). Large PWL was

* *Email:* dsphd2010@gmail.com or senadiriba2012@yahoo.com

seen in bulbs from non-fertilized plot and those fertilized with lower levels of both Basic and D-coder fertilizers at each storage weeks. The bulbs produced by the recommended NP had lower bulb weight losses over the storage periods than those bulbs from unfertilized plot, but were at par with the weight losses in bulbs fertilized with the lower levels of the rest compound fertilizers. Lower percent weight losses were recorded from fertilization by medium levels of Azofertil (200 and 300 kg ha^{-1}) and D-coder (200 and 400 kg ha^{-1}) fertilizers through all the storage weeks. This indicated that bulbs fertilized with optimum amounts of nutrients during growth produced quality bulbs which increased their shelf life. However, bulbs not treated with any of the fertilizers or fertilized with lower level of each compound fertilizer had more PWL compared to the bulbs fertilized with optimum amount. Azofertil and D-coder compound fertilizers having balanced nutrients (N S and N P S Zn) increased bulbs storability with less weight loss as the nutrients used increased dry matter content of bulbs. The results may be due to the role of sulphur as a constituent of pungency substances, which is positively connected with the storability of bulbs (Mansour, 2006). El-Sayed and El-Morsy (2012) also recorded a reduced total weight loss of garlic bulbs at application of $N_{120}P_{32}K_{80}$kg ha^{-1}. Ahmed et al. (2009) revealed that application of potassium sulphate increased garlic bulb storability with reduced total weight loss, decay and sprout percentage than potassium chloride applied over two seasons. Similar results were also reported by Kebede (2003) and Gebrehaweria (2007). Also, El-Tantawy and El-Beik (2009) revealed that application of 80 kg Nha^{-1} lowered PWL of onion bulbs; and Kale (2010) and Nabi et al. (2010) observed less onion bulb weight loss due to sulphate of potash, sheep manure and farm yard manure as compared to highest loss due to muriate of potash and urea respectively at all successive storage days.

As the storage period extends, there was an increase in cumulative weight loss that could be due to dry matter and water loss from the garlic bulbs. This could be associated with physiological parameters that lead to higher respiration rate under the ambient storage condition of this experiment (average daily 25/28^{o}C maximum and 13/11^{0}C minimum temperatures with 62/42% relative humidity during the rainy and dry storage seasons, respectively). Similarly, Ullah et al. (2008), Kale (2010) and Tekalign et al. (2012) reported that onion bulb storage weight losses were increased with storage time. Msika and Jackson (1997) also described cultivar specific weight losses of between 2 and 5% per month in warm ambient storage in Zimbabwe.

Also significant differences ($P < 0.01$) were observed in weight losses of stored bulbs due to storage season during all storage periods (Table 2). There were higher garlic bulbs PWL observed in dry storage season during all storage weeks than the rainy season which is in line with the results of Ahmed et al. (2009) and El-Sayed and El-Morsy (2012). This indicates that storing bulbs in dry season with high temperature increased the rate of respiration and in turn enhances bulbs weight loss that reduces the storability time of bulbs under ambient storage environment. Suojala et al. (1998) found that only a minor effect of N fertilization on the storage performance and shelf life of onions during three months of storage over two production years. However, bulbs weight loss was significantly affected by soil type only during second storage week and higher weight loss was recorded from Vertisol grown bulbs than Andosol, which might be due to lower nutrients content of the Vertisol soil that reduces the dry matter production of bulbs but the cumulative weight losses were increased with storage weeks.

Reduction in diameter of bulbs

Postharvest yield losses of bulbs are also characterized by bulb diameter losses, which significantly differed ($P < 0.01$) over twelve weeks of storage time due to the application of different rates of compound fertilizers (Table 2). Highest garlic bulb diameter losses were observed in bulbs produced without any fertilizer (control) over all storage weeks, but lowest percent diameter losses were recorded from bulbs fertilized with 200 and 400 kg ha^{-1} D-coder fertilizer, followed by bulbs fertilized by 200 and 300 kg ha^{-1}Azofertil fertilizer during all storage weeks. These also recorded lower bulb diameter loss than the one produced by recommended NP fertilizer. As higher NP nutrients increases fleshy bulbs growth, the increase in percent diameter loss due to increased NP nutrients supply could be attributed to higher water content of the bulbs and of neck thickness of bulbs by N, which shortened the shelf life by increasing the respiration rate thereby depleting the stored food in addition to loss of moisture (Currah and Proctor, 1990). However, the lower percent diameter loss due to Azofertil and D-coder fertilizers indicates that availability of many nutrients in compound fertilizers at optimum rates is significant for producing high dry matter that can preserve the diameter size of bulbs and in turn, bulbs quality. The nature of diameter losses could be explained in a similar manner to the bulb weight loss. According to Sebsebe et al. (2010) highest loss in shallot bulb diameter was in plot applied by 150 kg Nha^{-1}throughoutthe storage periods.

Garlic bulb diameter losses were significantly affected by storage season at different storage weeks, except at fourth and tenth storage weeks. Higher bulbs diameter losses were recorded due to rainy season at second, sixth and eighth storage weeks, but due to dry storage season at twelfth week. Higher diameter losses due to dry season than rainy season were observed at latter storage weeks than at initial weeks. Also garlic bulb diameter losses were significantly affected by soil types only at second and fourth weeks and highest losses were due to Vertisol, but soil types did not significantly affect it after fourth storage week period. The bulbs produced over Andosol got more nutrients that lead to be increased in weight and water uptake but lower in bulbs produced due Vertisol. This might be due suboptimal supply of nutrients by fertilizers for efficient production of carbohydrates and proteins that maintain bulbs integrity as the Vertisol had lower amount of nutrients in it before planted (Table 2).

During both the storage seasons there was no rotten or sprouted garlic bulb observed, except only after a year the edible organ of rainy season stored bulbs characterized by a deterioration, exhibited a loss of texture and weight. This might be because of the bulbs become faced with higher temperature at latter time that causes higher respiration which in turn diminishes the internal dry matter content and also due to loss of moisture from the bulbs as well as to hydrolysis of fructans that also leads the outer scales become soft. Rubatzky and Yamaguchi (1997) described that during storage translocations of carbohydrates occur via the stem plate from the outermost succulent swollen scales to inner scales.

* *Email:* dsphd2010@gmail.com or senadiriba2012@yahoo.com

Relationship between quality and shelf life of stored bulbs

Both bulb weight and diameter losses were negatively correlated with total soluble solids (TSS), pungency and dry matter over both soils; however, they were significantly and positively correlated with each other over both Andosol ($r = 0.27^{*}$) and Vertisol ($r = 0.46^{***}$). Pyruvate content of garlic bulb had significant and positive relation with both TSS ($r = 0.49^{***}$ and 0.45^{***}) and dry matter ($r = 0.51^{***}$ and 0.32^{**}) on Andosol and Vertisol, respectively (Table 3).These implies that garlic bulbs qualities increased with each other during storage, and as bulb weight loss increases the bulb diameter also decreases; but as cumulatively bulb weight and diameter losses increased bulb TSS, pungency and dry matter contents become decreased, which reduces its quality with decrease in shelf life. Similar results were reported by Islam et al. (2007), Dhotre (2009) and Nori et al. (2012).

Table 1. Effect of fertilizer, soil and storage season on dry matter, total soluble solids and pyruvate contents of garlic bulbs over three months of storage periods

Parameters	**Dry matter (%)**				**Total soluble solids (^{0}Brix)**				**Pyruvate content (μmolml^{-1})**			
Treatment	**Initial**	**1st month**	**2nd month**	**3rd month**	**Initial**	**1st month**	**2nd month**	**3rd month**	**Initial**	**1st month**	**2nd month**	**3rd month**
Fertilizer*												
T_1	23.99^{f}	29.94^{g}	33.09^{g}	32.19^{e}	17.66^{e}	21.21^{g}	22.59^{e}	20.57^{e}	3.98^{i}	.43^{i}	.17^{h}	8.94^{h}
T_2	29.01^{cd}	37.68^{c-f}	37.50^{f}	38.08^{cd}	22.97^{d}	26.74^{f}	27.64^{d}	25.61^{d}	4.85^{h}	.88^{h}	.53^{g}	10.67^{g}
T_3	28.42^{de}	35.83^{f}	37.83^{d-f}	38.64^{b-d}	24.07^{a-c}	28.16^{c-e}	29.09^{bc}	27.14^{bc}	6.85^{f}	.46^{fg}	0.19^{e}	12.27^{de}
T_4	30.66^{a-c}	39.79^{a-c}	39.84^{bc}	40.98^{ab}	22.99^{d}	29.00^{a-c}	29.52^{bc}	27.48^{b}	7.55^{e}	0.05^{e}	0.74^{cd}	12.82^{c}
T_5	29.08^{cd}	38.96^{b-e}	40.48^{ab}	40.99^{ab}	23.28^{cd}	28.09^{c-e}	29.42^{bc}	27.47^{b}	9.38^{c}	1.72^{c}	2.18^{b}	14.26^{b}
T_6	26.37^{e}	37.19^{ef}	37.67^{ef}	36.73^{d}	24.61^{ab}	28.20^{c-e}	28.85^{c}	27.05^{bc}	6.16^{g}	.31^{h}	.49^{f}	11.46^{f}
T_7	28.46^{de}	38.35^{b-e}	39.51^{b-d}	38.44^{cd}	23.42^{cd}	27.28^{ef}	28.56^{cd}	26.35^{cd}	6.45^{g}	.03^{g}	0.10^{e}	12.12^{e}
T_8	31.86^{a-b}	39.94^{ab}	41.95^{a}	42.27^{a}	23.93^{b-d}	28.24^{b-e}	29.54^{bc}	27.42^{b}	6.93^{f}	.81^{ef}	0.56^{de}	12.69^{cd}
T_9	29.96^{b-d}	39.45^{a-d}	38.46^{c-f}	40.28^{a-c}	23.23^{cd}	27.67^{d-f}	29.26^{bc}	27.17^{bc}	.55^{e}	.92^{ef}	0.89^{cd}	12.99^{c}
T_{10}	28.45^{de}	37.40^{d-f}	37.63^{ef}	38.21^{cd}	24.21^{a-c}	28.38^{b-d}	29.35^{bc}	27.19^{bc}	.01^{d}	0.63^{d}	1.08^{c}	13.01^{c}
T_{11}	32.19^{a}	41.33^{a}	41.93^{a}	42.09^{a}	24.66^{ab}	29.83^{a}	30.90^{a}	28.82^{a}	0.13^{b}	2.39^{b}	2.35^{b}	14.60^{b}
T_{12}	30.17^{a-d}	40.08^{ab}	39.33^{b-e}	40.09^{a-c}	25.00^{a}	29.23^{ab}	30.10^{ab}	28.02^{ab}	0.96^{a}	3.37^{a}	2.91^{a}	15.22^{a}
Significance	**	**	**	**	**	**	**	**	**	**	**	**
Season												
Rainy season	37.99^{a}	45.96^{a}	42.97^{a}	40.03^{a}	22.26^{b}	26.71^{b}	29.08^{a}	26.87	8.61^{a}	9.37^{b}	10.83^{a}	12.97^{a}
Dry season	20.11^{b}	30.03^{b}	34.57^{b}	38.13^{b}	24.40^{a}	28.63^{a}	28.39^{b}	26.52	6.19^{b}	10.46^{a}	10.20^{b}	12.21^{b}
Significance	**	**	**	**	**	**	**	ns	**	**	**	**
Soil												
Andosol	28.71	38.07	38.53	38.22^{b}	22.65^{b}	27.02^{b}	28.37^{b}	26.35^{b}	7.59^{a}	10.22^{a}	10.75^{a}	12.85^{a}
Vertisol	29.39	37.92	39.01	39.94^{a}	24.02^{a}	28.32^{a}	29.10^{a}	27.04^{a}	7.21^{b}	9.61^{b}	10.28^{b}	12.32^{b}
Significance	ns	ns	ns	**	**	**	**	**	**	**	**	**
CV (%)	**8.80**	**6.75**	**5.46**	**7.14**	**5.30**	**4.35**	**4.41**	**4.74**	**8.60**	**10.00**	**7.70**	**8.40**

*Fertilizer: T_1= control (unfertilized); T_2= recommended NP (92:40 kg ha^{-1}); T_3, T_4 and T_5= Azofertil at 100, 200 and 300 kg ha^{-1}, respectively; T_6, T_7, T_8 and T_9= Basic at 100, 200, 400 and 600 kg ha^{-1}, respectively; T_{10}, T_{11} and T_{12}= D-coder at 100, 200 and 400 kg ha^{-1}, respectively. Means followed by the same letters within column is not significantly differed; ns = indicate non-significant, and *, ** indicate significant at $P < 0.05$and 0.01LSD tests, respectively

Table 2. Effect of fertilizer, season and soil on percentage weight and diameter losses of garlic bulbs at different storage weeks

Parameters	**Cumulative bulb weight loss (%)**						**Cumulative bulb diameter loss (%)**					
Treatment	**2nd week**	**4th week**	**6th week**	**8th week**	**10th week**	**12th week**	**2nd week**	**4th week**	**6th week**	**8th week**	**10th week**	**12th week**
Fertilizer												
T_1	11.61^{a-c}	16.77^{a}	20.78^{a}	23.69^{a}	24.92^{a}	28.88^{a}	21.07^{a}	25.20^{a}	28.89^{a}	31.61^{a}	34.42^{a}	37.26^{a}
T_2	10.65^{b-d}	14.30^{a-c}	15.63^{b-e}	18.09^{b-e}	21.24^{a-d}	24.87^{ab}	15.44^{c}	20.54^{b}	21.73^{b}	23.92^{b}	25.96^{b}	28.74^{b}
T_3	9.85^{d-f}	14.27^{a-c}	16.57^{b-d}	18.54^{b-d}	19.49^{b-e}	21.42^{b-d}	15.45^{c}	19.69^{b}	21.82^{b}	23.86^{b}	26.62^{b}	28.92^{b}
T_4	7.30^{h}	10.99^{d}	12.31^{f}	14.30^{e}	14.86^{f}	17.78^{d}	11.43^{e}	16.28^{c}	16.21^{c}	17.61^{d}	19.76^{e}	21.55^{d}
T_5	8.42^{gh}	11.76^{cd}	13.23^{de}	14.92^{de}	16.57^{ef}	18.51^{d}	10.55^{ef}	15.72^{c}	16.32^{c}	17.28^{d}	18.65^{e}	20.30^{d}
T_6	12.21^{a}	15.37^{ab}	17.02^{bc}	20.11^{a-c}	21.74^{ab}	24.23^{bc}	15.63^{c}	19.58^{b}	21.04^{b}	22.96^{bc}	25.43^{bc}	28.00^{b}
T_7	8.88^{e-g}	13.13^{b-d}	14.98^{b-e}	17.05^{b-e}	17.75^{c-f}	19.61^{d}	12.88^{d}	17.18^{c}	17.27^{bc}	18.46^{cd}	20.23^{de}	21.15^{d}
T_8	8.44^{gh}	12.77^{b-d}	14.56^{c-e}	16.48^{b-e}	17.48^{d-f}	19.01^{d}	10.74^{ef}	15.47^{c}	16.22^{c}	18.91^{cd}	20.45^{c-e}	22.01^{cd}
T_9	8.77^{fg}	13.04^{b-d}	14.65^{c-e}	16.45^{b-e}	17.74^{c-f}	20.08^{cd}	11.96^{de}	15.66^{c}	15.87^{c}	16.75^{d}	18.23^{e}	20.24^{d}
T_{10}	12.00^{ab}	16.74^{a}	18.38^{ab}	20.41^{ab}	21.51^{a-c}	24.23^{bc}	17.43^{b}	19.87^{b}	21.26^{b}	23.15^{bc}	24.84^{b-d}	27.14^{bc}
T_{11}	10.25^{c-e}	13.15^{b-d}	14.50^{c-e}	16.21^{c-e}	17.02^{ef}	17.42^{d}	9.86^{f}	12.92^{d}	15.95^{c}	16.86^{d}	17.97^{e}	19.55^{d}
T_{12}	10.31^{cd}	14.17^{a-c}	15.32^{b-e}	16.79^{b-e}	17.96^{b-f}	20.01^{d}	10.77^{ef}	13.00^{d}	14.21^{c}	15.91^{d}	17.76^{e}	19.68^{d}
Significance	**	**	**	**	**	**	**	**	**	**	**	**
Season												
Rainy season	3.92^{b}	6.54^{b}	8.22^{b}	10.57b	13.04^{b}	14.26^{b}	14.60^{a}	17.84	20.20^{a}	21.63^{a}	22.38	23.29^{b}
Dry season	15.86^{a}	21.21^{a}	23.10^{a}	24.57a	25.01^{a}	28.42^{a}	12.60^{b}	17.35	17.60^{b}	19.59^{b}	22.67	25.80^{a}
Significance	**	**	**	**	**	**	**	ns	*	*	ns	*
Soil												
Andosol	9.52^{b}	13.78	15.55	17.89	19.28	21.75	11.59^{b}	16.56^{b}	18.81	20.43	22.24	24.58
Vertisol	10.26^{a}	13.97	15.77	17.62	18.77	20.93	15.61^{a}	18.63^{a}	18.98	20.78	22.81	24.51
Significance	*	ns	ns	ns	Ns	ns	**	**	ns	ns	ns	ns
CV(%)	**16.82**	**24.10**	**25.97**	**26.59**	**23.75**	**23.19**	**12.37**	**13.43**	**29.26**	**26.97**	**26.35**	**25.67**

*Fertilizer: T_1= control (unfertilized); T_2= recommended NP (92:40 kg ha^{-1}); T_3, T_4 and T_5= Azofertil at 100, 200 and 300 kg ha^{-1}, respectively; T_6, T_7, T_8 and T_9= Basic at 100, 200, 400 and 600 kg ha^{-1}, respectively; T_{10}, T_{11} and T_{12}= D-coder at 100, 200 and 400 kg ha^{-1}, respectively. Means followed by the same letters within column is not significantly differed; ns = non-significant, and *, ** indicate significant at $P < 0.05$and 0.01 LSD tests, respectively

* *Email:* dsphd2010@gmail.com or senadiriba2012@yahoo.com

Table 3. Pearson's simple correlation coefficient for observed quality and shelf life traits of garlic bulbs grown on Andosol (A) and Vertisol (V) soils

Parameters	Soil	Diameter loss	TSS	Pungency	Dry matter
Weight Loss	A	0.27*	-0.28*	-0.42**	-0.20ns
	V	0.46**	-0.64**	-0.50**	-0.04ns
Diameter Loss	A		-0.18ns	-0.42**	-0.30*
	V		-0.56**	-0.56**	-0.23ns
Total soluble solids	A			0.49**	0.20ns
	V			0.45**	0.06ns
Pungency	A				0.51**
	V				0.32**

ns= non significant; *, ** = significant at P< 0.05, and 0.01 probability level.
A and V= indicates the coefficient value of the garlic parameters correlated due to Andosol and Vertisol soils grown, respectively. TSS= Total soluble solids

CONCLUSION

The post harvest quality and storability of garlic bulbs rely on the application of the correct level and types of fertilizers depending on soil types and season of production and storage. Results of the study revealed the existence of differences in quality and shelf life of garlic bulbs in response to different compound fertilizers as well as their levels of application, soil types and storage seasons during three months of storage. Increasing fertilizers levels showed significant increases in the garlic bulb pungency, total soluble solids and dry matter contents on Andosol than on Vertisol and during rainy season storage than dry season storage. Higher losses were recorded in bulbs from control plots and lower level of each compound fertilizer treated. Similarly, higher percentage losses in bulb weight and diameter were observed in crops grown on Vertisol than Andosol as well as bulbs stored during the dry season than rainy season. From the study, it may be concluded that application of Azofertil, Basic and D-coder fertilizers at rates of 300, 400 and 200 kg ha^{-1}, respectively, as well bulb production on Andosol during dry season by irrigation but stored in rainy season is a good compromise for post harvest quality and storability of garlic bulbs under ambient storage conditions. However, higher levels of each compound fertilizers application over both soils increased bulb quality and storability suggesting that the Vertisol was deficient in different nutrients. Bulb storability was negatively associated with quality traits on both soils. Proper fertilizer management practices along storage seasons for optimum quality and long shelf life of bulbs requires further experiments under different agro-climatic conditions and storage seasons as the cumulative bulb weight, and diameter losses over the storage period of twelve weeks were substantially high and unacceptable.

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* *Email:* dsphd2010@gmail.com or senadiriba2012@yahoo.com

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* *Email:* dsphd2010@gmail.com or senadiriba2012@yahoo.com