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Effects of storage duration and bulb sizes on physiological losses of Agrifound light red onion bulbs (*Allium cepa* L.)

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Abstract. *The effect of storage duration and bulb sizes on physiological losses of the Agrifound light red onion bulbs stored in an Improved Naturally Ventilated Storage Structure-INVSS (constructed using locally available materials like; sand, cement, wood, corn stalks, wire mesh and grasses) under room condition was studied in 2012. Dry and wet bulb thermometers were installed to measure ambient temperature and relative humidity. Wind velocity was measurement by hand held Anemometer. The onion bulb samples were sorted and graded into three standard size categories (small: <50mm; medium: 50-70mm and jumbo: >70mm in diameter) and kept in the INVSS at the Department of Agricultural and Environmental Engineering Research Farm of Modibbo Adama University of Technology (MAUTECH), Yola. The samples were monitored and data taken on a daily basis for a period of twenty (20) weeks. The data were analyzed with ANOVA in CRD and the means were separated using LSD at p<0.05. The results indicated that storage duration had significant effects (p≤0.05) on weight, rot and sprout losses. Jumbo size onion bulbs had the highest Storage Weight Loss (SWL) by a mean of 5.1%, followed by medium and small size onion bulbs with means of 4.8% and 4.2%, respectively. Storage Sprout Losses (SSL) studied in the three of onion bulb sizes showed higher SSL among the small size Agrifound light red variety than the medium size onion bulbs with respective mean values of 5.0% and 3.8%, while the least value of SSL (2.6%) was observed in Jumbo size onion bulbs. Similar comparison was also made in terms of Storage Rot Losses (SRL) and it showed that relatively higher SRL among the Jumbo size onions (3.3%), followed by medium sizes (3.1%) while the least was observed from the small sizes (2.3%). The findings recommend that the INVSS should be used to store Jumbo and small size onion bulbs for at least 5 months to achieve minimum storage losses. Though, it is not cost effective to store medium size onion bulbs in the INVSS for more than 4 months.*

Keywords: *Allium cepa* L., naturally ventilated storage structure, physiological parameters, rotting, sprouting, weight loss

Introduction

Agrifound onion bulb (*Allium cepa* L.) belonging to the family Alliaceae is globular in shape with tight skin and light red in color. Its size ranges from 4-8cm in diameter and has TSS of 12-13%, and is highly valued worldwide for its pungency, flavor and nutritional value in supplying minor constituents such as minerals and trace elements (Illic et al., 2002). Its yield usually ranges from 20-32.5 t/ha under good growing and management conditions (Lannoy, 2001; Fariyike and Adewale, 2008). It also has good keeping quality. The estimated world total area under onion cultivation is 3.06 million hectares with a total output production of about 53.59 million tons (NRC, 2004). The major producing countries are China, India, USA, Netherlands, Spain and Turkey. Others are Niger, Nigeria, Burkina Faso, Mali, and Senegal. India is the second largest producer of onions in the world after China accounting for 10% of the world total production (FAO, 2000).

In Nigeria, generally onions of all varieties are mainly grown for their bulb. The bulbs are boiled and used in soups and stews, fried, or eaten raw. They are also preserved in the form of pickles. Onion leaves, especially from the Spring onion, are also used in salads and soups. An estimated total land area of 0.1-0.2 million ha is cropped annually with a production capacity of about 2.5 million tons, (Aduayi et al., 2002). Three varieties of onions such as red, white and yellow are grown annually under both wet and dry seasons in Northern Nigeria. Onions are commonly grown by farmers under dry season conditions and normally harvested between February and May with high yield of up to 35 t/ha. Generally, proper storage of bulbs is necessary for both consumption and for seed production in order to provide quality crops with minimal losses from physical, physiological and pathological agents, throughout the storage period (Sharma, 2017). Effective preservation can only be achieved by partial or complete control of the storage environment. Conventional methods of storing onions are costly. Storing onions in Controlled Atmosphere (CA) gives encouraging results but the gains usually do not justify the commercial application. Similarly, storing onions at 0ºC often requires expensive refrigeration systems, which is beyond reach of most subsistence farmers in Nigeria. It is therefore, necessary to explore alternative low cost and environment-friendly methods to store onions without compromising their quality.

The storage of onion bulbs for a long period under ambient conditions poses a great problem due to high air humidity and high air temperature prevalence in the area. A lot of work has been conducted to understand the causes of postharvest losses of onion bulbs in storage, especially at room temperature and humidity. Sharma (2017) reported that the

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major causes of bulb deterioration during storage are in order of importance from rotting, physiological loss of weight and sprouting. High temperatures of 30-35°C encourage bulb rot caused by *Aspergillus niger* while low temperatures favor bulb rot caused by *Botrytis alli* (Kader, 2002). Benkeblia et al. (2000) established that respiration was responsible for less than 20% of physiological weight loss of onions in storage. Other factors including variety of cultivars, bulb maturity, environmental conditions, agro-climatology, degree of physical damage, as well as pre-harvest factors such as soil type, fertilizer application, irrigation schedule among others largely influences onion preservation.

Several methods of onion storage have been designed throughout the ages and modified according to the local materials available for their construction. The methods used to store fresh onions in Northern Nigeria varied from one location to another. The common methods include hanging on trees in bunches, storage in traditional barns, cribs, and jute sacks as well as the use of sprout inhibitors to impede sprouting. However, simple onion storage structures have been developed and modified over the years such as mud, dung, and straw cottages commonly found in tropical developing countries. The principal function of these simple storage shelters is to protect the harvested onion bulbs from harsh weather (Abubakar, 2013). These structures have a slatted wooden stage inside on which the bulbs are piled up to about 1m deep, and ventilation is achieved by the natural prevailing wind passing through the structure. Square straw cottages are built on upright poles driven into the ground. Nails are then driven into the poles, and bunches of onions, plaited together by their tops, are suspended from these nails.

Despite the advancement in modern storage structures found in developed counties like USA and Europe, the storage system is still primitive in Nigeria, where the bulk of onion storage takes place in traditional structures made of mud bricks which are typically privately owned and are concentrated in the Northern part of the country where the onions are grown in large quantities. Walls are typically from 2.5 to 3.5m high and 30 to 60cm thick. Storage period is normally between 3-4 months. Roofs consist of thatched straw or grassand mud supported by wood or bamboo frames. The onions are sprayed with chemical and arranged in piles of 1.5 to 4m across and 0.8 to 1.0m high. The piles are sorted every two weeks and infested, diseased, or damaged onion bulbs discarded. However, most of this traditional storage structures are a constraint because of their high physiological losses and rodents attack. Temperatures within the storage structures are not much lower than the ambient temperatures in the shade outside, although within the heaps temperatures may be as much as 10°C lower. Losses from disease infestation, dehydration, excessive sprouting, and other causes average about 20-30%, although losses of up to 70% have been reported (Ranpise, 2001). The need for improving storage facilities such as the Improved naturally ventilated storage structures (INVSS) and practices of controlled atmosphere storage for storage of onions have been noted by several authors (Abubakar, 2013; Banuu et al., 2014; Falayi and Yusuf, 2014).

Natural ventilation is an energy efficient alternative for reducing the energy use in farm buildings, and maintaining quality and longevity of stored products. Increasingly, natural ventilation is employed to leverage freely available resources such as wind and outdoor air to satisfy cooling loads and provide quality and longevity of stored products. In its most basic form, natural ventilation provides openings in the building façade to allow fresh outdoor air in one area of the building and out in another. As the fresh outdoor air passes through, heat is removed and ventilation is provided. However, this technology is only appropriate where climatic conditions permit. In some parts of the world there is a large diurnal temperature swing, and, where the nighttime temperature is low enough, outside air may be used as a source of cooling. Night time cooling is especially useful on commodities that are stored at moderate temperatures (5–12^{o}C) such as pumpkins, potatoes, onions, sweet potatoes, and hard-rind squash. Natural ventilation during the night is usually sufficient if the outside temperature is below the required range for 5 to 7 hours each day (Chiu, 2004). In such climates it is advantageous to store harvested products for a long period of time. Typically, the energy cost of naturally ventilated structures is 40% less than that of air-conditioned structures (Majcen et al., 2016)

Considering high storage losses incurred by farmers annually as result of poor storage structures to keep the onion bulbs for a relatively long period of time. This purposely prompted the development and performance evaluation of the Improved Naturally Ventilated Storage Structures (INVSS) in terms of sprouting, rotting and weight losses of onions in relation to their sizes in order to identify the size ranges of onion bulbs that can best be stored in such structures, to extend the shelf life and reduce the substantial amount of storage losses incurred by small scale farmers particularly in tropical and sub-tropical regions of developing countries like Nigeria, as well as to help in controlling the supply of onion bulbs in relation to its demand on the market and thus to secure relatively better price to the product by adjusting the supply with reference to existing demand and thereby avoid gluts of produce on the market.

Material and methods

Study area

The research was conducted in the Department of Agricultural and Environmental Engineering Research Farm of Modibbo Adama University of Technology (MAUTECH), Yola in Girei Local Government Area (L.G.A.) of Adamawa State, Nigeria which lies between latitudes 9^{o}32' and 9^{o}47'N and between longitudes 12^{o}32' and 12^{o}44'E. The area is an agrarian environment marked by dry (November to May) and wet (June to October) seasons. The mean annual rainfall usually ranges from 700 to 1050mm (Adebayo, 2004). The Local Government Area shares boundaries with Song L.G.A. to the North, Yola-South L.G.A. to the West, and Yola-North L.G.A. to the South (Figure 1). It also shares boundary with the Fufore L.G.A to the East. The vegetation is basically of three types; Southern Guinea Savannah, Northern Guinea Savannah, and Sudan Savannah type, within each vegetation type there is an interspersion of thick tree Savannah, open grass savannah, and fringing forests in the river valleys (Adebayo, 2004).

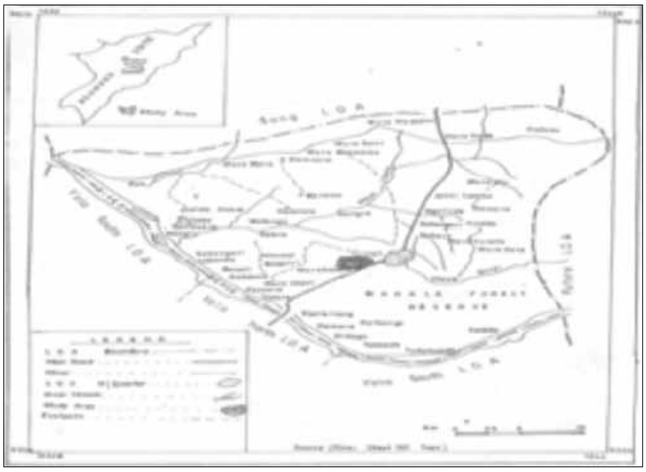

Figure 1. Map of Girei Local Government Area with study area

Cleaning and sorting onions bulbs

The cleaning process was carried out manually, whereby all the root attachments and dry necks were thoroughly trimmed off. The healthy onions were carefully separated from infected bulbs and foreign materials such as soils. In addition, all thick-necked bulbs were also screened for moisture content (90-95% wet basis) in order to increase the longevity (storage life) of the healthy onions. The onion bulbs were then sorted and graded for storage.

Varietal description

The variety of onions used for the study was Agrifound Light Red which is among the common varieties grown in Adamawa state. The sizes of onion bulbs used in this research were classified into 3 categories of sizes in accordance with the standard used by Bahnasawy et al. (2004). The categories include small, medium and jumbo with respective size ranges of <50mm, 50-70mm and >70mm in diameters.

Experimental design and sampling procedure

The onion bulbs were properly dried and cured to average moisture content of 84.1% w_b before storage; this conforms with the standard range of 80-85% w_b as recommended by Bakker-Arkema et al. (2004) and Rouamba, et al. (2010) for storage of onion bulbs in tropical regions. The onion bulb samples were sorted into three size categories. One hundred onion bulbs were selected from each category for storage and replicated thrice in a Completely Randomized Design (CRD). The total losses incurred during storage as a result of rotting, physiological loss of weight and sprouting were recorded and subjected to Statistical Analysis System (SAS) for the Analysis of Variance (ANOVA) among main effects and interactions. Least significant difference (LSD) test was used to compare all possible pairs of treatment means at 5% level of significance.

Description of the improved naturally ventilated storage structure (INVSS)

The onion storage structure used for this experiment was constructed using locally available materials like sand, cement, wood, corn stalks, wire mesh and grasses (Figure 2). The base of the structure was constructed using sandcrete blocks both at the center and the four sides of the structure to accommodate the weight. Wooden poles of 5.08x15.24 cm (2x6 inch) were erected vertically at the four corners to act as the main frame of the structure and 5.08x7.62 cm (2x3 inch) woods were used to connect the four poles to form a rectangular cross sectional structure. The four sides of the structure were covered with "Zana" mats made of grass. On the two longest sides of the storage structure four shelves each were constructed using wood and corn stalks to accommodate one ton of onion bulbs. The base on which the onion bulbs will be introduced was constructed in the form of a slated bottom to aid free movement of air through the stored onions. Each shelf has a volume of 0.18m^3 and capacity to store 125.1kg of onion bulbs with a bulk density of 695 kg/m^3 at the stacking height of 10cm as recommended by Bakker-Arkema et al. (2004) in design of a naturally ventilated onion bulb storage structure.

Figure 2. Improved Naturally Ventilated Storage Structure (INVSS)

The roof was constructed using 5.08x7.62 cm (2x3 inch) hard wood interwoven with corn stalks and covered with knitted dry grasses. The dimension of the structure is 2.0x3.0x2.5m for height, length and width respectively. The longest side was sited perpendicular to the direction of the prevailing wind to facilitate ventilation as recommended by Bakker-Arkema et al. (2004). The structure was raised on the sandcrete blocks 25cm above the ground to avoid moisture influx in the storage structure. A wooden door was provided to allow for accessibility to the stored onions.

Determination of onion bulbs physical parameters

After sorting the onion bulbs into their various size categories, 100 onion bulb samples were selected for each size category. Each bulb was weighed using G & G Digital Electronics Scale model-JJ300 (Figure 3) and their diameters were measured using a vernier caliper. The initial weight and size of each onion bulb before storage were recorded and labeled before they were introduced into the storage structure. The storage structure was fitted with a thermo-hygrometer device for temperature and relative humidity measurements and hand held Anemometer for wind velocity measurements. The measurements were recorded three times on a daily basis (6:00am, 12:00 noon and 6:00pm) and the average value of each was computed and recorded.

The pathological and physiological activities of the stored onion bulbs were carefully monitored and the number of spoiled onions in the form of rotting, physiological loss of weight and sprouting in each group was counted and recorded on a daily basis throughout the storage period from May to October, 2012.

Determination of Storage Weight Losses (SWL)

The weight of each onion bulb was taken as the initial weight before storage and labeled on its surface for easy identification. The cumulative loss in onion bulbs weight was calculated as the differences in weights between the initial weight before storage and the weight recorded at the intervals of one week for a period of 20-weeks (May–October) of storage expressed as percentage Storage Weight Loss (SWL) suggested by Kukanoor (2005):

$$SWL\,(\%) = [1 - Wf/Wi] \times 100, \quad (1)$$

Where:

W_i = initial onion bulbs weight before storage, g;

W_f = final onion bulbs weight after storage, g.

Determination of Storage Rot Losses (SRL)

The number of rotten onion bulbs at the end of each week was counted after physical observations using hand feel to test for the firmness of each bulb. The onion bulb was considered rotten when it became softened (Figure 4).

The percentage of SRL was calculated using equation (2) as was used for cocoyam by Obetta et al. (2007):

$$SRL\,(\%) = [1 - N_r/N_t] \times 100, \quad (2)$$

Where:

N_r = No. of rotten onion bulbs;

N_t= Total No. of onion bulbs.

Determination of Storage Sprout Losses (SSL)

The percentage SSL of onion bulbs on designated days of storage was determined by counting the bulbs showing a sprout, then recorded and separated from the lot. The onion bulb was considered sprouted when the leaf primordia of stored onion bulbs began to develop green leaves rather than scale leaves as described by Kukanoor (2005) as shown in Figure 5.

Figure 3. G&G Electronic Scale

Figure 4. Samples of rotten onion bulbs

Figure 5. Samples of sprouted onion bulbs

The percentage sprouts, which indicated the number of onion bulbs sprouted at the end of the storage period was calculated using equation (3) as was used for cocoyam by Obetta et al. (2007):

$$\text{Sprouted onions}\,(\%) = [1 - N_h / N_t] \times 100, \quad (3)$$

Where:

N_h = No. of healthy bulbs retained;

N_t= Total No. of stored onion bulbs.

Statistical Analysis

The data sets were analyzed following the generalized linear model of SAS for Windows version 8.0 for ANOVA. The sample means were compared using standard error (SE) and Least significant difference (LSD) was used for mean separation at $P<0.05$.

Results and discussion

Effects of environmental conditions on physiological losses in Agrifound light red onion bulbs

Data on environmental conditions of onion storage structures which include temperature, relative humidity and wind velocity were recorded for a period of 20 weeks (May-October, 2012). Table 1 shows that the highest mean temperature of 39^oC was recorded at noon during the first five weeks (May-June) of storage. However, the lowest storage temperature of 23.6^oC was recorded in the morning in September, 2012. The highest temperature observed during the earlier part of storage might have been responsible for abrupt sprouting and physiological loss of weight observed during the storage as a result of termination of their dormancy period due to temperature fluctuations (Banuu et al., 2014). This result further indicated that there was a significant temperature depression between day and night of approximately 17^oC. Similarly, the highest relative humidity reading of 79.4% between fourteenth to sixteenth weeks (August- September) was recorded in the morning and the lowest relative humidity reading (59.5%) was taken in the afternoon during the first two weeks of storage (May).

It was observed that air humidity was very high throughout the day from 10-16 weeks of storage. This might have been the cause of swelling of the bulbs due to moisture absorption leading to high rot loss in all the three size categories of onion bulbs observed in storage at that period (Falayi and Yusuf, 2014).

The mean monthly data on wind velocity for a period of twenty weeks (May-October, 2012) was recorded as shown in Table 2. The highest average wind velocities were recorded in the months of March and June, with the mean values of

Table 1. Monthly minimum and maximum temperatures and relative humidity recorded in the onion bulbs storage structure during the storage period (May-October, 2012)

Month	Temperature (T), °C		Relative humidity (RH), %		Average values	
	Min	Max	Min	Max	T, °C	RH, %
May	26.2	3.90	59.5	72.8	29.0	66.2
June	25.0	30.0	63.0	75.4	27.5	69.2
July	24.5	29.5	66.0	76.2	27.0	71.1
August	24.1	27.9	69.4	77.0	26.0	73.2
September	23.6	26.8	72.2	79.4	25.2	75.8
October	24.5	28.8	68.5	77.2	26.6	72.8

1.22 and 1.10 m/s, respectively. Also, the lowest prevailing wind speed was recorded in October with mean values of 0.70m/s. This could possibly be responsible for the lowest storage losses observed during the first four weeks of storage. The results of these findings showed that the mean wind velocity in the study area was 0.89m/s. This conforms to the minimum wind speed of 0.70m/s required to aerate natural ventilated storage structures in order to achieve tolerable physiological storage losses of onion bulbs (Kebede and Aklilu, 2007).

Effect of storage duration and bulb sizes on storage weight loss (SWL) among Agrifound light red onion bulbs

The results in Table 3 show that storage duration and bulb sizes had high significant ($P<0.01$) effects on Storage Weight Loss (SWL) in Agrifound light red onion bulbs. The highest SWL was observed during the twentieth week (October, 2012) of storage, irrespective of the size differences. The highest SWL of 5.1% was recorded among the largest (Jumbo) size onion bulbs, followed by the medium size with 4.8% and the least was observed among the small size Agrifound light red onion bulbs with a mean value of 4.2%. The high SWL observed during the twentieth week of storage could have been due to the high mean monthly temperatures of 26.0°C and 25.2°C and relative humidity 73.2% and 75.8% recorded in August and September, respectively (Table 1). These translated into 2.8 and 2.5 kPa water vapor pressure (P_{wv}) on a psychrometric chart, respectively, which is in line with the assertion made by Saeed and Heidarisoltanbadi (2015) that explained the rate of moisture loss from a fresh produce is mainly controlled by P_{wv} difference between the intercellular spaces of plant material and the surrounding air. This difference could be the major factor that contributed to the high SWL observed during the twentieth week of storage. However, no SWL was observed among the small size onion bulbs from the first week up to the seventh week of storage, this implies that there was no significant difference at $P<0.05$ level of significance among the small size categories of onion bulbs. The phenomenon observed among the small size onion bulbs could be attributed to the relatively low initial rate of water loss through the skin as a result of low level of respiration due to dormancy period of the bulbs that was followed by an abrupt change observed in the subsequent weeks, indicating more rapid weight loss due to high respiration rate and senescence of older fleshy scales after dormancy breaks which is in agreement with the findings of Ko et al. (2002)

Table 2. Average wind velocity (m/s) recorded outside of the onion bulbs storage structure during the storage period (May-October, 2012)

Month	Wind velocity (m/s) Morning (6:00am)	Noon (12:00)	Evening (6:00pm)	mean
May	1.25	1.10	1.30	1.22
June	1.10	1.00	1.15	1.10
July	0.90	0.69	0.91	0.83
August	0.85	0.65	0.90	0.71
September	0.80	0.68	0.85	0.78
October	0.70	0.68	0.72	0.70
mean	0.93	0.80	0.97	0.89

The higher SWL observed in Jumbo size (>70mm) onion bulbs was probably because the bulbs contained the highest moisture and had more surface area per unit of bulb that gave the highest rate of transpiration. Sighn and Sighn (2003) reported that large size onion bulbs exhibited the highest SWL compared to smaller size onion bulbs. This is in agreement with the findings of this work. The study also indicated that stored smaller onion bulbs had longer shelf-life than the medium and larger size onion bulbs. Similar assertion was found by Ko et al. (2002).

Effect of storage duration and bulb sizes on storage sprout loss (SSL) among Agrifound light red onion bulbs

The results presented in Table 4 show that storage duration had significant ($P<0.05$) effects on sprouting of Agrifound light red onion bulbs studied. The highest percentage (5.0%) sprouting was observed in the 20th week of storage among the small size onion bulbs, followed by the medium

Table 3. Effect of storage duration and bulb sizes on storage weight loss (SWL, %) among three size categories of Agrifound light red onion bulbs

Duration of storage (weeks)	Size category		
	Small (<50mm)	Medium (50-70mm)	Jumbo (>70mm)
1st	0.00	0.00	0.00
2nd	0.00	0.00	0.00
3rd	0.00	0.00	2.20
4th	0.00	0.00	2.20
5th	0.00	2.00	2.30
6th	0.00	2.20	2.45
7th	0.00	2.30	2.50
8th	2.00	2.45	2.64
9th	2.20	2.60	2.78
10th	2.30	2.64	2.82
11th	2.40	2.76	3.00
12th	2.60	2.77	3.15
13th	2.60	3.01	3.65
14th	2.70	3.15	3.90
15th	2.75	3.60	4.30
16th	3.00	3.80	4.60
17th	3.10	4.30	4.70
18th	3.60	4.40	4.90
19th	3.80	4.70	5.00
20th	4.20	4.80	5.10
LSD($p \leq 0.05$)	*	*	**
SE (±)	0.18	0.12	0.16

** = highly significant at 1%, level of probability, * = significant at 5% level of probability

and jumbo size onion bulbs with respective mean values of 3.8% and 2.6%. No sprouting was observed during the first four weeks of storage in both medium and jumbo size Agrifound light red onion bulbs. However, small size onion bulbs sprouted immediately during the third week of storage and it increased proportionately with time of storage. This may be attributed to the high fluctuations in storage temperature, which perhaps contributed to the termination of their state of dormancy that led to the increased sprouting among this variety of cultivar. Banuu et al. (2014) reported similarly in their earlier study on onion bulb storages.

Effect of storage duration and bulb sizes on storage rot loss (SRL) among Agrifound light red onion bulbs

The results presented in Table 5 show that storage duration had significant ($P<0.05$) effects on SRL in all the three size categories of the Agrifound light red onion bulbs studied. The highest percentage SRL was found during the twentieth week of storage among the jumbo size (>70mm) Agrifound light red onion bulbs, by 3.3% on average, followed by the medium size (50-70mm) onion bulbs which recoded 3.1% while the least was found among the small size (<50mm) onion bulbs with a mean of 2.3%. However, no SRL was observed during the first four weeks of storage among the small size Agrifound light red onion bulbs. This indicated that there was a significant ($P<0.05$) difference among the three size categories of Agrifound light red onion bulbs throughout the duration of storage except for the small size onion bulbs that indicated no significant difference ($P>0.05$) from seventh to fifteenth weeks of storage.

The high percentage of SRL observed in jumbo size Agrifound light red onion bulbs studied may be attributed to the fact that larger onions contain higher amount of water and thick necks with soft succulent tissues which prone them to attacks by disease causing microorganisms (Milenkovic et al., 2009). Ranpise (2001) earlier confirmed that the number of rotten onions increased with increasing bulb sizes. Sharma (2017) also reported that larger onion bulbs are more susceptible to bruising, disease and other damages than smaller bulbs. However, the probable cause of rotting observed was as a result of high relative humidity recorded during the last 4 weeks of storage which harbors fungal pathogens that were responsible for high percentage rots of onion bulbs among the jumbo size Agrifound light red onion bulbs. Kader (2002) also established that larger bulbs had higher incidences of bulb rot than smaller onion bulbs.

Conclusion

Based on the findings of this study it was observed that the major postharvest problems for storage of Agrifound light red onion bulbs were sprouting, weight loss (shrinkage) and storage rots. Among the physiological factors which affect storage of onion bulbs in the Improved Naturally Ventilated Storage Structure (INVSS), Storage Weight Loss (SWL) is the most prevalent with high manifestation of deterioration in all the 3 size ranges (<50mm, 50-70mm and >70mm). How-

Table 4. Effect of storage duration and bulb sizes on storage sprout loss (SSL, %) among Agrifound light red onion bulbs

Duration of storage (weeks)	Size category Small (<50mm)	Medium (50-70mm)	Jumbo (>70mm)
1st	0.00	0.00	0.00
2nd	0.00	0.00	0.00
3rd	1.00	0.00	0.00
4th	1.20	0.00	0.00
5th	2.40	0.67	0.00
6th	2.45	0.82	0.50
7th	2.60	1.00	0.67
8th	2.74	1.15	0.88
9th	2.80	1.35	1.00
10th	2.90	2.00	1.20
11th	3.10	2.15	1.30
12th	3.20	2.27	1.50
13th	3.60	2.51	1.60
14th	3.80	2.75	1.70
15th	4.20	2.90	1.78
16th	4.30	3.15	1.90
17th	4.50	3.30	2.10
18th	4.60	3.40	2.25
19th	4.90	3.60	2.40
20th	5.00	3.80	2.60
LSD($p \leq 0.05$)	*	*	**
SE (±)	0.17	0.11	0.15

** = highly significant at 1%, level of probability, * = significant at 5% level of probability

Table 5. Effect of storage duration and bulb sizes on storage rot loss (SRL, %) among Agrifound light red onion bulbs

Duration of storage (weeks)	Size category Small (<50mm)	Medium (50-70mm)	Jumbo (>70mm)
1st	0.00	0.00	0.00
2nd	0.00	0.00	0.00
3rd	0.00	0.67	1.00
4th	0.00	0.70	1.20
5th	0.60	0.80	1.35
6th	0.76	0.95	1.45
7th	0.88	1.00	1.50
8th	1.00	1.45	1.68
9th	1.00	1.50	1.84
10th	1.00	1.64	1.88
11th	1.00	1.86	2.00
12th	1.00	1.98	2.15
13th	1.00	2.10	2.25
14th	1.00	2.25	2.40
15th	1.00	2.40	2.60
16th	1.66	2.50	2.70
17th	1.88	2.67	2.90
18th	2.10	2.80	3.10
19th	2.20	2.90	3.20
20th	2.30	3.10	3.30
LSD($p \leq 0.05$)	*	*	**
SE (±)	0.15	0.11	0.16

** = highly significant at 1%, level of probability, * = significant at 5% level of probability ever, the choice of appropriate storage treatment for different sizes of onions can help sustain quality and reduce crop wastage while sorting and grading the onions per their size before storage. It was found that medium (50-70mm) size onion bulbs indicated the highest Storage Weight Loss (SWL) of 4.8%, Storage Rot Loss (SRL) of about 3.8% and sprout loss of 3.1% accumulated to gross marginal loss of 11.7%. While gross marginal losses in jumbo (>70mm) and small (<50mm) sizes ranked 11% each. Though the gross losses among the size ranges are not significant, the results indicated that jumbo and small size onions are more suitable for storage in the INVSS for a period of twenty weeks. Further studies on the changes of some important biochemical and physical characteristics during storage in onion (*Allium cepa* L.) cultivars are recommended for increasing the understanding of the mechanisms of onion bulb dormancy and shelf-life. The use of hydrated calcium to absorb CO_2 produced by the onion bulbs during storage is also recommended for further studies related to the onion bulbs shelf-life.

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